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SANTA CRUZ

INTEGRATING ZOOARCHAEOLOGY AND MODELING: TRANS-HOLOCENE FISHING IN MONTEREY BAY, CALIFORNIA

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ANTHROPOLOGY

by

Cristie M. Boone

March 2012

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Vice Provost and Dean of Graduate Studies

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ABSTRACT

Integrating Zooarchaeology and Modeling: Trans-Holocene Fishing in Monterey Bay, California

Cristie M. Boone

This research uses California's Monterey Bay as a case study for analyzing human decisions in acquiring marine fishes through different climatic regimes. I address behavioral, ecological, and biological aspects of fish species that affect their value to human diet. I also critically examine local evidence for Holocene climate changes. I question the common archaeological assumption that energetic rate of return is the key variable in prey taxa ranking and employ dynamic state variable modeling, long used in ecology, to predict optimal diet decisions. I assess how prior descriptions of Central Coast culture history compare to climatic evidence, model predictions, and my faunal analysis results.

I analyzed fish remains from 13 Monterey Bay area sites, representing multiple habitats and cultural periods, producing data on taxonomic distributions, modifications, and fragmentation. I radiocarbon dated fish specimens from each site to assess how these accorded with dates on other material and analyzed proximate compositions of several nearshore species to elucidate the role of nutrition in prey selection.

Dynamic state variable modeling suggests that probability of successful prey capture, mortality risk in a patch, and energy expenditure are very important in a forager's prey choices. The model predicts that foragers preferentially exploit

predictable, easily acquired resources, even those with relatively lower rates of return. This prediction is borne out in the archaeofaunal data.

Fish faunas show statistically significant shifts in prey types acquired in similar habitats over time. Sardines are common through time and dominate the later periods' archaeofaunas. Their abundance increases markedly during the Medieval Climatic Anomaly, suggesting they may have been valued for their high fat content. Sharks and rays are abundant only in the earliest estuary sites, most likely declining due to habitat degradation. Tidepool fishes rise from ubiquitous but low proportions to nearly a third of identified specimens in the last thousand years, suggesting heavy dependence on marine resources continued to historic contact.

Results indicate that people did not always acquire the nearest and most easily caught prey, as previous studies have suggested. People sometimes emphasized more difficult and dangerous patches and responded to changes in habitat and climate.

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CHAPTER 1

Human Behavior and the Marine Environment

Anthropologists and archaeologists used to argue that people would only turn to fishing in cases of hardship (see Pálsson 1988), yet more recent archaeological evidence from the Pacific Coast has shown substantial marine resource exploitation from many of the earliest sites identified (Colten 1991; Connolly et al. 1995; Erlandson 1988, 1991a, 1991b; Erlandson and Moss 1996; Jones et al. 2004; Newsome et al. 2004; Warren 1967), well before population pressure or subsistence stress could have developed (Rick and Erlandson 2000). The colonization of the Americas was probably initiated along the coastline, as people exploited kelp bed habitats for their rich vertebrate and invertebrate resources (Erlandson, Graham, et al. 2007; Erlandson, Rick, et al. 2007). Fishes, shellfish, marine mammals and aquatic birds are abundant in certain coastal habitats and present in early archaeological sites (Erlandson, Graham, et al. 2007). However, fully understanding human adaptations to the marine environment requires research that investigates the diversity *within* each of these groups.

I use the Monterey Bay area of the Central Coast of California as a case study to study human interactions with fishes, arguing that fishes are a diverse range of food resources that require different technologies and tactics to exploit and therefore must be analyzed with an eye towards that diversity. The Monterey Bay area is biologically rich, ecologically varied, and has a human history of several thousand

years, thus providing an excellent context within which to study this dynamic relationship. Marine resources were important enough that they might have comprised over three quarters of early peoples' diet (Newsome et al. 2004). However, despite this emphasis on marine foods, the Monterey Bay area thus far has lacked a comprehensive analysis of prehistoric fishing through time.

The main regional synthesis of Central Coast marine habitat exploitation to date, Gobalet and Jones (1995), highlighted the key taxa in archaeological assemblages, but considered only spatial and not temporal patterns. This dissertation contributes the first in-depth, regional, diachronic analysis of ichthyofaunal remains to explore how fish exploitation relates to human use of coastal habitats in the Monterey Bay region. I compare several sites from multiple habitats, and tie in the development of fishing through time with broader subsistence and settlement patterns, as well as fish nutritional composition and environmental conditions.

A key component of my work is a type of predictive modeling long used in ecology but previously unutilized in zooarchaeology. Dynamic state variable modeling (DSVM) allows a more nuanced consideration of multiple variables than traditional behavioral ecological methods as used in zooarchaeology. Using DSVM, I explore which variables are predicted to be most important in subsistence decisions, and then compare those predictions to my ichthyofaunal data to analyze changes in patch choice and procurement strategies.

Culture History and Geographic Scale

The Monterey Bay area often gets combined with much of California's open coast between San Francisco and Point Conception into the geographic unit of central California, but it is usually separated from the Santa Barbara Channel area (see Figure 1.1). Point Conception marks a major biogeographic boundary in the marine environment, and archaeological fish evidence suggests this boundary has existed for at least the past 10,000 years (Gobalet 2000). Consequently, separating Monterey Bay from the Santa Barbara Channel makes sense for addressing questions of subsistence.

Recent archaeological overviews of California's Central Coast typically use a chronology summarized in Jones et al. (2007), based on a synthesis of data from that region, but emphasizing the Big Sur coast. One feature of this chronology is the definition of a Middle-Late Transition Period, c. AD 1000-1250 (e.g., Jones 2003; Jones et al. 2007; Jones and Ferneau 2002; Joslin 2010). However, Breschini and Haversat (e.g., 2005, 2011) have argued that the chronology is not entirely applicable to the Monterey Bay area, especially for the Monterey Peninsula on the southern side of the bay. Furthermore, a scarcity of formal artifacts from Monterey Peninsula samples makes assessing the Jones et al. (2007) chronology with artifacts difficult. Instead, based on an extensive database of radiocarbon dates, as well as what artifacts were present, Breschini and Haversat (2011) suggested several local changes to the broader chronology. Among other adjustments, they remove the Middle-Late Transition Period and identify a time span, 1200-200 BC, to which no archaeological sites in the area date.

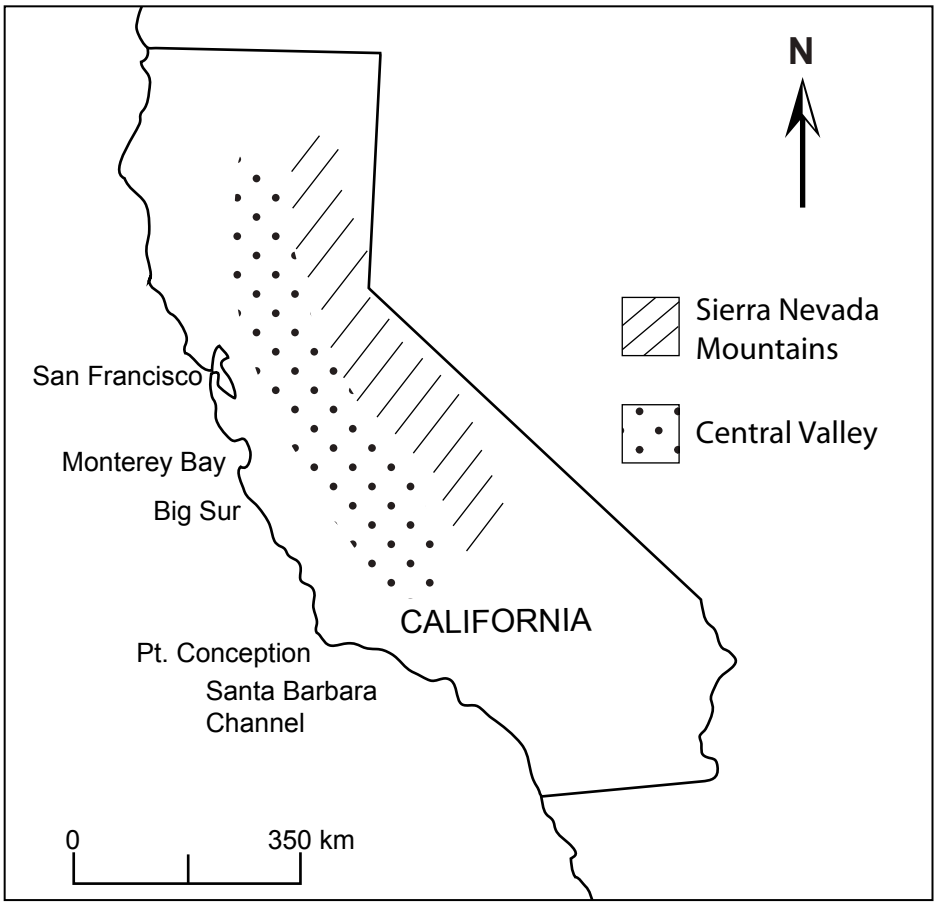


Figure 1.1. Map of California showing major coastal regions and landmarks discussed in the text. Redrawn from Google Earth satellite image.

I will discuss such chronological discrepancies in more detail in Chapter 3, but their very existence indicates that the Monterey Bay area may have taken a different cultural trajectory than the coastline to the south. Joslin's (2010) recent work on the San Simeon Reef area, between Big Sur and Point Conception, identified subsistence and settlement pattern changes during the Middle-Late Transition, supporting the use of the Jones et al. (2007) chronology in that area. As part of my analyses of Monterey Bay area ichthyofauna, I separate out sites that radiometrically

date to the time span of the Middle-Late Transition, to see if similar shifts are evident in this region. In Chapter 9, I investigate whether my data provide support for one chronology or the other.

Zooarchaeological Methodology

In the past thirty years, zooarchaeology has grown to address a much greater variety of research questions, take a more rigorous approach to method, and craft a deeper understanding of how faunal assemblages are created. In many cases, archaeologists can agree on the important considerations in analyzing an assemblage, even when they do not agree on the implications of the data they collect. However, fishes often have remained sidelined, especially in cultural resource management contexts, which are subject to budgetary constraints.

The variability within fishes is extensive, in part because they have a long evolutionary history and extremely high numbers of species. As of 2010, over 30,000 living fish species have been identified as valid taxa (Eschmeyer et al. 2010). Fishes are no longer placed into Class Pisces, but are considered paraphyletic, because any taxonomic category that includes all fishes must also include all tetrapods, such as mammals and reptiles. This taxonomic diversity has important practical implications for the study of fish remains from archaeological sites. Whether a species is caught in the backwaters of an estuary or out in the kelp beds can affect the difficulty, risk, and probable rate of success of exploiting it. Fish body size and behavior, such as whether the taxon schools, also affect what types of fishing gear are used. In my

characterization of patch types, I incorporate information about fish species' habitat, size, and most likely method by which they were caught.

Nutritional composition is also a component in what makes certain taxa more valuable than others. Fats are a good source of easily digested calories and are important in hunter-gatherer diets, especially during seasons when terrestrial game is lean (Speth and Spielmann 1983). Some fishes are not only high in fats, but provide a source of essential fatty acids required for human brain development (Alfin-Slater and Aftergood 1980). Recent research suggests the modern human brain may not have evolved until people emphasized exploitation of shoreline habitats, with their rich sources of EFA (Crawford 2010; Cunnane 2010; Cunnane and Crawford 2003; Muskiet and Kuipers 2010). Fats are thus clearly integral to both human development and survival. Therefore, for fish taxa common in Central Coast archaeological sites but not commercially exploited today, I sampled several modern individuals for proximate composition (fat, protein, and ash), and supplemented that with data available from the literature.

Throughout this dissertation, I employ ichthyological terminology, wherein *fishes* refers to multiple species, and *fish* can signify one or more individuals of the same species (Helfman et al. 1997).

Theoretical Approach and Dynamic State Variable Modeling

In North American zooarchaeology, the study of subsistence among foraging groups is often grounded in behavioral ecology, using optimal foraging theory (OFT)

to predict the decisions people make about exploiting resources. The classic prey and patch choice models both use the concept of energetic rates of return, which assumes that organisms exploit the resources that provide the most energy in relation to what the forager has to expend per unit of time (Charnov 1976a, 1976b). Prey body size was initially employed as a substitute for rate of return in archaeological analyses (Broughton 1994), and since then, ethnographic and experimental research has greatly increased our understanding of rates of return and prey ranking (Bird et al. 2004; Bliege Bird 2007; Bliege Bird and Bird 1997; Hawkes et al. 1982; Jones 2004; Jones and Richman 1995; Lindström 1996; Simms 1985; Sosis 2000, 2002; Ugan 2005).

Despite this research, several limitations are inherent to the traditional prey and patch choice models, including the reliance on a single currency such as rate of return. Some advances have occurred in the anthropological applications of behavioral ecology, led for the most part by Bruce Winterhalder, Rebecca Bliege Bird and Douglas Bird. Winterhalder and his colleagues (e.g., Winterhalder 2002; Winterhalder et al. 1999) have critically analyzed numerous methods of modeling in anthropology, developed adaptive models sensitive to the risk of not finding food when searching for it, and emphasized the need for increased interaction between biology and anthropology. Bird and Bliege Bird (2002; Bird et al. 2004, 2009; Bliege Bird 2007; Bliege Bird and Bird 2008) have made extensive ethnographic studies of two different foraging groups in Australia, describing how such variables as age and sex can influence subsistence choices, and pointing out difficulties with ranking prey.

Dynamic state variable modeling (Clark and Mangel 2000; Houston and McNamara 1999; Houston et al. 1988; Mangel and Clark 1988; Mangel and Ludwig 1992) addresses some of the limitations of rate maximization models as implemented archaeologically. This type of model can incorporate several currencies and tradeoffs, resulting in patches that may be considered optimal for different reasons and at various times. Dynamic state variable modeling (DSVM), as implied by its name, also acknowledges the importance of an organism's physiological and ecological state. In the context of optimal foraging, if the state is defined to reflect a level of energetic reserves, DSVM indicates that an organism's optimal decision can vary depending on the level of those reserves. Furthermore, DSVM does not assume that foragers always experience a patch's average conditions, and instead provides simulations that can be based on a stochastic environment. For all of these reasons, traditionally defined "lower-return" patches may be exploited more often than expected by simple caloric calculations.

In this dissertation, I develop a DSVM to explore such behavior. Building off of a basic patch choice model, this DSVM equates patches with activity choices and I explore which of several variables have the most influence on a forager's decisions about patch exploitation. The first part of the model calculates which patches are optimal for various combinations of environmental conditions and state values. In the second part of the model, I run a Monte Carlo simulation to predict the outcomes if a forager were to follow those optimal choices.

Geologic History and Modern Conditions of the Central Coast

Even within the greater Monterey Bay region, a diversity of habitats exists, and the environmental structure of the area is important for understanding human subsistence. To provide an environmental context for my research, I here describe the region's environment in modern times and its important geological features, summarizing its diverse marine and terrestrial habitats and resources.

Current Structure of Monterey Bay

Monterey Bay is a large, semicircle-shaped bay approximately 40 km north to south, with the town of Santa Cruz located at its north margin and those of Monterey and Pacific Grove to the south (Figure 1.2). Almost exactly in the middle, the village of Moss Landing lies at the mouth of Elkhorn Slough. The Monterey Bay *region* extends beyond the bay itself, and is generally considered to extend from Point Año Nuevo in the north to Carmel in the south, both of which are located on the outer coast (Gordon 1996). The southern Coast Ranges run north–south between the ocean and the Central Valley, and in the Monterey Bay region are called the Santa Cruz Mountains (Oakeshott 1971).

The same tectonic forces that created the Coast Ranges continue to affect this region as it undergoes tectonic uplift at a rate of 15-61 cm/1,000 years (MBAF 1997). The San Andreas Fault, a major geological fault, runs along the Santa Cruz Mountains (Gordon 1996) and forms the boundary between the Pacific and North American continental plates (Schwartz 2002). Steep cliffs along the rugged exposed coastline outside of the bay are eroded by waves, creating sandy beaches (MBAF

1997; Oakeshott 1971). Tectonic movements have raised the beach terraces above sea level, and these ancient marine terraces form tablelands at several levels from the coast inland to the mountains (MBAF 1997).

The ocean moderates climatic variability, so the coastal climate is fairly mild (MBAF 1997). Winters are wet and summers dry, though as Gordon (1977:13) said, "seasons are weakly developed" and temperature differences are slight. During the spring and summer, heavy morning fog occurs when upwelling cold water lowers the temperature of the warmer moist air (Caffrey 2002; Gordon 1996; MBAF 1997). The fog mitigates spring and summer temperature extremes, with average highs and lows diverging by barely 2ºC (Caffrey 2002). Annual rainfall varies from north to south, with Santa Cruz averaging 28 in (71 cm) and Monterey 15 in (38 cm). It is heavier in the mountains than immediately on the coast (Gordon 1996; MBAF 1997).

Though regional tectonic uplift over time has raised the land, the global rise in sea level has shifted the Monterey Bay shoreline eastward. At 16,050 BC, sea level was 90-120 m lower and the coast was 5-8 km west of where it is now (Schwartz 2002), except at Moss Landing, where the deeply incised Monterey Submarine Canyon brought the coastline only 2 km away from the present shore (Jones 2002b). By 6050 BC, sea level was 10-15 m lower than present (Masters and Aiello 2007), and by 3050 BC, the shoreline had reached a position similar to modern conditions (MBAF 1997), so that archaeological sites created since then would have been situated in topographic contexts similar to today.

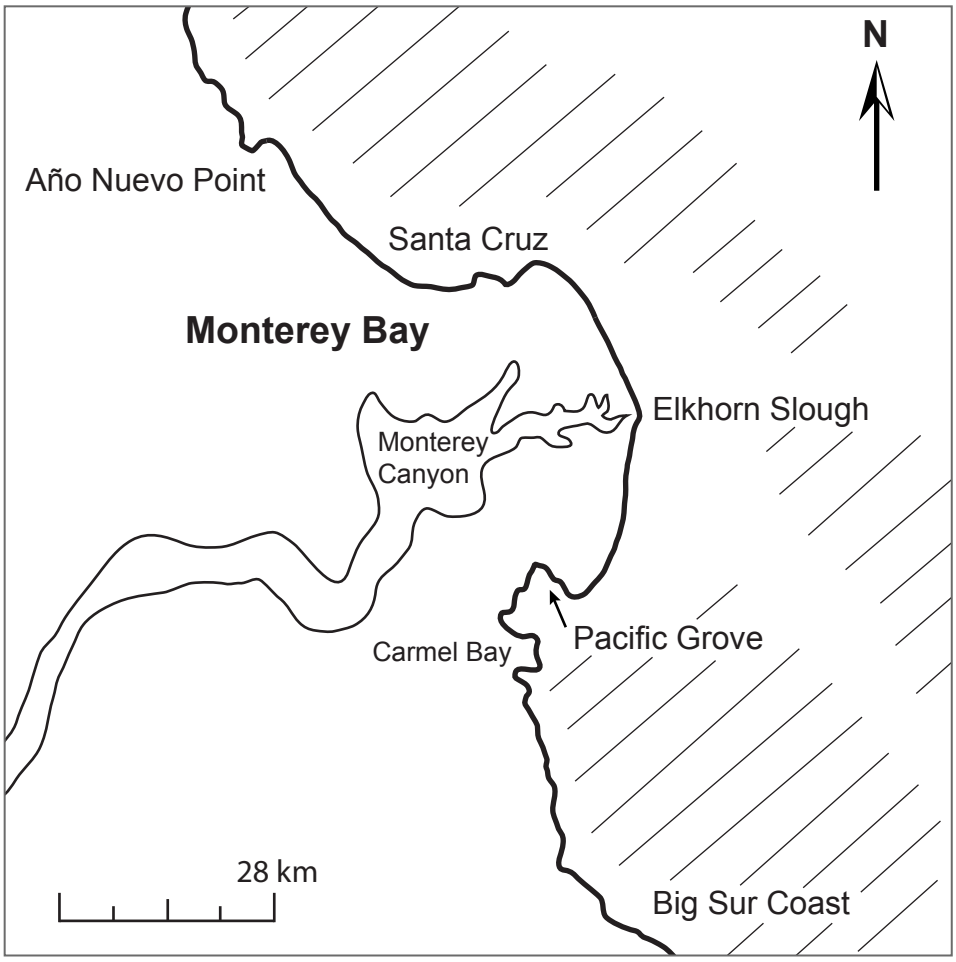


Figure 1.2. Map of the Monterey Bay region extending south to the Big Sur coastline. Hatching indicates Coast Ranges. Redrawn from Google Earth satellite image.

With its head only 100 m offshore of present-day Moss Landing, the Monterey Submarine Canyon is a major feature of the bay, reaching 2.9 km deep, and covering at least 110 km of seafloor (Caffrey et al. 2002; MBAF 1997). One of the largest submarine canyons of North America and comparable in size to the Grand Canyon (Caffrey et al. 2002; NOAA NMSMB 2003), the Monterey Canyon formed about 30 million years ago as part of a much larger gorge that extended on land into

Elkhorn Valley around what is now the slough (Schwartz 2002). Elkhorn Valley may have played an important role in the past as part of a large-scale drainage that funneled water from the Santa Clara Valley, and possibly the Central Valley, into the Pacific Ocean, carving the canyon in the process. About 500,000 years ago, the Elkhorn Valley was what Schwartz (2002:19) called "beheaded," cut in two as the San Andreas Fault shifted its seaward side north, shrinking its drainage to Carneros Creek (Schwartz 2002; Schwartz et al. 1986).

Presently, the San Lorenzo, Pajaro, and Salinas Rivers all converge toward the head of Monterey Canyon (Gordon 1996). Elkhorn Slough at Moss Landing is part of this drainage system, and is itself another important feature of the bay, due to its highly productive habitat. It comprises a narrow, winding, marshy waterway (MBAF 1997). In its modern form, it is technically not a slough, because recent human intervention has changed it from a "stagnant backwater" (Caffrey and Broenkow 2002:25). The detailed and complicated history of Elkhorn Slough is presented in the section on Monterey Bay paleoclimate in Chapter 2.

The contemporary Elkhorn Slough extends 11.3 km inland and is a seasonally well-mixed estuary in the winter, when freshwater flows from Carneros Creek and mixes with tidal salt water (MBAF 1997). In summer and fall, the creek turns dry and the slough's backwater areas become a negative estuary, with salinity levels higher than the ocean (Caffrey and Broenkow 2002; MBAF 1997). Salt marsh comprises the most extensive habitat at Elkhorn Slough, followed by mudflats, saltponds, dunes, beach, and water channels (Browning 1972). The slough's relatively shallow waters

and tidal influence provide prime habitat for abundant vegetation, which decays and provides nutrients for the rest of the food web (Caffrey et al. 2002; MBAF 1997). As a result, Elkhorn Slough is a biologically rich locale along the Monterey Bay. The presence of major archaeological sites at or near Elkhorn Slough reflects aboriginal Californians' focus on this ecosystem's productivity.

Significant upwelling in and near Monterey Bay brings nutrients into the surface zone of the ocean where other organisms can use them, thus creating a highly productive marine environment. In the spring and summer upwelling season, the North Pacific High and the North American Low pressure systems in the atmosphere combine to create northwest winds (Barron and Bukry 2007; Barron et al. 2003). These winds, along with the earth's rotation, move warm surface water away from the coast, allowing colder water from below to rise in the so-called Ekman transport process (Caffrey 2002; MBAF 1997), responsible for most of the upwelling in the Monterey Bay area (Graham and Largier 1997). Most surface upwelling in the Monterey Bay region occurs May-August and lessens September-October (Diffenbaugh et al. 2003). Because the Monterey Canyon contains the deepest water in the region, it has often been given credit for the significant presence of nutrient-rich water in the bay (see Rosenfeld et al. 1994). However, recent analyses show that surface upwelling mainly occurs off of Año Nuevo and then the cold (10-13ºC), upwelled water flows south into the bay (Graham and Largier 1997; MBAF 1997; Rosenfeld et al. 1994). "Bathymetrically induced" upwelling probably does occur within the canyon, but does not reach the surface (Graham and Largier 1997:511).

Ocean temperature and productivity are also influenced by the wind-driven California Current, which generally flows south along California's Central Coast, carrying low salinity, low temperature, high nutrient water from the subarctic (Diffenbaugh et al. 2003; MBAF 1997). Water joins the California Current mainly through advection, meaning currents move the water horizontally, but also from upwelling (Diffenbaugh et al. 2003). Sea surface temperature (SST) in the region is therefore cool even during non-upwelling seasons, ranging from 10-18ºC (50-65ºF) throughout the year. In addition to its effects on ocean environment off the Pacific Coast, the California Current also influences atmospheric climate over western North America (Diffenbaugh et al. 2003). In the winter, wind direction helps activate the Davidson Current, which flows north along the coast inside of the California Current from about November through February (Barron and Bukry 2007).

Overall, SST within Monterey Bay seems to be less variable than that on the open coast (Breaker 1989), a factor not often considered in archaeological work. Past SST data drawn from mollusks from the Big Sur coast south of Monterey Bay have been used in arguments about settlement patterns and subsistence in the region (Jones and Kennett 1999). Its proximity to Monterey Bay makes it tempting to use Big Sur uncritically as a proxy for the bay. However, modern SST measuring stations at Pacific Grove, in the bay, and at Granite Canyon, on the Big Sur coast, show that, while Pacific Grove conditions are fairly representative of the bay, those of the outer coast are not, and vice versa (Breaker 1989). For example, Pacific Grove appears to have a less variable response to El Niño events described further in Chapter 2, with

peak SST staying more similar between El Niño and other years compared to the range of variation at Granite Canyon. Additionally, the transition to the colder upwelling season often occurs very abruptly in both places, but typically up to 10 days later in Pacific Grove than on the outer coast (Breaker 1989). Thus, the difference between open coastal SST and SST in the bay itself should be kept in mind when generalizing Big Sur coast data. I therefore use open coast SST data circumspectly in this research.

Bay and outer coast aquatic habitats and resources

This dissertation's focus on fishing necessitates a discussion of habitat types and associated resources in the Monterey Bay. Habitats can vary significantly in their resources, their productivity, and the ease of exploiting their resources. The Monterey Bay Aquarium Foundation (MBAF) divided aquatic habitats into eight general types, and I have added a freshwater category to the list of habitats discussed here. While I will later merge some of these categories together for modeling purposes, I describe each discretely here, to emphasize the similarities and differences among them. In Table 1.1 I summarize which fish species are common in such habitats in Monterey Bay specifically, and include the Linnaean binomials for each species.

Moyle (2002) defined a Monterey Bay Subprovince of freshwater habitat, comprising the Salinas, Pajaro, and San Lorenzo Rivers, along with smaller creeks in the region. The number of freshwater species available in these waters is much lower than that of saltwater species. Native species currently consist of hitch, California roach, Sacramento blackfish, Sacramento pikeminnow, and speckled dace (all of

which are minnows), Sacramento sucker, riffle sculpin, and rainbow trout (Moyle 2002:13). Some marine taxa are occasionally found in freshwater, including sculpin species, lamprey, and threespine stickleback (Moyle 2002).

Table 1.1. Common fish species found in different habitats around Monterey Bay.

Habitat	Common species	Linnaean binomial	References
Freshwater	Thicktail chub	*Gila crassicauda*	Gobalet 1990, 1993; Moyle 2002
	Hitch	*Lavinia exilicauda*	
	California roach	*Lavinia symmetricus*	
	Sacramento blackfish	*Orthodon microlepidotus*	
	Sacramento pikeminnow	*Ptychocheilus grandis*	
	Speckled dace	*Rhinichthys osculus*	
	Sacramento sucker	*Catostomus occidentalis*	
	Rainbow trout	*Oncorhynchus mykiss*	
	Riffle sculpin	*Cottus gulosus*	
	Sacramento perch	*Archoplites interruptus*	
	Tule perch	*Hysterocarpus traski*	
Wetland	Leopard shark	*Triakis semifasciata*	Barry et al. 1996; Yoklavich et al. 1991, 2002
	Bat ray	*Myliobatis californica*	
	Pacific herring	*Clupea pallasi*	
	Northern anchovy	*Engraulis mordax*	
	Silversides	Atherinopsidae	
	Pacific staghorn sculpin	*Leptocottus armatus*	
	Surfperches	Embiotocidae	
	Shiner surfperch	*Cymatogaster aggregata*	
	Black surfperch	*Embiotoca jacksoni*	
	White surfperch	*Phanerodon furcatus*	
	Speckled sanddab	*Citharichthys stigmaeus*	
	Starry flounder	*Platichthys stellatus*	
	English sole	*Parophrys vetulus*	
	Sandsole	*Psettichthys melanosticus*	
Rocky intertidal	Plainfin midshipman	*Porichthys notatus*	MBAF 1997
	Sculpin (small)	Cottidae	
	Cabezon	*Scorpaenichthys marmoratus*	
	Reef surfperch	*Micrometrus aurora*	
	Monkeyface prickleback	*Cebidichthys violaceus*	

(continued on next page)

Table 1.1. (continued)

Kelp forest	Bat ray	*Myliobatis californica*	MBAF 1997; Stephens et al. 2006
	Leopard shark	*Triakis semifasciata*	
	Blue rockfish	*Sebastes mystinus*	
	Kelp greenling	*Hexagrammos decagrammus*	
	Sculpin	Cottidae	
	Surfperches	Embiotocidae	
	Giant kelpfish	*Heterostichus rostratus*	
Natural reef	Shallow water rockfishes	*Sebastes* spp.	MBAF 1997; Stephens et al. 2006
	Sculpin	Cottidae	
	Cabezon	*Scorpaenichthys marmoratus*	
	Surfperches	Embiotocidae	
Sandy beach	Sardines and herrings	Clupeidae	Allen and Pondella 2006; MBAF 1997
	Northern anchovy	*Engraulis mordax*	
	Silversides	Atherinopsidae	
	Striped bass	*Morone saxatilis*	
	Surfperches	Embiotocidae	
	Sanddabs	*Citharichthys* spp.	
Sandy bottom	Sharks and rays	Chondrichthyes	MBAF 1997
	Flatfishes	Pleuronectiformes	
Muddy bottom	Sculpin	Cottidae	MBAF 1997
	Pacific halibut	*Hippoglossus stenolepis*	
	Dover sole	*Microstomus pacificus*	
	English sole	*Parophrys vetulus*	
Water column above sandy floor	Pacific sardine	*Sardinops sagax*	Cailliet et al. 1979; Love et al. 2002; MBAF 1997
	Pacific herring	*Clupea pallasi*	
	Northern anchovy	*Engraulis mordax*	
	Salmon	*Oncorhynchus* spp.	
	Night smelt	*Spirinchus starksi*	
	Plainfin midshipman	*Porichthys notatus*	
	Rockfishes	*Sebastes* spp.	
	Jack	Carangidae	
	Yellowtail	*Seriola lalandi*	
	Jackmackerel	*Trachurus symmetricus*	
	White seabass	*Atractoscion nobilis*	
	Pacific bonito	*Sarda chiliensis*	
	Pacific mackerel	*Scomber japonicus*	
	Pacific sanddab	*Citharichthys sordidus*	
Open water	Sardines and herrings	Clupeidae	MBAF 1997
	Northern anchovy	*Engraulis mordax*	
	Salmon	*Oncorhynchus* spp.	
	Pacific hake	*Merluccius productus*	
	Rockfishes	*Sebastes* spp.	
	Tuna	Scombridae	

Four species that used to be available in freshwater contexts in the region are no longer found. Thicktail chub is extinct throughout its entire range (McGinnis 2006; Page and Burr 1991), but bones from archaeological sites testify to its past regional presence (Gobalet 1990, 1993). Sacramento perch was once common throughout the Central Valley drainage system and the Pajaro and Salinas Rivers, but is now only found in scattered areas around California and has vanished from the Monterey Bay Subprovince (Moyle 2002). Tule perch went locally extinct from the Monterey Bay area in the mid-twentieth century (Moyle 2002). Archaeofaunal remains also indicate the native presence of anadromous coho salmon in coastal streams at least as far south as Point Año Nuevo (Adams et al. 2007; Gifford-Gonzalez et al. 2006; Gobalet 2012).

Wetlands, the second habitat type, are especially rich (Monaco et al. 1992), and Elkhorn Slough is the major wetland in the Monterey Bay area (Caffrey et al. 2002). Invertebrates are diverse and numerous, numbering over 550 species of worms, clams, snails, shrimp, crabs, etc. (Wasson et al. 2002). The highest species diversity is found at the mouth of the Elkhorn Slough, where taxa endure less variation in salinity, oxygen, temperature, and pH levels than they do at the slough's head (Wasson et al. 2002). Water at the slough's mouth is typically quite similar to the ocean's, whereas that at the head varies from much more saline, when Carneros Creek stops flowing in the summer, to much less saline in the winter, when increased fresh water enters the system as stream flow and runoff (Wasson et al. 2002). Such drastic changes in salinity, accompanied by greater water turbidity and finer

sediments that can clog invertebrate feeding structures, create an environment in which fewer species can thrive. Several species of large edible clams are found mostly in the lower slough, as are nonnative bay mussels (*Mytilus galloprovincialis*); native oysters (*Ostrea conchaphala*) extensively colonize the upper slough (Wasson et al. 2002).

Harbor seals and sea otters are the only marine mammals currently found in the slough year round, but California sea lions enter it at times (Harvey and Connors 2002) and archaeological evidence supports the presence of a local northern fur seal rookery approximately 150 BC-AD 450 (Burton et al. 2001; Gifford-Gonzalez and Sunseri 2009).

Due to its richness and diversity of bird species, Elkhorn Slough today is a major bird-watching destination. Over 200 species of migratory birds use Elkhorn Slough as a stopping ground in late fall and winter when flying south and in spring when flying north (Harvey and Connors 2002; MBAF 1997). Approximately 40 bird species are permanent residents, though more than 265 bird species can be found over the year and upwards of 20,000 individual shorebirds can be present during the height of migration in spring and fall (Harvey and Connors 2002).

Fishes in the slough include over 100 species, of which at least 82 are marine. Some fish species are permanent residents, such as Pacific staghorn sculpin, black surfperch, bay pipefish, and several species of gobies (Yoklavich et al. 2002). Others are partial residents, meaning they are common in and spawn in the slough, while spending part of their life histories or part of the year at sea. Partial residents in

Elkhorn Slough include silversides, some surfperch species, leopard shark, and bat ray (Yoklavich et al. 1991). Sixteen species, including northern anchovy, Pacific herring, cabezon, and several species of flatfish, are known as marine immigrants, mainly ocean-dwelling but reproducing in or using the slough as a nursery ground (Yoklavich et al. 2002). Six freshwater species currently inhabit the slough, of which prickly sculpin and threespine stickleback are native (Yoklavich et al. 2002).

Of all the slough taxa, the most common are shiner surfperch, Pacific staghorn sculpin, white surfperch, black surfperch, northern anchovy, speckled sanddab, English sole, starry flounder, Pacific herring, sand sole (Yoklavich et al. 1991), and leopard shark (Yoklavich et al. 2002). Summer brings the greatest number and diversity of fishes, as some species enter to spawn or to spend the juvenile stage of their life histories, and certain locally spawned juveniles still remain, whether or not they migrate out to sea later (Yoklavich et al. 1991, 2002). Mostly resident species remain in the winter, as they can generally tolerate the wider range of habitat characteristics, though some immigrant species like anchovy can also be found (Yoklavich et al. 2002).

The third habitat type, the rocky intertidal zone, is also biologically diverse, because waves bring food and oxygen to organisms living among the rocks (MBAF 1997). At the same time, the waves create a turbulent, highly variable environment. Oftentimes, receding tides leave only small pools of water, and resident fishes must be able to survive hours of air exposure (Horn and Martin 2006). On the Central Coast, mild climate, upwelling, and summer fog protection from the sun, combined

with low summer tides before sunrise, create an intertidal zone that produces, "more biomass…than any other intertidal region in the world" (MBAF 1997:100). An assortment of plants, shellfish, fishes, birds, and marine mammals are found throughout the intertidal. Fishes include small sculpin, cabezon (younger fish and adult males guarding nests), monkeyface pricklebacks, plainfin midshipman nesting in spring, and reef surfperch (MBAF 1997). The rocky intertidal zone also serves as a summer nursery, undergoing an increase in population due to high proportions of juveniles, as well as an increase in species richness (Moring 1986).

Kelp forests in the Monterey Bay, typically found off rocky coastlines, are also rich with sea life, to the extent that Stephens Jr. et al. (2006:227) said, "California's kelp bed and rock-reef habitats are among the most spectacular marine habitats in the world." Because the forests have a complex structure, many kinds of animals are present, including invertebrates living on the kelp forest floor, numerous fishes throughout the environment, and sea otters and other marine mammals swimming through to forage (MBAF 1997). Common bony fishes include several species of rockfish, sculpin, greenling, surfperch, and kelpfish, as well as assorted cartilaginous fishes like bat ray and leopard shark. Additionally, the young of several species use the kelp forest as a nursery environment (Stephens Jr. et al. 2006). Kelp beds have to anchor themselves to a hard substrate and are usually connected to rocky reefs (Stephens Jr. et al. 2006).

In the Monterey Bay, rocky reefs are generally created out of mudstone by rock-boring clams, which then die and allow other invertebrate species to move in

(MBAF 1997). Rockfishes, surfperches, greenlings, and sculpin are some of the most common fishes found in shallow (<30 m) rocky reef habitat (Stephens Jr. et al. 2006). The particular species composition of a rocky reef or kelp forest is related to depth, habitat, and vegetation (Stephens Jr. et al. 2006).

One of the least biologically diverse and productive habitats is the sandy beach, which extends along much of the central Monterey Bay shoreline (MBAF 1997). Waves bring sand onto the beach, and the sand can build into dunes as it clusters around objects. Once the dunes are above high water level, they are colonized by plants and become stabilized, providing a habitat for small mammals, reptiles, birds, and insects (MBAF 1997). The "Monterey dune complex" covers at least 36 km of coastline from Sunset State Beach near Watsonville in the north half of the bay to the marina in Monterey. The California Coastal Commission (CCC) described it as "one of the most extensive dune systems on the West Coast" (CCC 1987:206).

The sandy beach itself is limited to algae for flora, and animals mostly comprise mollusks, crustaceans, polychaete worms, and insects (MBAF 1997). However, dynamic wave action exposes the invertebrates, allowing certain fish species to feed on them just beyond the surf (Allen and Pondella 2006) and shorebirds to forage on them in the surf zone. Among the most common fishes found in the surf zone are silversides, anchovies, herrings, surfperches, flatfishes and rays (Allen and Pondella 2006; MBAF 1997).

The sandy bottom habitat is home to invertebrates and fishes, especially flatfishes, sharks, and rays. More species occur in a muddy bottom habitat, and fishes

include sculpin and larger adult flatfishes like English sole, Pacific halibut, and Dover sole (MBAF 1997). Such soft bottom habitats are included in the so-called coastal pelagic zone, which exists between the surf and the continental shelf break (Allen and Pondella 2006). In Monterey Bay, many species feed at the surface at night, including anchovies, which dominated the historic purse seine hauls, and Pacific herring, plainfin midshipman, night smelt, and Pacific sanddab (Cailliet et al. 1979). Other fishes commonly found in the water column above the ocean floor are Pacific mackerel, jackmackerel, white seabass, bonito, salmon, jack, yellowtail, rockfishes, and juveniles of several species (MBAF 1997).

In the deeper open water, many fish species spend their early development as meroplankton, dispersing along the coast regardless of whether they are intertidal or benthic as adults (MBAF 1997). As they gain more control over their mobility, the larvae eventually develop into nekton, animals that can choose their direction of movement even against currents (Moser and Watson 2006). In central California, the largest spawning area for sardine, anchovy, and hake is south of Point Conception, where the upwelling is weaker. Some species on the Central Coast, such as greenlings and brown Irish lords, spawn in winter before the strong spring upwelling starts (MBAF 1997). In the epipelagic zone, the top 200 m of ocean, fishes tend to be particularly active swimmers, some migrating thousands of kilometers each year. These species are swift and often form large schools (Allen and Cross 2006).

Some of the most common nekton in Monterey Bay are anchovies and sardines, and other fish such as herrings, mackerels, salmon, hake, tuna, etc., as well

as marine mammals, birds, and sea turtles (MBAF 1997). Humpback whales, blue whales, gray whales, and several species of dolphins and porpoises can all commonly be seen off of the Central Coast (CCC 1987). Large mammals like orcas forage for food in Monterey Canyon, taking advantage of the productive cold water (NOAA NMSMB 2003).

Some marine fish species can occasionally be exploited on the land. Historic records described enormous schools of sardines, herrings, and anchovies piling up on the shore for unknown reasons. These could extend for miles along the beach, up to 15-61 cm deep (Gordon 1996). Massive strandings occasionally occur in modern times; at least 3,000 tons of anchovies stranded near Half Moon Bay, south of San Francisco, in the summer of AD 2000, and similar events happen about every ten years (McCabe 2000).

Despite my own work's emphasis on fishing, indigenous peoples of the California coast certainly did not subsist entirely on aquatic resources. To fully contextualize how people made decisions about what resources to exploit, an understanding of the terrestrial habitats is also necessary. The next section describes some important aspects of the Central Coast's terrestrial environment.

Terrestrial habitats and resources

Plant communities are divided into several major groupings, and a substantial number of species have distribution boundaries in the Monterey Bay area. Pine forests were likely more common close to the coast in the past (Gordon 1996). One stand of ponderosa pine exists at unusually low altitude close to the coast on the

University of California at Santa Cruz campus. Numerous habitats can be found in relatively small areas. For example, the CCC (1987:187) described the UC Santa Cruz campus has having "redwood forest, mixed-evergreen forest, ponderosa pine, chaparral, and grassland." These habitats support a diverse selection of species from small to large mammals, birds, amphibians, and reptiles (CCC 1987). However, the terrestrial habitats around Monterey Bay do not represent a rich environment for edible plant foods. Wohlgemuth's (2010) assessment of plant communities along the Monterey Bay shoreline ranged from marginally- to non-productive for terrestrial roots, seeds, and nuts.

Of edible flora, various oak species were extremely important to indigenous peoples in the later part of their precolonial history, as the acorns would be processed into flour (Lightfoot and Parrish 2009). Black oak (*Quercus kelloggii*), coast live oak (*Quercus agrifolia*), and valley oak (*Quercus lobata*) are all found in the Coast Ranges (Gordon 1996; Lightfoot and Parrish 2009). Coast live oak is frequently found fairly close to shore (CCC 1987), and used to be more common around Elkhorn Slough, Moro Cojo Slough, the Pajaro River, and in other areas that are now farmed or grassland (Gordon 1996). A false oak, the tan-oak (*Lithocarpus densiflorus*), was especially sought after for its acorns (Gordon 1996; Lightfoot and Parish 2009).

Coast redwood (*Sequoia sempervirens*) forest is common, though not immediately on the coast, reaching the southern extent of its range in southern Monterey County (CCC 1987). Gordon (1996:135) says that although redwoods "do not thrive at the shoreline itself because of their intolerance to salt in the air, the trees

probably once approached the coast, on favorable sites, more closely than they do at present." Significant increases in redwood pollen in cores along the California coast suggest redwood forest expanded in the region c. 3250 BC. The expansion of redwood forest reflects the establishment of modern maritime climate, with cool foggy summers and mild winters (Barron et al. 2003).

Black-tailed deer (*Odocoileus hemionus*) and mountain lions (*Puma concolor*) are the main large mammal species still present in the Monterey Bay area, but past environments would have included grizzly bears (*Ursus arctos horribilis*), pronghorn antelope (*Antilocapra americana*) in Salinas Valley and north bay coastal prairie, and tule elk (*Cervus elaphus canadensis*) in the lowlands and marshes of the Pajaro and Salinas Valleys and Elkhorn Slough (Gordon 1996). Written accounts from both Spanish cattlemen and British naturalists in Monterey described problems with wolves killing livestock (Gordon 1996). Small- and medium-sized mammals of the area include coyotes (*Canis latrans*), bobcats (*Lynx rufus*), raccoons (*Procyon lotor*), and rabbits and hares of the family Leporidae (Lightfoot and Parrish 2009).

Marine mammals of various species are found throughout the bay and often haul out on land. California sea lions (*Zalophus californianus*) and harbor seals (*Phoca vitulina*) are present both in modern contexts and archaeologically (Burton et al. 2001). Steller sea lions (*Eumetopias jubatus*) historically had a rookery at Año Nuevo (Emory 1999; NOAA NCCOS 2003), but their bones are rare in archaeological sites (Gifford-Gonzalez and Sunseri 2009; Gifford-Gonzalez et al. 2006). Northern elephant seals (*Mirounga angustirostris*) breed today at Año Nuevo,

but colonized the point in the twentieth century and are nearly absent from the prehistoric archaeological record (Le Boeuf and Panken 1977; Orr and Poulter 1965). Northern and Guadalupe fur seals (*Callorhinus ursinus* and *Arctocephalus townsendii*) are found archaeologically, but are not components of the modern ecological system (Gifford-Gonzalez 2011; Gifford-Gonzalez and Sunseri 2009).

Historic records show higher bird populations in the past, especially of larger birds, such as California condor (*Gymnogyps californianus*), various albatrosses and eagles (Gordon 1996). California brown pelicans (*Pelicanus occidentalis*), cormorants, gulls, ducks and geese are some of the more common larger birds that were exploited by Native Americans in the past (CCC 1987; Lightfoot and Parrish 2009). Land and seabirds are both still abundant on the Central Coast.

Radiocarbon Date Calibration

The variety of formats in which dates are provided in the primary literature presents difficulties for a synthesis. Much of the research that discusses earlier parts of the Holocene uses BP (Before Present), while in later periods, BC/AD dates are frequently employed. Some articles that cover long spans of time actually switch from BP to BC/AD. Moreover, calibrations for radiocarbon dates are not always provided. As evidenced by a recent debate in *American Antiquity*, being clear about whether or not dates are calibrated is extremely important, because it can substantially affect chronological interpretations of archaeological data (Hildebrandt et al. 2010; Jones and Codding 2010).

I have decided to use a calibrated BC/AD scheme in this dissertation for several reasons. First, most recent archaeological and paleoclimatic sources use calibrated dates, so either calibrated BP or BC/AD dates are appropriate. Second, the archaeological sites I consider in this dissertation come from the latter two-thirds of the Holocene, and extend nearly to the time of European contact, so Gregorian calendar dates are easier to connect with later material. Third, the Medieval Climatic Anomaly, c. AD 800-1400, a prominent climatic event of the later Holocene with significant repercussions for humans globally, is usually discussed using AD dates. Finally, Gregorian calendar dates are typically acceptable in major archaeological journals, and sometimes required for California-focused publications.

When a source used calibrated BP radiocarbon dates, I subtracted the published date from 1950 to switch to a BC/AD format. Frequently, the reported BP dates were clearly rounded to the nearest hundred years. As a result, many of my transformed dates end in "50," which is probably more specific than the original dates warrant, but unavoidable.

Uncalibrated radiocarbon dates were more problematic, but fortunately relatively rare. To calibrate those dates, which mostly come from the paleoclimatic literature and refer to terrestrial samples, I used the CALIB 6.0html radiocarbon calibration program, available at http://calib.qub.ac.uk/calib/. I entered an arbitrary 100-year standard deviation in age, and selected the IntCal04 calibration curve, recommended for non-marine samples from the Northern Hemisphere. The program provides calibrated date ranges at one and two sigma standard deviations, and if there

are multiple ranges due to radiocarbon fluctuations in the atmosphere, the program indicates how much area under the probability curve each set of dates covers. Using the one-sigma date ranges that covered more than 50% of the curve, I determined the middle of the date range, rounded to the nearest ten years. This is by no means an elegant solution, but at least provides a figure to which calibrated dates can be compared, though obviously with caution.

Except in a few cases where dating methods and discrepancies form part of my discussion, I first report a calibrated BC/AD date, regardless of what the source used. I list all sources that used dates requiring transformation or calibration, and which they needed, by author, in Appendix 1. In the text, if the original date was uncalibrated, I supply it in brackets immediately after the BC/AD date, using the term "^{14}C years bp." If the date was calibrated years BP, I only note that point in the appendix, since it merely required subtraction to be transformed into my preferred format. Dates reported in the literature as calibrated BC/AD are used as is, and are not included in Appendix 1. This structure preserves the original data and makes clear exactly how much I have transformed the numbers.

As a final point regarding radiocarbon dates, I occasionally refer to AMS dates. These are samples radiocarbon dated using applied mass spectrometry, which require much smaller samples, count ^{14}C atoms directly, and are more accurate than conventional dating methods. I only note when dates were run using AMS in a few contexts, where it might increase the validity of some results over others.

Research Significance and Dissertation Structure

This research contributes to methodological, theoretical, and culture historical arenas. I combine detailed zooarchaeological analyses with a dynamic state variable model to investigate the relationship among prehistoric fishing, local habitats, climatic change, and human nutrition. Fishes were important in past human diets in the biologically rich Monterey Bay region, and evidence indicates that this was true from the area's earliest occupations. I hypothesize that, during times of terrestrial drought and resource stress, the marine environment provided a more consistent source of both protein and fat. Further, I challenge the common zooarchaeological assumption that energetic rate of return is the appropriate variable on which to focus in behavioral ecological analyses, and argue that dynamic state variable modeling provides more sophisticated predictions about optimal decision-making. Finally, I show how detailed analyses of fish remains can inform the local culture history sequence.

The next two chapters of this dissertation provide the climatic and culture historical backgrounds necessary for contextualizing my research. In Chapter 2, I highlight the evidence for regional paleoclimate variability, presenting an extensive overview of the current knowledge, with an emphasis on the diversity of climate proxies and findings in western North America. I stress the need to use local data and synthesize the climatic history for the Monterey Bay area. In Chapter 3, I review culture history for the California coast, emphasizing a comparison between the Northern Coast, Central Coast, and Santa Barbara Channel, and the exploitation of

marine resources in each of those areas. In Chapter 4, I provide a theoretical overview of behavioral ecology, the perspective with which I approach decision-making by foragers in the Monterey Bay region, and argue for the adoption of dynamic state variable modeling in zooarchaeological research. Chapters 5 and 6 describe the sites from which I examined ichthyofauna and my analytic methodology, respectively. In Chapter 7, I present the results of my dynamic state variable model, examining which factors had the most influence on the model's predictions about foraging decisions. The zooarchaeological results are then evaluated in Chapter 8. In Chapter 9, I investigate the relationship between the modeling predictions, zooarchaeological results, climate, and nutrition, to produce conclusions about optimal foraging in rich coastal environments.

CHAPTER 2

Climate Cycles and the Holocene – A Critical Review

Habitat and climate play a role in decisions people made in the past about where and how to acquire food, although not in a simple, deterministic way. Climate affects species ranges, community diversity, and biological productivity, thereby structuring which resources people have available and how easily they are acquired. To understand why past peoples exploited particular resources, it is essential to first understand their environmental contexts. The archaeological sites I analyze in this dissertation all derive from the Holocene, an epoch that represents a warming of the Earth's atmosphere following the last glacial period. Here I discuss details of the Holocene and problems with dating it, but it essentially began c. 9550 BC and continues today. In this chapter, to provide a climatic context for California prehistory, I examine what researchers currently know about climate at multiple scales.

I begin with the largest-scale processes affecting global climate change and move toward a more local focus on the western coast of North America, California, and the Monterey Bay area. In each section, I first discuss atmospheric paleoclimate and then changes in ocean conditions. The main message of this chapter is that local climate does not necessarily tightly match global, hemispheric, or even regional conditions, so using locally gathered evidence is imperative. In the Monterey Bay area, such data are scarce for key spans of human occupation, yet archaeologists have

not shrunk from writing about the effects of climate change on regional populations. The last part of this chapter addresses interpretive issues in this connection.

At the outset, I stress that research on paleoclimate has been heavily weighted toward regions surrounding the north Atlantic, with particular focus on Europe and Greenland. Much of the recent research has therefore emphasized determining whether past climatic events identified in Europe and Greenland also affected other regions on the planet. Data suggest that only some events are truly global in scale, and that local manifestations of even those events can be highly variable. As a result, broader generalizations about certain climatic events deserve critical assessment.

I provide significant detail in this chapter because I want to stress the variability among different regions and fully explain why I do not employ some of the same climate proxies that are common in archaeological discourse. Since I discuss many different places in California and adjacent regions, I show the location of the important areas in Figure 2.1.

The Great Basin and California's Sierra Nevada Mountains are frequently employed as sources of paleoclimate data for all time periods I discuss in this dissertation. In Tables 2.1 and 2.2, I describe the locations of common sites in these two regions. The Bonneville Basin in the northeastern Great Basin held the enormous Lake Bonneville during the Pleistocene, covering much of northwestern Utah. Starting about 9760 BC [10,100 ^{14}C years bp] water levels dropped quickly, though not continuously, eventually reaching levels typical of the present-day Great Salt Lake (Madsen et al. 2001).

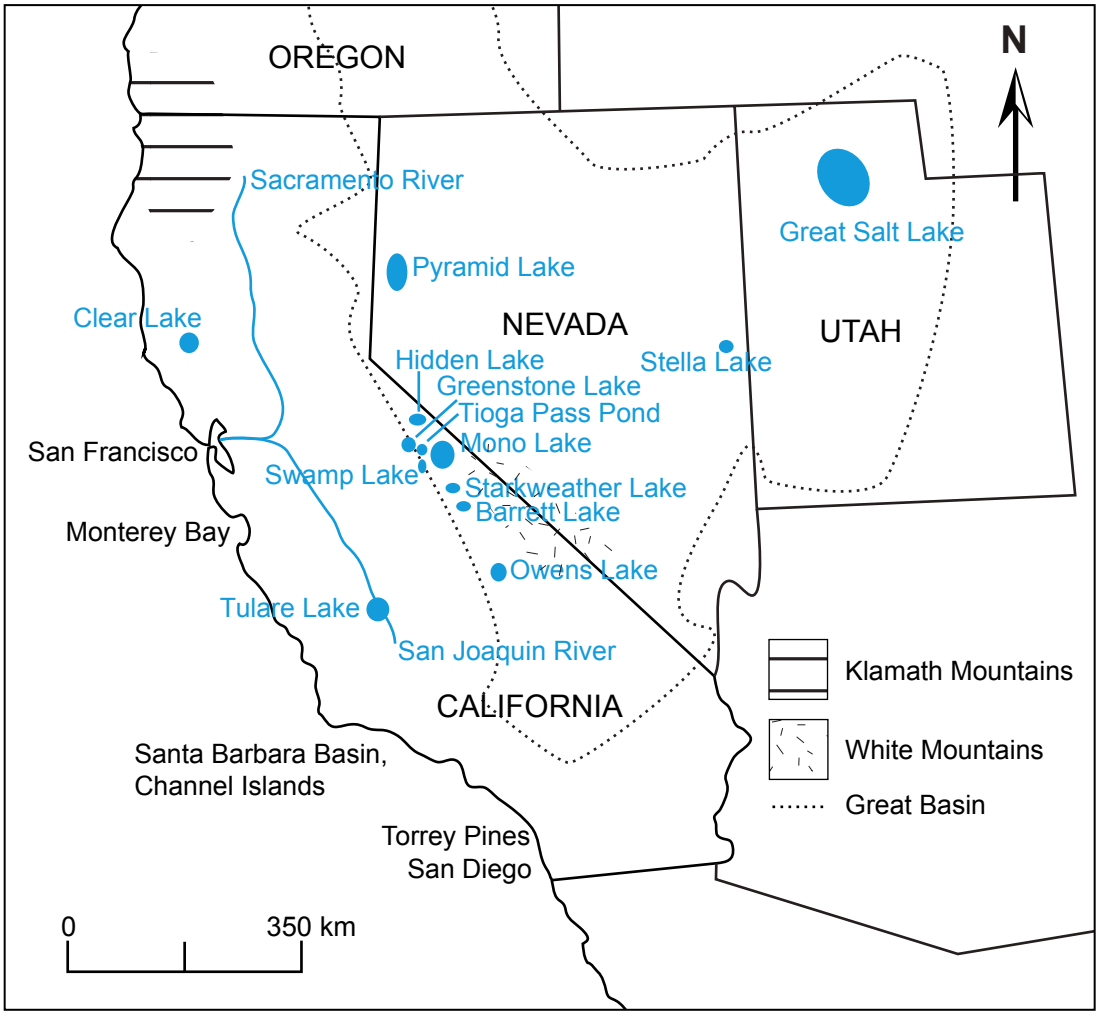


Figure 2.1. Map of major locations discussed in this chapter. See Figure 1.1 for locations of the Sierra Nevada and Central Valley. Base map is traced from Google Earth, and Great Basin is outlined from Grayson (2000).

Table 2.1. Location and elevation of Great Basin (GB) sites with paleoclimatic data referenced in this chapter.

Site	Location in GB	Elevation	Source
Bonneville Basin	Northeast	1503 m at highest in Holocene	Madsen et al. 2001
Homestead Cave	Northeast, in Bonneville Basin	1406 m	Grayson 2000; Madsen et al. 2001
Stella Lake	Central	3170 m sub-alpine	Reinemann et al. 2009
Pyramid Lake	West	1177 m spill level	Benson et al. 2002
White Mountains	Southwest	1200-4344 m	Feng and Epstein 1997
Owens Lake	Southwest	1118-1128 m at transition to Holocene	MacDonald et al. 2008

Table 2.2. Location and elevation of Sierra Nevada Mountain and nearby sites with paleoclimatic data referenced in this chapter. Ordered from west to east, by elevation.

Site	Location	Elevation	Source
Swamp Lake	Yosemite, western Sierra	1554 m	Smith and Anderson 1992
Montane meadows	Western Sierra	1857-2219 m	Anderson and Smith 1994
Starkweather Lake/Pond	West side of crest	2424-2438 m	Anderson 1990; MacDonald et al. 2008
Tioga Pass Pond	Crest	3018 m	Anderson 1990
Greenstone Lake	East side of crest	3067 m	Porinchu et al. 2003
Barrett Lake	East side of crest	2816 m	Anderson 1990; MacDonald et al. 2008
Hidden Lake	Eastern Sierra slope	2379 m	Potito et al. 2006
57 lakes	Eastern Sierra (modern)	2115-3475 m	Porinchu et al. 2002
Mono Lake	Closed basin on eastern edge of Sierra	1942-1960 m	Davis 1999a
Pyramid Lake	Western Great Basin, fed by Truckee from Sierra	1177 m spill level	Benson et al. 2002
Owens Lake	Southwestern Great Basin, at edge of Sierra	1118-1128 m at transition to Holocene	MacDonald et al. 2008

The Great Basin and Sierra Nevada lakes together provide a good example of how much climate can vary in adjacent regions and by elevation. Even in modern times, the height of the Sierra Nevada crest can strongly affect climatic conditions to the east and west. The southward movement of the Aleutian Low during the winter

sends storms into the Sierra Nevada Mountains, while high pressure systems in the summer cause warmer, drier weather (Anderson 1990). The eastern side of the Sierra Nevada, however, forms the western edge of the area affected by the North American monsoon system in its maximum extent, and therefore can receive summer thunderstorms (Adams and Comrie 1997). Smith and Anderson (1992:93) described how "communities on the west slope experience smaller seasonal temperature differences and approximately twice as much precipitation as east-slope communities at comparable elevations, reflecting the rain-shadow effect of the range."

Climate Cycles

Milankovitch Cycles

Climate cycles occur on several temporal and spatial scales, with several of the longest and largest called Milankovitch cycles, long-term fluctuations referring to the relationship between the earth's climate and various parameters of its orbit (Bennett 1990). One type of Milankovitch cycle is the "precession of the equinoxes," which refers to the shift in timing of seasons due to changes in the earth's distance from the sun, and occurs in cycles about 21,700 years long (Bradley 1999:35). For example, at c. 7050 BC ["9000 years ago"], the earth was closest to the sun in July, but the timing has steadily moved until it is now closest in January. Therefore, seasonality and summer insolation (the rate of solar radiation hitting a unit of the earth's surface) in the Northern Hemisphere were the strongest in the early to middle Holocene, decreasing thereafter (Dunbar 2000).

Other Milankovitch cycles are based on the earth's orbital eccentricity, which leads to cycles of ~95,800 years that affect the difference in extremes between seasons, and axial tilt, which particularly influences polar regions' summer radiation at periods of about 41,000 years (Bradley 1999). General circulation models (GCM) combine these different factors to predict how orbital forcing will affect climate regionally, and have had varying success (Alley et al. 2003).

El Niño/Southern Oscillation

The combined El Niño/Southern Oscillation (ENSO) system is a sea-level atmospheric pressure differential – the Southern Oscillation – between the high pressure Pacific subtropics and the low pressure Indonesian region, combined with anomalously warm sea surface temperatures along the Peru and Ecuador coasts (Dunbar 2000). ENSO events can affect weather and water temperatures across the globe. In North America they often result in wet and warm terrestrial conditions, with the strongest climatic variations manifesting in the southern U.S. and east-central Canada (Smith and Sardeshmukh 2000).

ENSO events occur at several periodicities, with strong 40-50 and 90-year cycles during the Holocene (Dunbar 2000). From 13,050 to 5050 BC, ENSO events were weak and occurred every 15 years or more, then strengthened and became more frequent later in the Holocene (Rodbell et al. 1999). Because orbital forcing influences seasonality and therefore wind direction, cool easterly wind anomalies kept ENSO events from developing fully in the mid-Holocene (Clement et al. 2000). Periodicities of 2-8.5 years developed c. 3050 BC, as evidenced by clastic laminae

(inorganic layers) in an Ecuadorian lake (Rodbell et al. 1999). In northern California cores, pine pollen alternates with alder and redwood more frequently and extremely after 1550 BC, indicating the onset of modern ENSO cycles (Barron et al. 2003).

ENSO effects are less predictable in central California than farther north or south along the Pacific Coast. In the Northwest Coast of North America, ENSO years usually result in dry and warm conditions, whereas the American Southwest and southern California receive higher than average rainfall (Cayan et al. 1999). I provide a brief summary of atmospheric ENSO effects in California and adjacent areas in Table 2.3.

As central and northern California fall between these two regions, the local response is more variable. The jetstream that generally delivers ENSO conditions does not pass directly over central California, making predictions of El Niño effects problematic. In the Central Valley and Central Coast, ENSO events can sometimes result in *drought* rather than wet conditions (Schonher and Nicholson 1989). As Schonher and Nicholson (1989:1266) stated, "central California consistently experiences highly abnormal rainfall during ENSO events, but conditions can be extremely wet or dry." This historically documented fact makes it imperative to use local data, rather than proxies from other regions, when reconstructing past climate.

Table 2.3. Modern measurements of El Niño effects in California and adjacent regions. SOI: Southern Oscillation Index. Sources: 1. Cayan et al. 1999; 2. Schonher and Nicholson 1989; 3. Smith and Sardeshmukh 2000.

Place (N to S)	Dates (AD)	El Niño Effects (negative SOI)	La Niña Effects (positive SOI)	Source	Comments
Northwest	1948-1995	Dry	Wet	1.	
California	1950-1982	Likely to be more wet, but strong regional variations	N/A	2.	
California	1959-1998	Not much temperature anomaly	Not much temperature anomaly	3.	Temperature anomalies centered in east-central Canada
Northern California	1950-1982	Regionally averaged rainfall 20-25% above mean	N/A	2.	Least affected by El Niño events
Highland Sierra	1950-1982	More likely to be wet	N/A	2.	More comparable to rest of state's conditions than Central Valley/Coast
Sierra Nevada	1948-1995	Not as affected	More likely to flood	1.	
Central Coast California	1948-1995	Days of unusually heavy precipitation more frequent, more likely to flood	N/A	1.	Does not extend into Sierra, only ~100km inland
Central Valley and Coast	1950-1982	Highly abnormal rainfall, either wet or dry, 1/11 ENSO years has normal rainfall	N/A	2.	
San Diego	1948-1995	Heavy precipitation more common	Heavy precipitation less common	1.	With strong El Niño events, "Southwest" region extends across much of southern CA
Southern California	1950-1982	Regionally averaged rainfall up to 160-185% of mean	N/A	2.	Southern CA has strongest response to El Niño events
Southwest	1948-1995	Wet	Dry	1.	With strong El Niño events, "Southwest" region extends across much of southern CA

Off central California, El Niño cycles can cause warmer sea surface temperature (SST), lower salinity, weaker upwelling or even downwelling, and delay the phytoplankton bloom that supports productivity (Lenarz et al. 1995). The population size of marine species can therefore drop (Dunbar 2000), and southern fishes become more abundant along the Central Coast as they spread out with the warmer water (Lenarz et al. 1995). Though warmer water species such as garibaldi (*Hypsypops rubicundus*) and blacksmith (*Chromis punctipinnis*) do not appear to spawn in the region, their larvae can reach the Central Coast and survive to adulthood, making them available to fishers (MBAF 1997).

ENSO conditions also affect how close pelagic species come in to the coast, shifting non-migratory species distributions closer to the coast off Oregon and Washington (Brodeur et al. 2003). SST in El Niño years warms the most in fall and winter seasons, and the least in spring (Breaker 1989). As recorded at Pacific Grove, SST in the Monterey Bay is less influenced by El Niño events because of its more sheltered setting within the bay (Breaker 1989).

Pleistocene–Holocene Transition

The most recent major global climate change occurred as the last glacial maximum of the Pleistocene shifted into the warmer Holocene. During the transition, large-scale fluctuations occurred over the course of about 3,500 years. The Bølling-Allerød warming period lasted about 2300 years, 13,050-10,750 BC, and the subsequent Younger Dryas cold stage about 1200 years c. 10,850-9650 BC (Peteet

2009). In Tables 2.4 and 2.5, I summarize the existing evidence for the Bølling-Allerød and Younger Dryas, showing that these climatic regimes were widespread in the Northern Hemisphere. Since the Younger Dryas is the last major cold stage before more modern Holocene conditions develop, I discuss it in more detail.

Younger Dryas Cold Period

The Younger Dryas began abruptly, with drastic temperature drops in some places in less than a decade (Alley et al. 2003). Peteet's (2000) review reports that atmospheric temperatures decreased 2-10ºC in Europe, 7-15ºC in Greenland, and 1-6º in the United States and Canada, with regional variation. Interestingly, the Virginia area was apparently *warmer* and wetter in the younger Dryas, indicating that Younger Dryas climatic effects did not occur to the same degree, nor even in the same general direction, everywhere (Peteet 2000). The Southern Hemisphere was relatively stable during this time span (Peteet 2000).

As a Northern Hemispheric event, the Younger Dryas is dated to about 11,050-9650 BC (Peteet 2000). Its time span varies slightly by region: 10,750-9580 BC in Norway and Switzerland (Birks and Ammann 2000; Birks et al. 2000), and 10,730-9500 BC (10,800-10,000 ^{14}C years bp) in the northeastern United States (Peteet et al. 1993:608). Because the timing of the Younger Dryas–Holocene transition is still debated, I further discuss the dating below.

Table 2.4. Evidence for Bølling-Allerød warming period, c. 13,050-11,050 BC. Data are sorted north to south within the two oceanic regions. *Date was published in original source as uncalibrated.

	Dates	Place (N to S)	Climate	Evidence	Source
Pacific Regions	Bølling-Allerød	British Columbia	Warmer atmosphere	Chironomid abundances	Walker and Cwynar 2006
	Bølling-Allerød	Vancouver Island, British Columbia	Warmer SST	Changes in SST index based on unsaturated C_{37} alkenones	Kienast and McKay 2001
	Bølling-Allerød	Northern CA and Oregon	Warmer atmosphere	Increased alder and oak pollen	Pisias et al. 2001
	12,650-10,950 BC	Northern CA	Warmer SST and atmosphere	Alkenone concentrations, appearance of alder pollen	Barron et al. 2003
	12,050-11,050 BC	Northern CA and Oregon	Warmer SST	Low percentages of left coiling *Neogloboquadrina pachyderma*	Mix et al. 1999
	17,230-14,880 BC*	Western Sierra Nevada	Deglaciation	Pollen, charcoal, macrofossils	Smith and Anderson 1992
	11,050-10,050 BC	Eastern Sierra Nevada	Warmer lakes	Chironomid abundances	Porinchu et al. 2003
	13,620-11,400 BC*	Bonneville Basin, NE Great Basin	Drying, warming, but still cool	Major changes in small fauna and pollen	Madsen et al. 2001
	12,750-10,950 BC	Santa Barbara Basin and Gulf of California	Low ventilation (low oxygen)	Low concentrations of molybdenum and cadmium	Zheng et al. 2000
Atlantic Regions	Bølling-Allerød	North Atlantic	Warmer SST	Planktonic foraminifera abundance, decreased *benthic* $\delta^{18}O$ in cores	Waelbroeck 2001
	12,730 BC	Greenland	Warmer atmosphere	Ice cores	Alley et al. 1993
	Transition	Switzerland	Warmer atmosphere	Tree rings show rapid reforestation	Friedrich et al. 2001
	12,760-10,910 BC*	Southern Ontario	Warmer lake temperatures	Increased $\delta^{18}O$ in lake carbonates	Yu and Eicher 1998

Table 2.5. Evidence for Younger Dryas cold period, c. 11,050-9650 BC. Data are sorted north to south within the two oceanic regions. *Date was published in original source as uncalibrated.

	Dates	Place (N to S)	Climate	Evidence	Source
Pacific Regions	10,350-9450 BC	Southeast Alaska	Cool atmosphere	Pollen cores show drastic switch to tundra vegetation	Hansen and Engstrom 1996
	11,050-9450 BC	Vancouver Island, British Columbia	Colder SST	Changes in an SST index based on unsaturated C_{37} alkenones	Kienast and McKay 2001
	10,680-9500 BC*	Washington State	Cool atmosphere	Increased mountain hemlock pollen	Mathewes 1993
	10,550-9550 BC	Northern CA and Oregon	Colder SST	High abundances of left-coiling *Neogloboquadrina pachyderma*	Mix et al. 1999
	11,050-9550 BC	Northern CA and Oregon	Colder SST	Alkenone concentrations, lower carbonate and diatoms	Barron et al. 2003
	11,050-9550 BC	Northern CA and Oregon	Cool atmosphere	Pine pollen abundant	Barron et al. 2003 Pisias et al. 2001
	10,050-9550 BC	Eastern Sierra Nevada	Cool atmosphere	Chironomid community composition	Porinchu et al. 2003
	10,950-9550 BC	Sierra Nevada Crest	Cool atmosphere	Chironomids, diatoms, charcoal, $\delta^{18}O$	MacDonald et al. 2008
	11,910-9500 BC*	Western Sierra Nevada	Cool and moist	Alpine vegetation, especially hemlock, abundant in pollen cores	Smith and Anderson 1992
	11,050-9250 BC	Santa Barbara Basin, California	Colder SST	More coldwater foraminifera, higher $\delta^{18}O$, less-laminated soil structure	Hendy and Kennett 2000 Kennett and Ingram 1995
Atlantic Regions	Peak cold period	Greenland	15ºC colder than today	Gas mixtures and isotopes from ice cores	Severinghaus et al. 1998
	10,750-9580 BC	Norway and Switzerland	4-7ºC colder than Bølling-Allerød	Chironomids, plant macrofossils, pollen, crustaceans, and beetles	Birks and Ammann 2000 Birks et al. 2000
	10,910-9500 BC*	Southern Ontario	Cool atmosphere	Lower $\delta^{18}O$ in mollusks, carbonates and pollen show more open forests	Yu and Eicher 1998
	10,730-9500 BC*	Northeastern USA	Cool atmosphere	More boreal species, less white pine and oak	Peteet et al. 1993
	10,910-9500 BC*	Northeastern USA	Cool atmosphere	High % of paper birch and spruce	Peteet et al. 1990
	Younger Dryas	Connecticut	Colder lakes	Increased $\delta^{18}O$ in biogenic opal	Shemesh and Peteet 1998

Greenland provided some of the first evidence for the Younger Dryas; $\delta^{15}N$ data from an ice core at its summit shows that the Younger Dryas was 15ºC colder than today at peak cold temperatures (Severinghaus et al. 1998). European temperatures were also extremely cold, based on data from Kråkanes Lake in Norway, and Gerzensee in Switzerland (Birks and Ammann 2000; Birks et al. 2000).

On the western side of the Atlantic, North America yields evidence for substantial temperature drops. Studies with chironomids (midges) are beginning to show promise as paleoclimatic indicators: the distributions and percentages of various species with known environmental requirements are affected by climate (Porinchu et al. 2007). Chironomid community composition analysis identified the Younger Dryas in northern New England (Walker and Cwynar 2006). The Younger Dryas is also apparent in pollen records from the Northeastern United States (Peteet et al. 1990) and oxygen stable isotope analyses from southern Ontario (Yu and Eicher 1998).

Direct AMS dating of the climate indicators in New Jersey (Peteet et al. 1990) and Ontario (Yu and Eicher 1998) puts the cool period at 10,910-9500 BC [11,000-10,000 ^{14}C years bp]. Cores across New England show similar pollen sequences, so the cooling probably extended over the entire region (Peteet et al. 1990). The significant increase in boreal species and contemporary decrease in oak, eastern white pine, and other warmer climate species suggests the atmospheric temperatures may have decreased by 3-4ºC (Peteet et al. 1993). Greater temperature reductions may have occurred in places like Connecticut, where average temperature probably decreased 6-12ºC (Shemesh and Peteet 1998).

Overall, atmospheric temperatures on landmasses around the Atlantic dropped at least 4ºC in many places, and evidence exists for temperatures 10-12ºC lower in certain areas. By contrast, most of the evidence for the Younger Dryas in western North America suggests temperature decreases of 4ºC or less.

Timing varies slightly for Younger Dryas evidence in North America. Southeastern Alaskan peat cores show vegetation change 10,350-9450 BC (Hansen and Engstrom 1996), and cores from the Pacific Northwest's Olympic Peninsula have their most extreme cold temperatures 10,680-9500 BC [10,700-10,000 ^{14}C years bp], based on abundant mountain hemlock pollen (Mathewes 1993).

In the western Sierra Nevada, cooling started more than 1,000 years earlier. Alpine vegetation was present 11,910-9500 BC [12,000-10,000 ^{14}C years bp] at elevations above 2000 m, in areas that today are subalpine (Smith and Anderson 1992). Similarly, Swamp Lake, at 1554 m, has montane vegetation today, but at 11,910 BC [12,000 ^{14}C years bp] had more subalpine species, especially hemlock. Climate was probably moist, and 3-3.7ºC cooler than today (Smith and Anderson 1992).

Samples from Sierra Nevada sites along the crest and east indicate cold conditions more closely constrained within the defined Younger Dryas time span. Chironomids, diatoms, charcoal, and δ^{18}O from sediment organics all suggest that two lakes on either side of the crest cooled c. 10,950-9550 BC, down 2-4ºC from the highest temperatures of the Bølling-Allerød (MacDonald et al. 2008). Chironomids also signify colder temperatures for a shorter time span, 10,050-9550 BC, at

Greenstone Lake (Porinchu et al. 2003), coinciding with findings from lake-level analyses at Owens Lake in the southwestern Great Basin (MacDonald et al. 2008).

The best evidence for the Younger Dryas's influence on atmospheric climate in coastal California comes from ocean cores. A peak of pine pollen abundance in cores off northern California and Oregon coasts indicates cooler temperatures (Barron et al. 2003; Pisias et al. 2001). The later Younger Dryas has abundant alder pollen, representing warmer and wetter atmospheric climate, a transition that occurred "nearly 600 years earlier than the warming of SSTs offshore" (Barron et al. 2003:12).

Ocean Conditions in the Younger Dryas

Most evidence for marine paleoclimate points to colder conditions in the Northern Hemisphere, and several studies exist for the Pacific Coast of North America. Around Vancouver Island in British Columbia, SST dropped to 6ºC at 11,050-9450 BC, 3-4ºC colder than the preceding Bølling-Allerød (Kienast and McKay 2001). Pisias et al. (2001), studying radiolarians, found no evidence for cooler ocean temperatures off northern California 11,050-9550 BC, but Barron et al. (2003) argued for a decrease in SST to <8ºC, based on alkenone analyses of sediment combined with lower carbonate and diatom abundances. Water temperatures 2-3ºC cooler during the Younger Dryas are also indicated in northern California and Oregon by high abundances of left-coiling *Neogloboquadrina pachyderma* 10,550-9550 BC (Mix et al. 1999). Though increased upwelling is usually associated with cooler SST, the ocean off northern California appears to have had reduced upwelling (Pisias et al.

2001). Both reduced upwelling and colder temperatures, then, may have occurred off northern California in the Younger Dryas.

In the Santa Barbara Basin, an ocean core indicates the Younger Dryas began c. 11,020 BC and probably lasted until 9250 BC, though the latter date was harder to calibrate due to a radiocarbon plateau in the calibration curve (Kennett and Ingram 1995). The Younger Dryas section displays higher oxygen isotope values, higher proportions of coldwater foraminifera, and less-laminated soil structures (Hendy and Kennett 2000), but the SST ranges are ambiguous. To the north and south, temperatures shifted 2-4ºC, so a similar scale may be applicable to the Santa Barbara Basin (Kennett and Ingram 1995).

While an ocean response to the Younger Dryas is clear from both northern and southern California, Central Coast ocean cores provide little definitive evidence for any change in SST or in upwelling (Pisias et al. 2001). Myers (2007) has identified a possible drop in SST in the Monterey Bay, but only very tentatively assigned it to the Younger Dryas, due to the same difficulties with a radiocarbon production plateau mentioned above. If the Younger Dryas truly had much less effect on SST off central California compared to the north and south, archaeological evidence for marine exploitation during the Younger Dryas could show divergent strategies in these respective regions. More research in California is required to make a defensible climatic reconstruction for the Central Coast during this period.

Possible Causes of the Younger Dryas

The warm-cold-warm-cold oscillations during the transition between the Pleistocene and Holocene require an explanation than can account for very widespread drastic climatic shifts (Alley et al. 1993), and the cause of the Younger Dryas is still much debated (MacDonald et al. 2008). Because the effects of the Younger Dryas were strongest in maritime regions, Mathewes (1993:330) proposed that the underlying mechanism probably included "interactions between ocean circulation and atmosphere."

Thermohaline circulation occurs after deep waters develop from high salinity cold water at high latitudes (Stocker 2000). One source, North Atlantic Deep Water (NADW), forms off Greenland, then flows via deep boundary currents south along the Americas and then east. Eventually, NADW can work its way to the north Pacific (Stocker 2000). The system is too complicated to explain in depth here, but a major freshwater input into the North Atlantic could affect deep water formation and the thermohaline circulation that moves water across the globe (Broecker 2003).

Evidence exists that ocean circulation changed during the Younger Dryas, possibly caused by a large influx of freshwater that slowed down or halted NADW circulation (Alley et al. 1993; Broecker 2003; Carlson et al. 2007; Stocker 2000; Teller et al. 2002). Decreased thermohaline circulation is supported by planktonic foraminifera from an ocean core off Venezuela showing a higher ^{14}C:^{12}C ratio in ocean surface water (Hughen et al. 1998), and greater oxygenation of the Santa Barbara Basin (Kennett and Ingram 1995). Lake Agassiz, the largest lake in North

America during the last deglaciation, may have provided the freshwater input necessary to prevent deep water formation and initiate the North Atlantic cooling (Broecker 2003). As the Laurentide Ice Sheet receded, it suddenly opened a channel from Lake Agassiz to the Great Lakes, draining an estimated 9500 km^3 of freshwater into the Atlantic via the St. Lawrence Valley (Broecker 2003; Teller et al. 2002). Teller et al. (2002) estimated that Lake Agassiz's contents entered the ocean within one year's time.

The geological evidence for the timing of Lake Agassiz's draining is somewhat contentious, with data for the ice sheet edge suggesting the lake drained 1000 years after the Younger Dryas (Lowell et al. 2005). On the other hand, strontium isotopes, uranium, magnesium, and calcium from two cores in the St. Lawrence estuary indicate major freshwater input from western Canada at the beginning of the Younger Dryas (Carlson et al. 2007). The draining of Lake Agassiz is the best current candidate for causing a decline in NADW formation and the onset of the Younger Dryas.

Some researchers have argued that the freshwater input and slower thermohaline circulation resulted from a comet impacting or exploding over the North American continent (Firestone 2009; Firestone et al. 2007; Jones 2009). At numerous North American archaeological sites dating to the Younger Dryas, archaeologists identified black deposits rich in organic matter and full of materials that suggest an extraterrestrial impact, such as particular kinds of magnetic spherules, carbon

spherules, and nanodiamonds (Firestone et al. 2007; Firestone 2009). Whether such an impact did cause the Younger Dryas, however, is still much debated.

Similar effects in both the North Pacific and North Atlantic testify to the widespread nature of the Younger Dryas, and atmospheric transmission is considered necessary because of the speed at which it developed. Though NADW circulation is a likely culprit for the onset of the Younger Dryas, how the ocean's change was transmitted to the atmosphere over a very short time scale is still unclear (Broecker 2003).

Younger Dryas–Holocene Transition

Dating the beginning of the Holocene varies by school of thought and has undergone debate and revision since the mid-twentieth century. One perspective considers the beginning of the Holocene to be "time-transgressive," emphasizing how geology and pollen both show that climate shifted at varying times in different regions of the world. Watson and Wright (1980:156-157) argued for a "flexible scheme for subdivision of the Holocene, to provide units that are definable on stratigraphic grounds (e.g. pollen zones) at type localities but that may change facies beyond the region and may have time-transgressive boundaries even within the region." They contended this approach should also be used for the Pleistocene-Holocene boundary, which should be considered at the end of the last cold period, and identified by region (Watson and Wright 1980).

A second view, proposed by the International Union for Quaternary Research (IUQR), sets an uncalibrated radiocarbon date to be used for the beginning of the Holocene at 10,000 ^{14}C years bp (Roberts 2009). This date represents the time at which "now-temperate Europe became forested" (Watson and Wright 1980:155). At the time this approach was proposed, researchers attempted to find a type-site, as is typical of traditional geological practice, but criticisms of the selected site led some to question the value of trying to find a type site at all (Watson and Wright 1980). Many researchers use the IUQR's 10,000 ^{14}C years bp date for the beginning of the Holocene, which corresponds to a calibrated date of 11,500 BP (Roberts 2009), 9550 BC if I transform the BP date, and 9500 BC if I use CALIB on the uncalibrated date.

Although the transition between the Younger Dryas and Holocene seems to occur at fairly similar times across the globe, at this point the time-transgressive option is the preferable perspective, because researchers must identify how such transitions manifested locally. This viewpoint is even more important for climatic events within the Holocene, as these tend to be smaller-scale, more locally variable shifts than those of major glaciations and deglaciations. Due to this fact, Roberts (2009) noted that most researchers simply use radiocarbon age rather than epoch or stage to define events within the Holocene.

I follow Roberts (2009) in emphasizing the fundamental importance of regional variation in climatic events for understanding California coastal climate over time. In the rest of this section, I describe the degree and speed of warming at the

Younger Dryas-Holocene transition, as it affected the North Atlantic region and North America.

The time warming began is remarkably similar in many places, though the degree and pace of warming varies substantially. In general, the Younger Dryas ended even more abruptly than it began (Alley et al. 1993, 2003), with significant warming within years to decades, depending on the location from where evidence was recovered, and what evidence was examined, e.g., oxygen isotopes, foraminifera, or tree rings (Stocker 2000).

The North Atlantic once again provides much of the climatic data available for this point in time. The Greenland summit ice core shows that the last 5-10ºC warming during the transition to the Holocene occurred within a span of decades, around 9650 BC (Severinghaus et al. 1998). Using these data, Alley et al. (1993) defined the end of the Younger Dryas at c. 9690 BC, marked by a drastic increase in annual rates of ice accumulation, lower dust concentrations, and stable isotope composition reflecting a warmer climatic regime. Major changes occurred in Norway at Kråkenes Lake during the Holocene transition at 9580 BC, with the lake's glacier melting within the first five years, rapid vegetation change within the first 50 years, (Birks et al. 2000), and 6ºC warming in the first 500 years (Birks and Ammann 2000). In Switzerland, temperatures at the Younger Dryas-Holocene transition increased either 2-3ºC in 160 years based on pollen, or 5-6ºC in 400 years based on crustacean data (Birks and Ammann 2000). German tree rings suggest that warming there took at least 60 years (Gulliksen et al. 1998). Though total warming in some cases took a few

hundred years, drastic temperature increases and vegetation changes would have been easily noticeable within one person's lifespan.

In the United States, evidence from the northeast and Appalachians shows that "local extinctions and extensive ecosystem disruptions occurred in fewer than 50 years following the end of the Younger Dryas" (Alley et al. 2003:2007-2008). Southern New England took only 50-75 years to switch forest composition from the Younger Dryas to the 3-4ºC warmer early Holocene (Peteet 2000). Pines increase abruptly in pollen cores, and needles and macrofossils from multiple boreal species drop out of the record within a hundred years (Peteet et al. 1993).

Unfortunately, the Pacific Coast has not yet had comparable levels of climatic research on the Younger Dryas–Holocene transition. Chironomid data from British Columbia suggest a 6-8ºC rise in temperature inland, from before 9550 BC to 8050 BC (Palmer et al. 2002). At Point Reyes Peninsula, on the California coast about 40 km north of the entrance to San Francisco Bay, cores display two main pollen zones around the transition to the Holocene, one 11,910-9500 BC [12,000-10,000 ^{14}C years bp] and one 9500-5890 BC [10,000-7000 ^{14}C years bp]. Among other changes, oak pollen increases substantially in the more recent period, representing generally modern climate (Rypins et al. 1989). As noted earlier, cores off northern California show atmospheric climate warming about 600 years before the hemispherically-defined end of the Younger Dryas at 9650 BC (Barron et al. 2003:12).

As for the ocean, in the northeastern Pacific region, SST may have increased more than continental atmospheric temperatures. Around Vancouver Island, a 7ºC

SST during the Younger Dryas rose to 12ºC in less than 400 years (Kienast and MacKay 2001). In northern California and Oregon, however, lower abundances of left-coiling *N. pachyderma* indicate SST rose only 2-3ºC after 9550 BC (Mix et al. 1999). Off central California, as mentioned previously, little evidence exists for oceanic effects of the Younger Dryas.

Overall, the Younger Dryas-Holocene transition was notable in how quickly climate warmed, how drastic this warming was in some places, and how extreme the sea surface temperatures and vegetational effects could be. At the beginning of the Holocene, people were not faced with a slow transition from a glacial to non-glacial environment. Instead the transition was abrupt, with substantial climatic changes occurring within years or decades in some places, and under 500 years in many others. Significant temperature shifts would have been noticeable within a person's lifetime, impacting their decisions on where to live and how to survive.

The Holocene

Compared to the Pleistocene, climatic shifts during the Holocene were smaller in amplitude (Mayewski et al. 2004; O'Brien et al. 1995; Walker and Cwynar 2006). Walker and Cwynar (2006) concluded that North American Late Glacial temperatures could change over 10ºC, while in the Holocene, shifts were on the order of 1-4ºC, and often took longer to occur. The smaller-scale climate changes resulted in regionally specific outcomes of precipitation and temperature. In this section, I discuss Holocene climate in western North America and California in particular, as these are the most

relevant to my research. To contextualize what occurred in the North American West, I sometimes add data from other Northern Hemisphere localities. I review atmospheric climate data first and then that for the ocean environment, including a discussion of "reservoir ages," their use in radiocarbon dating marine organisms, and their implications for the upwelling history of California's coast.

Paleoclimatic data are not as extensive for the Monterey Bay area of the California coast as they are for the San Francisco Bay and north, and the Santa Barbara Channel area to the south. Much of what this chapter indicates is just how localized climatic responses to broad forcing factors can be, and that it is still unclear how far climatic data can be generalized from any given area to another. For example, Malamud-Roam et al. (2006) found differences in precipitation levels between the Sacramento and San Joaquin watersheds, even though they both feed into San Francisco Bay. The relative closeness of San Francisco Bay and the Santa Barbara Channel to Monterey Bay does not inherently make them reliable proxies for it. The Sierra Nevada Mountains and Great Basin area also commonly used for comparison to Monterey Bay, despite their greater distance. Though the western Sierra Nevada reflects the amount of precipitation coming in from the Pacific, the substantial rain shadow effect caused by the mountain range makes eastern Sierra Nevada and Great Basin data unreliable for explaining coastal climate.

General Sequence of the Holocene

Traditionally, Holocene North America was discussed as having three parts: early, middle, and late. However, as Clague et al. (2009:2232) described for North

America, “the numerous high-resolution proxy climate records that have become available in the past few decades show that climate varied through the Holocene and cannot be easily divided into simple units.” Even in places where climatic history can be subdivided into three units, climate does not change the same way simultaneously across large areas, so temporal boundaries vary by region (Benson et al. 2002).

This temporal discrepancy may in part be due to which paleoclimatic data are analyzed, and by which season the indicators are most affected. Because of the relationship between the earth’s orbit and the equinox, Holocene insolation maxima have occurred at different times for various parts of the year, and their timing can influence vegetation condition (Davis 1984). Based on orbital data, I show the insolation maxima for early, middle, and late summer in Table 2.6. For instance, vegetation most dependent on warm summer temperatures would peak with maximum midsummer insolation, whereas vegetation most affected by growing season length would grow best when early or late summer insolation was particularly strong (Davis 1984).

General circulation models for the Northern Hemisphere have suggested that the interseasonal difference in insolation was greatest c. 7050 BC (Kutzbach and Guetter 1986), which should have resulted in a drier early Holocene than today (Anderson and Smith 1994; Kutzbach and Guetter 1986). However, evidence indicates that not all North American regions were drier during the early Holocene; for instance, much of California seems to have been relatively moist during this span.

Table 2.6. Example of insolation maximum varying by season over time. Data are from Davis (1984). Dates in original were reported as 13,000, 10,000, and 5000 "years ago," which should correlate with years BP, since they refer to the earth's position and tilt.

Season	Months	Insolation maximum
Early summer	May and June	11,050 BC
Midsummer	July and August	8050 BC
Late summer	September and October	3050 BC

In an overview of North America's Holocene climatic history, Viau et al. (2006) compiled 30,000 pollen spectra samples and divided the Holocene into *four* alternating warming and cooling periods, based on the mean July temperatures reflected by the samples (Viau et al. 2006). Aridity reached maximum levels at 4050 BC in both the eastern and western regions of North America (Thompson et al. 1993; Webb et al. 1993).

However, Viau et al. (2006:4) also noted that significant interregional variability was manifest in both "the magnitude and direction of change." The timing of maximum Holocene warmth varied by thousands of years according to region. For example, although the highest mean July temperatures for North America as a whole occurred c. 1050 BC (Viau et al. 2006), arctic Canada reached maximum temperatures c. 8810 BC [9500 ^{14}C years bp] (Gajewski and Atkinson 2003; Viau et al. 2006). In eastern North America, summer and winter maximum temperatures have shifted in different directions and speeds during the Holocene (Webb et al. 1993).

The term "Hypsithermal" has been used to refer to a warm period in the early to mid-Holocene (Fairbridge 2009a), but Watson and Wright (1980) argue that the Hypsithermal should be considered regional, limited in the United States to the

Midwest and perhaps a few other areas. This is a similar situation to that of Europe, where a warm mid-Holocene seems "confined to northern Europe, and more especially to the summer months" (Davis et al. (2003:1713).

Arbitrarily dividing the Holocene for all of North America into three periods thus appears, on the basis of modern climatic evidence, to be an ineffective exercise. To understand human history in a given region, it is more important to consider how climate varied locally, and what specific conditions were produced over time. While some regions, such as the Great Basin, may be conducive to a tripartite Holocene sequence, we cannot assume this holds true even for surrounding areas. That said, I do divide out a "mid-Holocene" section in the overview below, mainly for ease of discussion, given that many authors, especially in earlier works, discuss climate based on what happened in early, middle, and late Holocene periods. Although the timing and direction of climate change varies markedly, many regions do undergo a climatic shift at some point in the middle several thousand years of the Holocene. In Appendix 2, I provide an extensive, detailed table that summarizes Holocene climatic data for California and adjacent regions, with some sources for global climatic shifts. In the remainder of this chapter, I discuss the most relevant data as well as difficulties with making broad generalizations.

Specific Climatic Events of the Earlier Holocene

In the early Holocene, the presence of the large Laurentide Ice Sheet still affected climate in North America (Viau et al. 2006; Webb et al. 1993) by splitting the jetstream (Thompson et al. 1993). The effects of strong seasonal insolation

manifested earliest in areas farthest from the receding ice sheet (Thompson et al. 1993) and sea level did not stabilize until the ice sheet was completely gone, c. 4850 BC (Wanner et al. 2008). Mayewski et al. (2004:248) described, "widespread, severe climatic disruption" across the globe from 7050 to 6050 BC. The Northern Hemisphere was cooler, Southern Hemisphere warmer, lower latitudes drier, and the Middle East and Chile had more precipitation (Mayewski et al. 2004).

The western United States comprises many different ecosystems, and "temperature and seasonality patterns in the West are strongly correlated with latitude, elevation, and distance from the coast" (Thompson et al. 1993:469). In modern times, the months of most rainfall are January and February in California and Oregon, affected by the interaction between the Aleutian low and North Pacific high pressure weather systems, versus July and August in the American Southwest, influenced by the North American monsoon system. Strong monsoon years in the Southwest are coupled with drier conditions in surrounding regions, including the Pacific Northwest, Great Plains, and Mississippi Valley (Harrison et al. 2003). The Pacific Coast has a maritime climate, with fairly mild temperatures, wet winters, and weak differences between seasons (Thompson et al. 1993).

At c. 8140 BC [9000 ^{14}C years bp], strong monsoonal conditions affected the Southwest, resulting in high levels of effective moisture there (Mock and Brunelle-Daines 1999). To the north, the Olympic Peninsula, western Washington, and British Columbia were dry, reflected in part by a high percentage of Douglas fir pollen (Thompson et al. 1993). Milankovitch forcing would have caused increased summer

insolation at this time, strengthening the monsoon system and the North Pacific high and causing this dichotomy in regional climate (Mock and Brunelle-Daines 1999).

The early Holocene in the Bonneville Basin was probably wetter and at least 3ºC cooler than today (Madsen et al. 2001). Around 6910 BC [8,000 ^{14}C years bp] temperatures warmed substantially and animal and plant diversity declined (Madsen et al. 2001). At mid-elevation Hidden Lake in the eastern Sierra Nevada, cooler and wetter conditions continued for at least a thousand years later than at Bonneville, until 5250 BC (Potito et al. 2006). Mono Lake, also in the eastern range but at a somewhat lower elevation, displayed higher sedimentation and pollen accumulation rates over much of this time span, suggesting cooler climate. The lake maintained a high level until 5890 BC [7000 ^{14}C years bp], though the Mono pollen core indicates *lower* precipitation (Davis 1999a). The combination of high water levels and greater aridity may result from "insolation-driven seasonality," where higher insolation in the summer caused drought, but lower insolation in the winter resulted in more snowpack (Davis 1999a:1). Eastern Sierra Nevada and Great Basin data therefore agree that the early part of the Holocene was still fairly cool, but the timing of subsequent warming and interpretations of precipitation vary by locality.

In contrast, western and high elevation Sierra Nevada sites indicate a warmer and drier early Holocene. At Swamp Lake, oak was common and fir minimal at 9500-5460 BC [10,000-6500 ^{14}C years bp], which, combined with high charcoal concentrations, suggests a warm and dry period and the development of modern pollen spectra (Smith and Anderson 1992). High proportions of montane chaparral

pollen in Starkweather Pond at 8140-6390 BC [9000-7500 ^{14}C years bp] represent lower effective moisture, and therefore lower lake water levels, than is typical today (Anderson 1990). The temporally overlapping record from Barrett Lake, just on the east side of the Sierra crest, also reflects low water levels 6910-4350 BC [8000-5500 ^{14}C years bp] (Anderson 1990). Other cores from western Sierra Nevada montane meadows have an abundance of sage, chinquapin, and oak, all plants which prefer drier environments, until 5890-4350 BC [7000-5500 ^{14}C years ago] (Anderson and Smith 1994). In general, the western Sierra Nevada was warm much earlier than the Great Basin, and started cooling during the Great Basin's warm period.

Overall, high-altitude Sierra Nevada data fit better with the Pacific Northwest, including southwestern Canada and Alaska, than they do with the nearby Great Basin, or even the Clear Lake cores from the Coast Ranges (Anderson 1990). The same is true of the western Sierra range. This might be because of their geographic position in relation to major weather systems, as both are affected by the Aleutian Low.

Northwestern California paleoclimate data are available from the eastern side of the Klamath Mountains, which Daniels et al. (2005) compared with pollen analyses from other parts of the region. They determined that climate became much warmer and drier 9050-5950 BC than it had been before the Holocene and than it is today.

Moving to California's Central Valley, a pollen core from the large Tulare Lake in southwest central California provided evidence for cool and wet climate conditions 8390-5890 BC [9200-7000 ^{14}C years bp] (Davis 1999b), paralleling the Great Basin lakes record in this regard. High percentages of green algae reflect high

lake levels during this time span, though with a low point at c. 7530 BC [8500 ^{14}C years bp]. Vegetation at Tulare Lake changed most drastically c. 7210 BC [8200 ^{14}C years bp], a few hundred years after that low lake level fluctuation (Davis 1999b). What Davis calls Great Basin woodland was replaced by oak woodland at that time.

Current data for the California coast suggest conditions were wet, but varied in terms of temperature. The Central Coast, including this dissertation's study region, may have been *warm* and wet in the Holocene until 6250 BC (Myers 2007). In contrast, northern and southern California coastal environments more closely resembled Tulare Lake, being cooler and with more effective moisture compared to later periods. In pollen cores from Clear Lake, north of San Francisco Bay and the largest lake in the Coast Ranges, pine (*Pinus*) dominates during cooler conditions, then oak (*Quercus*) percentages increase with the transition to the Holocene, becoming the most abundant pollen today (Adam, Sims, and Throckmorton 1981).

Cool and wet conditions may also have prevailed in the Santa Barbara Basin, followed at 5850 BC by expansion of semi-arid open environments. Although pollen from coastal sage (*Salvia*) and assorted chaparral species peaked at 4050 BC (Heusser 1978), these data come from a core with poorly justified chronological placement according to Kennett and Kennett (2000), so the timing of the shift is suspect.

Another major global cooling event occurred in Europe and Greenland around 6250 BC (Alley et al. 2003; Peteet 2000), as reflected by chemical concentrations and low methane levels from Greenland ice cores (Alley et al. 1997). The cold, dry, and dusty event peaked at 6300 BC, lasted for less than a hundred years, and was about

half as extreme as the Younger Dryas. Some data also show that the Great Lakes area of North America was dry and windy at this time (Alley et al. 1997), and half as cold as the Younger Dryas (Yu and Eicher 1998). Like the Younger Dryas, this cold snap may also have been caused by an influx of freshwater into the North Atlantic from Lake Agassiz, this time through Hudson Bay (Teller et al. 2002).

The "Mid-Holocene" in this Research

As noted above, I do not believe that dividing the Holocene into general categories, based on continent-wide or other regions' data, is a useful tool in my research. I focus on a fairly small geographical area, to emphasize how people adapt to different coastal habitats in varying climatic conditions. As a result, I prefer to use the most detailed, local paleoclimatic data possible, rather than dividing the climatic sequence into broad temporal periods. These more specific data can then be compared to my ichthyofaunal results and the culture history established so far for the Monterey Bay area. I discuss the current state of a local sequence further in the Monterey Bay Paleoclimate section.

However, in certain cases, the concept of a middle Holocene can be relevant, and in many areas, at least part of this interval was warmer and drier than present. Here, I group as "mid-Holocene" data from about 6850-2550 BC, because many paleoclimatologists discuss events in the "mid-Holocene," as well as the early and late Holocene, while not assigning precise dates. Some authors do stipulate dates, such as Sandweiss et al. (1999), who defined the mid-Holocene as 6050-1050 BC, based on variability in climate, along with many cultural changes across the world.

Diffenbaugh et al. (2003:1) used the same time frame, while Davis (1999b:254) called 5890-2530 BC [7000-4000 ^{14}C years bp] the "middle Holocene." The divergent nature of local climatic events, however, requires that each region's climatic sequence be considered separately, which is why I do not provide an overarching description of Holocene temperature and moisture trends.

During the 6050-1050 BC period, "orbital variations [provided] the primary forcing of global climate" (Diffenbaugh et al. 2003:1). Sea level continued to rise at c.1 m/century, until 4900 BC [6000 ^{14}C years bp], and at 10 cm/century thereafter (Carbone 1991), reaching essentially modern levels on the central California coast by c. 3050 BC (Masters and Aiello 2007; MBAF 1997).

At 4900 BC [6000 ^{14}C years bp], orbital forcing caused increased insolation in summer and fall, and decreased it during the rest of the year, thereby causing a stronger seasonal cycle than today (Harrison et al. 2003). The western United States was generally drier, but parts of the Southwest were still subject to strong monsoon conditions (Mock and Brunelle-Daines 1999). The southeastern Great Basin had greater effective moisture (Harrison et al. 2003), as did the southern Rocky Mountains (Thompson and Anderson 2000). Overall, however, the difference in summer climate between the Southwest and surrounding areas was less marked than at 8140 BC [9000 ^{14}C years bp] (Mock and Brunelle-Daines 1999). Moreover, despite the strong monsoonal conditions, pollen and packrat midden data indicate that desert biomes in the Southwest had essentially the same distribution as they do today (Thompson and Anderson 2000).

Great Basin data support the conclusion that much of the American West was arid during part of the mid-Holocene. In general, researchers have identified a warmer and drier period about 5050-2050 BC (Reinemann et al. 2009), though some people put it at 6050-1050 BC (Benson et al. 2002). However, peak warm temperatures were not temporally synchronic for the entire Great Basin. Central regions had the warmest temperatures at 3450 BC, while western Great Basin temperatures peaked substantially earlier, 5550-4350 BC (Reinemann et al. 2009). Some of the internal variation might be expected, given the extensive area of the Great Basin, and that the southern part is more susceptible to monsoon activity.

The Bonneville Basin in the north went through a warm and dry period 5890-4140 BC [7000-5300 ^{14}C years bp] (Madsen et al. 2001). Drastic declines in small mammal richness and evenness from owl roost bones in Homestead Cave also suggest that, 6910-3760 BC [8000-5000 ^{14}C years bp], climate was much warmer and drier than both the preceding and succeeding periods (Grayson 2000). In the central Great Basin, chironomids from sub-alpine Stella Lake support climate warming and drying c. 5050-3450 BC, when mean July air temperature peaked at about 11ºC (Reinemann et al. 2009). Stella Lake is at 3,170 m elevation, so while it reached peak warmth in the middle part of the Holocene, it was by no means hot. The southwestern Great Basin was also warmer, and hydrogen isotope analyses from bristlecone pine tree rings from the White Mountains describe a temperature maximum “plateau” at 4850 BC (Feng and Epstein 1994), which coincides with the middle of the Bonneville

Basin warm period. Tree stumps from Owens Lake in the southwestern Great Basin indicate a longer dry span 5750-1250 BC (Benson et al. 2002).

Close to the eastern Sierra foothills at Pyramid Lake, total inorganic content (the authors used the abbreviation TIC without defining it, but TIC typically refers to total inorganic content in paleoclimatic literature) and $\delta^{18}O$ analyses from sediment cores and drowned tree stumps show that the lake was dry 5680-3650 BC. This span overlaps with, though ends earlier than, the southern California Owens Lake dry spell (Benson et al. 2002). The calculated 7.5ºC increase in water and air temperature is much higher than in some other regions (Benson et al. 2002).

For the Sierra Nevada as a whole, Thompson and Anderson's (2000) summary of pollen and packrat middens suggests a drier environment with open conifer woodland at 4900 BC [6000 ^{14}C years bp], subsequently replaced by cool conifer forest. Though difficult to determine easily from the article, data appear to be mainly from the central part of the Sierra Nevada. On the whole, Thompson and Anderson's (2000) overview better matches western slope and crest data than it does with those from the eastern side, which in turn generally agree with those from the Great Basin. However, I show in the following descriptions that the Sierra Nevada displays somewhat mixed climate signals.

Chironomid abundances from Hidden Lake in the eastern Sierra Nevada suggest Holocene summer surface temperatures were warmer 5250-2550 BC, with a peak in temperature at 4550 BC. From 4550 to 1550 BC, climate was highly variable, and alternated between warmer and cooler temperatures every 300-1000 years (Potito

et al. 2006). Mono Lake, on the other hand, stayed at more or less intermediate and constant levels 5890-2530 BC [7000-4000 ^{14}C years bp] (Davis 1999a).

Higher elevation sites near the crest show results that disagree with the eastern slope data. On the east side of the crest, Barrett Lake was lowest 6910-4350 BC [8000-5500 ^{14}C years bp] (Anderson 1990), much earlier than the eastern Sierra warm period. At the crest, Tioga Pass Pond formed as a lake at c. 5460 BC [6500 ^{14}C years bp], indicating at least the beginning of more rainfall. By 4900 BC [6000 ^{14}C years bp], evidence from those two lakes and Starkweather Lake show precipitation along the crest had noticeably increased (Anderson 1990).

Western Sierra data correlate more closely with the crest than the Great Basin does. Swamp Lake, in Yosemite, underwent a cool and moist period during 5460-2080 BC [6500-3700 ^{14}C years bp] (Smith and Anderson 1992). This begins in the middle of Barrett Lake's low stand, but continues well into the span of greater rainfall. In Sierra montane meadows, plants requiring moist soils, such as mountain hemlock, fir, and giant sequoia, all replaced earlier drier environment species c. 4900-3220 BC [6000-4500 ^{14}C years bp] (Anderson and Smith 1994).

Northern California, including the coast, probably had more summer droughts in the mid-Holocene, c. 7050-2050 BC. Increasing pine and oak pollen, with decreasing redwood and cedar, suggests higher temperatures and more arid summers (Heusser and Barron 2002). Clear Lake pollen cores show that the mid-Holocene was warmer and potentially drier, which Adam and West (1983:169) stated was enough "to change the local pollen rain but not enough to affect the regional vegetation

significantly." Though the exact timing is not identifiable from Adam and West's (1983) article, a warm period may be supported by an increase in growth rates from tule perch (*Hysterocarpus traski*) scales in Clear Lake. The growth rates indicate water temperatures may have warmed from 8810 to 940 BC [9500-2800 ^{14}C years bp], with most of the increase occurring after 2530 BC [4000 ^{14}C years bp] (Casteel et al. 1977). Though Clear Lake is in the Coast Ranges, its location on the eastern side still makes it a problematic proxy for Central Coast climate conditions.

About 420 km to the southeast, Tulare Lake levels were low 5890-2530 BC [7000-4000 ^{14}C years bp], followed by a high stand at 1840-650 BC [3500-2500 ^{14}C years bp], based on high pelagic algae percentages (Davis 1999b). Abundant pine (*Pinus*) pollen also indicates wetter climate in the valley (Davis 1999b).

Similarly, about 230 km farther south, pollen from a Santa Rosa Island core suggests arid climate from at least 3250 BC to 1300 BC [5200-3250 BP] (Cole and Liu 1994). Radiocarbon dates from the core were on bulk sediment (Cole and Liu 1994), which are somewhat suspect, though a drier middle Holocene in general fits well with many other data sources from the west. One Santa Barbara Basin core might have evidence for more arid vegetation during 7860-2380 BC [8800-3900 ^{14}C years bp], after which conifers expanded in a more moderate climate (Heusser and Sirocko 1997). However, Kennett et al. (2007) interpreted the pine and oak pollen from that core as revealing no useful atmospheric climate trends between the middle and later Holocene, similar to another core from San Diego County.

All of these data show that, within the western United States, the definition of "middle" Holocene as a description of changes in climate can vary regionally in terms of timing, temperature, and aridity. If the middle Holocene is considered a period when climate was noticeably different than the rest of the Holocene for a span of thousands of years, in most cases it seems to fall within about 6850 to 2550 BC, with variation in exact millennia. The climatic evidence suggests much of western North America was warmer and drier within this period, yet some places, like Yosemite Valley, show just the opposite. I discuss the Monterey Bay area in more detail below, but it may have been *cooler* and drier 6250-1750 BC (Myers 2007).

The Rest of the Holocene

In this section, I review climate from approximately 2550 BC onward, with separate sections for the Medieval Climatic Anomaly and Little Ice Age, the most notable climatic changes of the later Holocene (see Hughes and Diaz 1994). Early in this span, most continents in the Northern Hemisphere underwent major and widespread low rainfall conditions, represented in mid-continental North America at 2350-2150 BC. In the United States, this drought was centered west of the Great Lakes (Booth et al. 2005). Overall, however, relatively milder temperatures characterize this part of the Holocene.

Great Basin data suggest that temperatures cooled over much of the later part of the Holocene, though the exact timing varies by location. Some of the internal differences could be due to either location or elevation. In Table 2.7, I summarize climate data over the last 5000 years from three major parts of the Great Basin.

Additionally, in the very western Great Basin, Pyramid Lake was low but not dry 790-350 BC (Benson et al. 2002). The White Mountains data in Table 2.7 are all derived from bristlecone pines, growing in colder conditions at high elevations (about 2,200-3,700 m in the Great Basin). Note, however, that tree ring widths and hydrogen isotope results do not correspond, perhaps because the hydrogen study averages 50-year periods together (Feng and Epstein 1994), while the tree rings are annual. Modern conditions developed by 450 BC in the Bonneville Basin (Madsen et al. 2001), and AD 150 near Stella Lake (Reinemann et al. 2009).

Table 2.7. Great Basin paleoclimate from c. 3500 BC. Sources: 1. Madsen et al. (2001); 2. Reinemann et al. (2009); 3. LaMarche (1974); 4. Feng and Epstein (1997). *Dates in this column were originally 2400-580, 2950-2400, and 4400-2950 ^{14}C years bp. All others were BP.

<table>
<tr><th>Bonneville Basin[1]</th><th>Stella Lake[2]</th><th>White Mountains (tree rings)[3]</th><th>White Mountains (hydrogen isotopes)[4]</th></tr>
<tr><td></td><td rowspan="2">post-AD 150
Modern conditions, with temperatures rising steadily</td><td>post-AD 300
Cool summers</td><td></td></tr>
<tr><td rowspan="2">c. 480 BC-AD 1340*
Modern conditions, though lake levels variable</td><td rowspan="2">200 BC-AD 300
Warm summers</td><td rowspan="2">50 BC-AD 1550
Climate appears to stay the same</td></tr>
<tr><td rowspan="4">3450 BC-AD 150
Decreasing mean July temperatures, low of 9.4ºC at AD 150</td></tr>
<tr><td>1160-480 BC
Colder</td><td rowspan="2">1300-200 BC
Cool summers</td><td rowspan="4">4850-50 BC
Temperatures cooling over this period</td></tr>
<tr><td>3010-1160 BC
Cooler than previous millennia, more effective moisture</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">3500-1300 BC
Warm summers</td></tr>
<tr><td></td><td></td></tr>
</table>

Along the crest of the Sierra Nevada Mountains, a cooler climate occurred at c. 1250-650 BC [3000-2500 ^{14}C years bp] (Anderson 1990), very similar to the cool periods described from the Great Basin. Cores from Mono Lake in the eastern Sierra Nevada recorded droughts around 2530 BC and 480 BC [4000 and 2400 ^{14}C years bp] (Davis 1999a), the second of which is during Pyramid Lake's low stand. As discussed earlier, however, the western Sierra had a cool and moist period in the mid-late Holocene that lasted until c. 3220-2080 BC (Anderson and Smith 1993; Smith and Anderson 1992). The region reached modern conditions earlier than the Great Basin, with Yosemite Valley climate transitioning slowly at 2800 BC [3700 ^{14}C years bp] into a warmer and drier environment similar to today (Smith and Anderson 1992).

Some areas of California west of the Sierra Nevada range display evidence for droughts, and others for wet periods, even during similar time spans. As I noted above, Tulare Lake levels were low 5890-2530 BC, then high 1840-650 BC (Davis 1999b). To the northwest, sediment analysis from the San Francisco Bay indicates a wetter period 3150-1850 BC (Malamud-Roam et al. 2006). Though this contradicts parts of the Tulare Lake data, San Francisco Bay is fed by both the Sacramento and San Joaquin drainages, so it is possible its wetter conditions resulted from increased precipitation runoff from the northern Sierra, as opposed to that feeding Tulare Lake from the drier southern Sierra.

The mouth of San Francisco Bay is approximately 100 km from the northern edge of Monterey Bay, and its southern shoreline is about 50 km due north from Monterey Bay (see Figure 2.1). In theory, San Francisco Bay's proximity might make

it a better proxy for Monterey Bay than either Mono or Tulare Lakes. However, using the former as a proxy for Monterey Bay is complicated, because of the two drainages described above. No connection with Sierra runoff exists in the case of Monterey Bay. Moreover, although the Sacramento and San Joaquin watersheds join together before draining into the San Francisco Bay, the Bay's northern and southern sections display somewhat divergent evidence for high and low freshwater inflows over time. Radiocarbon dating estuarine material also presents challenges, due to the variable mixture of oceanic and riverine waters, and their influence on reservoir effects. Due to this, Ingram et al. (1996a, 1996b) stated their AMS dates were only accurate to within ±100 years. This uncertainty could account for disagreements among the different studies described here and in Appendix 2, which includes the details of San Francisco Bay's climatic history from work by Byrne et al. (2001), Ingram et al. (1996a, 1996b), and Malamud-Roam et al. (2006).

Tree ring analyses of giant sequoia in the south-central Sierra Nevada indicate periods of frequent drought for the San Joaquin drainage area during AD 236-377 and AD 699-823 (Hughes and Brown 1992; Woodhouse and Overpeck 1998). The latter period immediately precedes the Medieval Climatic Anomaly, itself a warm and dry span in much of California. Hughes and Brown (1992:166) noted that the "transition from almost drought-free periods to those of very frequent extreme droughts has, on occasion, occurred almost as a step function," as it did around AD 700.

Pollen cores along the California coast to the north and south of San Francisco Bay suggest cooler and wetter climate through much of the later Holocene, compared

to that of the middle Holocene, with northern areas becoming moister earlier than Santa Barbara and farther south. Effective moisture on the northwest California coast increased after 2050 BC, and upwelling seemed to develop at the same time as coastal redwood forests (Heusser and Barron 2002). Cooler lake water temperatures are indicated by decreased growth rates in tule perch scales from Clear Lake after 940 BC [2800 ^{14}C years bp] (Casteel et al. 1977).

Farther south in the Santa Barbara Channel, high levels of carbonate and sedge pollen, along with low δ^{13}C, reflect greater freshwater input at a marsh on Santa Rosa Island from 1300 BC until AD 1800 (Cole and Liu 1994). Since the island would only have been supplied by rainfall, rather than runoff from another area, this indicates increased precipitation over the channel. Near the California–Mexico border, at Torrey Pines State Reserve, evidence implies that moisture levels did not rise until after 650 BC, when cottonwood and fern pollen, among others, increased (Cole and Wahl 2000). Both of the Santa Rosa Island and Torrey Pines studies still used dates on bulk sediment, which is problematic, but Cole and Wahl (2000) attempted to better specify date ranges by also directly dating plant and wood fragments from the cores. Overall, both cores do indicate a warmer mid-Holocene followed by a moister late Holocene.

San Joaquin Marsh, on the mainland California coast approximately midway between the Channel Islands and Torrey Pines, underwent freshwater events at 1850 BC, 850 BC, 350 BC, and after AD 1390. The middle two events “appear to have been very rapid, large-scale climatic fluctuations" (Davis 1992:97).

Medieval Climatic Anomaly

Scientists formerly thought that such climate regimes as the Medieval Climatic Anomaly (MCA) and Little Ice Age were expressed as uniform global phenomena. The MCA was originally labeled the "Medieval Warm Period," because it was first identified as a period of substantial warming in Europe. I use the term Medieval Climatic Anomaly here, because subsequent global research indicated that some areas underwent much greater changes in precipitation than temperature, making "climatic anomaly" a more appropriate descriptor than "warm period" (Stine 1994). Moreover, MCA conditions were not always warm, as glaciers actually advanced in Alaska AD 1050-1150 (Wanner et al. 2008). Temperature estimates for atmospheric climate in western North America during the MCA are rare, possibly because data mainly come from tree rings. As such, most evidence for the MCA focuses on levels of precipitation, which were frequently low.

The exact timing of these climatic events, like the others I have discussed in this chapter, is now known to vary by location. In Europe, the MCA lasted c. AD 850-1300 and was warmest AD 1150-1300 (Fairbridge 2009), but conditions varied between northern and southern parts of the continent (Hughes and Diaz 1994). In California, dendrochronological studies in the Sierra Nevada Mountains indicate an unusually warm period AD 1100-1375 (Graumlich 1993). If California is considered as a whole, the MCA occurred AD 800-1400 (Jones et al. 1999).

Warm climate and low precipitation are common traits of the MCA in western North America. A multi-decadal "megadrought" occurred in the last quarter of the

thirteenth century in the west, at least in the White Mountains of California, the American Southwest, and the Great Plains (Woodhouse and Overpeck 1998). The Great Basin had persistent droughts AD 900-1400 (Hughes and Funkhouser 1998), including a very warm period in the White Mountains c. AD 1200 (LaMarche 1974), and a widespread drought in the Bonneville Basin region AD 1270-1350 [700-600 ^{14}C years bp] (Madsen et al. 2001). Hydrogen isotope values in the White Mountains essentially stayed stable through the Medieval Climatic Anomaly (Feng and Epstein 1994), but as mentioned before, this may be a result of averaging 50-year periods.

Along the Sierra Nevada crest, summer temperatures were warmer than modern AD 1100-1375, with the highest temperature anomalies between AD 1118 and AD 1169 (Graumlich 1993). At the most, temperatures were 0.64ºC higher than mean values today, though the middle of the twelfth century was also accompanied by negative annual precipitation anomalies of -23 cm (Graumlich 1993). In the eastern part of the Sierra Nevada, Mono Lake levels were low at AD 940 [1100 ^{14}C years bp] (Davis 1999a). Two long periods of severe drought in the Sierra Nevada, AD 892-1112 and 1209-1350, can be identified in tree rings from lakes on both the eastern and western sides of the range (Stine 1994). Those droughts were separated by an extremely wet period, which led Stine (1994:549) to state that, "the mediaeval period in California was thus marked not only by severe and prolonged drought, but by abrupt and extreme hydroclimatic shifts."

Data from the California coast and the Mojave Desert show that much of terrestrial southern and central California underwent high temperatures and low

precipitation during the MCA, but with variation in time and space (Jones et al. 1999; Malamud-Roam et al. 2006). Tree ring evidence from the Transverse Ranges of the Santa Barbara region indicates several time spans of low rainfall or extreme drought during AD 500-1250 (Jones et al. 1999; Raab and Larson 1997). Based on stable isotope analyses, the San Francisco Bay had lower freshwater inflow c. AD 1000-1200 (Ingram et al. 1996a, 1996b), followed by higher levels of freshwater input, though multiple decadal periods of lower freshwater inflows occurred over the next several hundred years (see Appendix 2). A reconstruction of Sacramento River Flow into the San Francisco Bay, from AD 869 to the present, showed that "extended periods of drought may have been more common before AD 1400 than after" (Meko et al. 2001:1035). An extreme drought of about seven years around AD 980 represented less rainfall than characterized the Great Plains during the dustbowl years of the 1930s, and slightly less severe but longer droughts (~20-50 years) occurred in the late AD 1200s to about 1312 (Meko et al. 2001).

Overall, much of California displays evidence for high temperatures and aridity for at least some years between AD 850 and 1400, as I show in Table 2.8. However, as with all the other climatic events discussed, timing differs among regions, and it is therefore difficult to determine when the MCA manifested along the Monterey Bay area part of the Central Coast, if it did so at all. Given Ingram et al.'s (1996a, 1996b) statements that their radiocarbon dates should only be considered accurate to within a hundred years, it is possible that the San Francisco Bay data actually correlate quite closely with either the Santa Barbara or central Sierra Nevada

climatic history, which are both based on tree rings. Further research is decidedly necessary to fine-tune the radiocarbon dating sequences.

Table 2.8. Drought and low river flow conditions in California close to the time of the Medieval Climatic Anomaly.

<table>
<tr><th>Northern SF Bay[1]</th><th>Southern SF Bay[2]</th><th>Santa Barbara[3]</th><th>Central Sierra[4]</th><th>Southern Sierra[5]</th></tr>
<tr><td></td><td></td><td rowspan="3"></td><td></td><td rowspan="4">AD 1100-1375 unusually warm</td></tr>
<tr><td colspan="2">late AD 1200s-1312 low Sacramento River flow[6]</td><td rowspan="3">AD 1209-1350 extreme drought</td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="6">AD 250-1220 low freshwater input</td><td rowspan="3">AD 1000-1240 low freshwater input</td><td rowspan="2">AD 1100-1250 drought, worst AD 1120-1150</td></tr>
<tr><td></td><td rowspan="4">AD 892-1112 extreme drought</td><td rowspan="5"></td></tr>
<tr><td rowspan="4"></td><td>AD 980-1030 developing drought</td></tr>
<tr><td></td></tr>
<tr><td rowspan="4"></td><td>AD 770-800 really low rainfall</td><td rowspan="4"></td></tr>
<tr><td>AD 750-770 extreme drought</td></tr>
<tr><td>AD 650-750 really low rainfall</td></tr>
<tr><td>AD 550-650 low freshwater input</td><td rowspan="2">AD 500-650 low rainfall</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

1. Byrne et al. (2001). 2. Ingram et al. (1996a, 1996b). 3. Jones et al. (1999); Raab and Larson (1997). 4. Stine (1994). 5. (Graumlich 1993). 6. Meko et al. 2001).

Little Ice Age

Alley et al. (2003:2007) termed the Little Ice Age (LIA) a "moderate climate oscillation" of the Holocene. The LIA is well identified in Europe, where

temperatures were on average 1-1.5ºC colder than today, and it affected other regions around the North Atlantic (Shindell 2009). Substantial variation existed in the strength of the LIA, however, and the *timing* of the Little Ice Age is also variable by region, but generally occurred in the AD 1500s-1800s (Shindell 2009). Fairbridge (2009b) placed it at AD 1300-1750, and notes that it began extremely abruptly, essentially cutting off the Medieval Climatic Anomaly.

Because the Little Ice Age did not cool all Northern Hemisphere regions, nor did it cool the places it affected to the same degree, Clague et al. (2009) argued that the stage should not be based on climate, and instead the term Little Ice Age should remain only to define a period of glacial advance. In Alaska, for example, glaciers advanced even further during the LIA, or AD 1300-1850 in this case, than they had during AD 1050-1150 (Wanner et al. 2008).

In western North America, LIA climate changes were also heterogeneous. Hydrogen isotopes suggest temperatures in the White Mountains cooled markedly c. AD 1600 for 100-300 years (Feng and Epstein 1994). Other studies show the Great Basin had settled into essentially modern conditions by AD 1370 [550 ^{14}C years bp], and may even have been warm and dry over that span (Madsen et al. 2001). The Sierra Nevada, AD 1450-1850, was about 0.5ºC cooler than modern with variable temperatures (Graumlich 1993). A megadrought affected much of the western U.S. in the last half of the sixteenth century (Woodhouse and Overpeck 1998).

Coastal California climate was also variable. Santa Barbara had a >50-year period of below-normal rainfall in the late 1400s and a similar period of abnormally

high rainfall around the turn of the seventeenth century, based on tree-rings from big-cone spruces (Haston and Michaelsen 1994). Modern levels of precipitation in the area are mostly higher than they were over the last 400 years (Haston and Michaelsen 1997). In contrast, blue oak tree rings in San Francisco Bay indicate they are more moisture-stressed presently than any other time in the last 400 years (Stahle et al. 2001). Oxygen and carbon isotope analyses of shells from sediment cores in San Francisco Bay suggest several fluctuations between drier and wetter conditions over this time (Ingram et al. 1996a, 1996b; Malamud-Roam et al. 2006).

Haston and Michaelsen (1997), in research on precipitation over the last 400 years, noted that the northern and southern sections of the southern half of California have different precipitation anomalies. Atmospheric circulation seems to heavily influence whether the entire region is wet or dry, or whether the northern and southern areas change in different directions (Haston and Michaelsen 1997). Similarly, based on tree rings from the Pacific Northwest, Graumlich (1987) identified a north-south pattern of anomalies AD 1675-1975 between Washington and northern Oregon versus southern Oregon and northern California. These patterns serve to emphasize that much of California is in a transitional climatic zone, and that climate generalizations should be made cautiously.

Pacific Ocean Conditions in the Holocene

In addition to atmospheric climate, people living on the California coast had to deal with an ocean environment that possessed its own variations in temperature and upwelling strength. The Santa Barbara Basin has been particularly well studied.

Some more recent cores off the coast of central and northern California, as well as farther north, have expanded our knowledge of ocean conditions in the past, as have isotope studies of archaeological material that assessed evidence for upwelling.

More northward flow from the Davidson Current probably caused the warmer early Holocene SST identified in ocean cores from the Oregon to central California coasts (Barron and Bukry 2007). Northern California SST was similar to today, at 12-13ºC, 9650-6250 BC, then decreased to <11ºC from 6250 to 1250 BC (Barron et al. 2003). Over this latter time span, a warmer water diatom species (*Fragilariopsis doliolus*) decreased drastically in abundance (Barron and Bukry 2007). At c. 1450-1250 BC, *F. doliolus* increased once more (Barron and Bukry 2007) as SST quickly rose about 1ºC, staying warmer from then to the present (Barron et al. 2003). However, in the middle of this span, salinity decreased at 4050 BC (Mix et al. 1999), indicating that salinity and temperature do not necessarily couple. Upwelling levels in northern California and Oregon also shifted at different intervals and times than SST, being stronger c. 6050-3050 BC, then weakening 2850-1650 BC. Modern conditions, with upwelling in the spring-summer and warmer SST in the fall, developed 1550-1250 BC, around the end of the colder SST period (Barron and Bukry 2007).

On the Big Sur coast south of Monterey Bay, oxygen isotopes from mussel shells indicate SST was 1ºC cooler than present AD 1-1300, then highly variable AD 1300-1500, with more extreme high and low temperatures compared to today, and 2-3ºC cooler AD 1500-1700 (Jones and Kennett 1999). Similar but weaker trends from AD 1300 onward are present from CA-MNT-3 material, but a limited sample size

makes interpretation tentative (Jones and Kennett 1999). Jones and Kennett (1999) argued that the presence of northern anchovy in Central Coast sites from 600 BC-AD 1450 suggests productive levels of upwelling during that period. Unfortunately, the excellent fine-grain analysis of their study is difficult to compare with other northern California data that cover longer time spans but provide a coarser-grained view.

Though some evidence from San Francisco and Monterey Bay reflects California coastal upwelling as slowly declining over the last 4,000 years, with a decrease in summer insolation (Myers 2007; Van Geen et al. 1992), this slow shift would be unlikely to have suddenly required drastic changes in human behavior. Given how productive these bays remain today, the decreasing upwelling and lower productivity of the late Holocene, compared to that of the middle Holocene, would still have provided ample resources for human foragers.

The marine paleoclimatic history of the Santa Barbara Channel (SBC) is necessary to understand the cultural developments in that area, and perhaps sheds some light on why Monterey Bay cultural change moved in a different direction. The SBC area has an extensive history of environmental research and sediment core analysis, which has encouraged much speculation on how environment and human behaviors interacted over time. Unfortunately, the earliest work depended on less effective methods of dating, and it can now be difficult to sort out who used which cores, and which work is more reliable.

Early coring in the Santa Barbara Basin and analyses of radiolarian fossils suggested a warm-water regime 6050-3450 BC, followed by a cool-water period

(Pisias 1978). Because these dates were based on counting varves and extrapolating deposition rates, Kennett and Kennett (2000) argued that these cores probably represent a much shorter time sequence than originally believed. Kennett and colleagues (Kennett and Kennett 2000; Kennett et al. 2007) performed a new high-resolution core analysis, anchored by 20 AMS radiocarbon dates. They estimated average Holocene SST in the Santa Barbara Basin at c. 12.5ºC, but with temperatures fluctuating between warm and cold periods on a scale of about 1500 years (Kennett et al. 2007).

In Table 2.9, I list the SST and marine productivity history of the Santa Barbara Basin based on oxygen isotopic analysis of foraminifera from Kennett et al.'s (Kennett and Kennett 2000; Kennett et al. 2007) more recent core. Despite the use of the same core, Kennett and Kennett (2000) and Kennett et al. (2007) provide slightly different dates, so I include the two sources separately. The alternating warm and cold regimes are clear, and ocean productivity sometimes but not always correlates closely with temperature. In general, SST was less variable (3ºC) in the early and middle Holocene than it was (5ºC) in the late Holocene (Kennett and Kennett 2000). The cool SST through much of the MCA is supported by another core in the same basin, though oxygen isotopes show the ocean was *warmer* c. AD 1200-1450 (Field and Baumgartner 2000). However, this latter core was dated based on varve layers and correlation with chronologies "verified by ^{210}Pb dating" (Field and Baumgartner 2000:696). Kennett and Kennett's core probably provides the most reliable data.

Table 2.9. Sea surface temperatures and productivity in the Santa Barbara Channel using stable isotopes. Sources: 1. Kennett and Kennett 2000. 2. Kennett et al. 2007, dates originally reported as BP.

<table>
<tr><th>SST[1]</th><th>SST[2]</th><th>Productivity[2]</th></tr>
<tr><td rowspan="2">post-AD 1300
SST warmer, stable</td><td>post-AD 1450 warm SST</td><td></td></tr>
<tr><td rowspan="2">AD 450-1450 cool SST</td><td rowspan="2">AD 950-1550
high productivity</td></tr>
<tr><td>AD 450-1300
SST colder, variable,
average 11ºC</td></tr>
<tr><td rowspan="2">1050 BC-AD 450
SST warmer, stable,
average 12.5ºC</td><td>350 BC-AD 450 warm SST</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">2050-350 BC cool SST</td></tr>
<tr><td rowspan="5"></td></tr>
<tr><td rowspan="2">3850-1850 BC warm SST
(warmest 2550-2050 BC, 15ºC;
moderate 3850-3250 BC)</td><td>3950-1950 BC
low productivity</td></tr>
<tr><td rowspan="2">4350-3850 BC cool SST
(coldest at 4050 BC, 12ºC)</td><td rowspan="2">4550-3950 BC
high productivity</td></tr>
<tr><td rowspan="3">6250-4350 BC warm SST</td></tr>
<tr><td>4850-4550 BC
low productivity</td></tr>
<tr><td>5550-4850 BC
high productivity</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Some archaeologists had previously cited red abalone abundances as a proxy for changes in SST, but the data fit uneasily with isotopic analysis, and abalone abundances should probably no longer be considered an appropriate proxy (Braje et al. 2009). Red abalone generally prefer cooler temperatures (Rick et al. 2006), but their times of high abundance (Braje et al. 2009; Glassow et al. 1994; Rick et al. 2006) overlap so much with both warm and cold periods of SST, as identified by

Kennett et al. (2007), that their abundance may be due to other factors. Braje et al. (2009) argued that prehistoric overexploitation of the sea otters that structure sea urchin and abalone populations could have allowed a proliferation of those species.

Kennett et al. (2007) compare their SBC data to the White Mountains, and argue that cool SST seems to correlate fairly well with lower precipitation since 2050 BC, but with less correlation in the Middle Holocene. Though Kennett et al. (2007:356) point out that warmer SST "at the millennial-scale" does not always occur with more or stronger ENSO years, 2050 BC is at a similar time as the shift from weaker to stronger ENSO effects, as discussed earlier in this chapter. Perhaps more intense ENSO phenomena result in a connection between SST and precipitation that is otherwise less coupled. Nonetheless, for several thousand years of the Holocene, precipitation and SST did *not* covary, and it is therefore important to continue investigating them separately. Moreover, the White Mountains are over 340 km away from Santa Barbara, across the Sierra Nevada, and 1,200-4,344 m in elevation. Comparing the two areas does make sense for understanding how large-scale certain climatic events were, but rainfall in one place should not be used as a proxy for climatic history in the other.

The MCA has been a frequent discussion topic in the Santa Barbara Channel area by both archaeologists and paleoclimatologists, and interpretations about its relationship to SST have changed over time. Originally, as evidence for warmer SST AD 1150-1250, archaeologists cited the greater abundance of warm water shellfish species in archaeological sites from Santa Cruz Island (Colten 2001), and decreased

growth rates of black abalone (Arnold 1992), supported by the now questionable Pisias (1978) core. Archaeological shellfish data are in fact mutually contradictory (see Colten 2001; Kennett and Kennett 2000), and may represent local environmental conditions better than regional ones. For example, in modern times, ocean currents are cooler around Santa Rosa Island than nearby Santa Cruz Island (Pletka 2001).

During the MCA, though SST was low and the greatest upwelling in the Santa Barbara Basin occurred AD 950-1550, variability in marine conditions was also high. The oxygen isotopes suggest SST was the coldest and most variable from AD 450-1300 (Kennett and Kennett 2000). Kennett and Kennett (2000) argued that people in the Santa Barbara region might have developed more complex social organization during the MCA based less on poor oceanic productivity and more on trying to adapt to extremely variable terrestrial and marine conditions.

It seems likely that in the past, as today, certain parts of the SBC would have cooler ocean temperatures than others, affording people differential access to more productive marine habitats. Data from the more recent marine sediment core, however, fits well with the Big Sur data, suggesting that at the very least, during a time of terrestrial climatic stress along the California coast, the marine environment stayed mostly productive and reliable. The most difficult period may have been from AD 1300-1400, when SST was highly variable (Jones and Kennett 1999) and the MCA was causing warm temperature anomalies in California (Graumlich 1993).

Marine paleoclimate data from the Santa Barbara Channel area are frequently used as proxies for farther north on the California coast, simply because the SBC is

much better studied. However, ocean SST and upwelling, while in some cases overlapping, are not predictably coupled, making the SBC an inappropriate proxy. The Monterey Bay region links much better with northern California, so when local data are not available, proxies from the north should be used.

Monterey Bay Paleoclimate

Local paleoclimate data for the Monterey Bay area are still fairly scarce. Recent ocean cores provide some of the best data for the Holocene, though by nature of the samples, these data are rather coarse-grained. The combination of sea cores with regional pollen cores, along with limited dendroclimatological sequences, allows a preliminary characterization of climate. In this section, I present the paleoclimatic research from the Monterey Bay region, and assemble a basic climate chronology using the most reliable local research and the best proxies from nearby regions. In Figure 2.2, I provide a map showing the major locations discussed in this section.

Some of the earliest work came from a terrestrial pollen core from the Laguna de las Trancas marsh, north of Monterey Bay proper and just south of Año Nuevo. Adam, Byrne, and Luther (1981) identified three pollen zones, which they equate to an interstadial (a warmer span within a glacial period), the last full glacial period, and the early Holocene, respectively. Unfortunately, only one date was available for the formation of the marsh 30,000 years ago, and the authors divided the core temporally based primarily on their view of how the pollen profiles would fit into global climatic events, as known in the early 1980s. In what Adam, Byrne, and Luther (1981)

interpreted as the early Holocene, redwood pollen was more abundant than any other species. However, we now know that while redwood trees first appeared on the Northern and Central Coasts of California in the early part of the Holocene, redwood forests did not fully develop until closer to 3250 BC (Barron et al. 2003). As such, while the Laguna de las Trancas core does provide a general sequence, the temporal context is still vague.

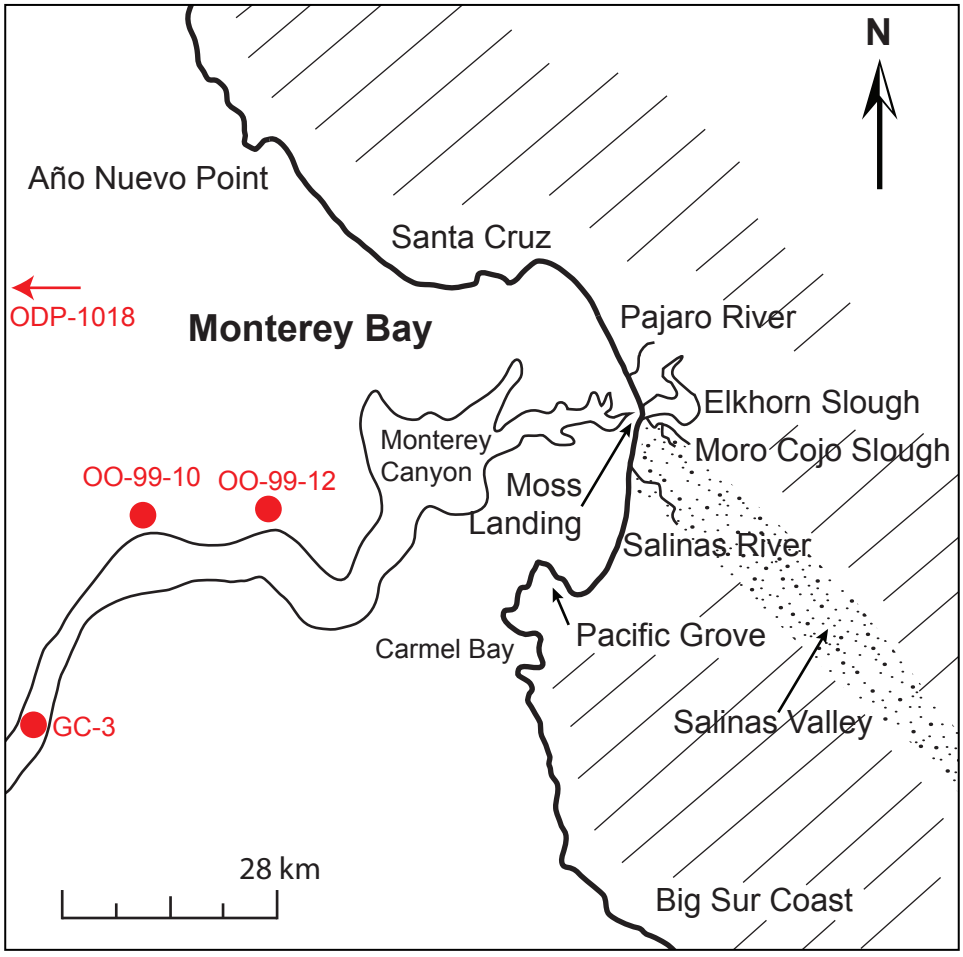


Figure 2.2. Important locations in the Monterey Bay area. Hatching indicates Coast Ranges, and red signifies the cores cited in Myers (2007).

A much better dated climatic sequence, though significantly shorter, comes from the Salinas Valley, which drains via the Salinas River into Monterey Bay, and lies between two extensions of the Coast Ranges: the eastern Gabilan Range and the western Santa Lucia Range. Using tree rings from blue oak (*Quercus douglasii*), Griffin (2007) developed a precipitation chronology extending back 600 years for the Salinas Valley. The reconstruction is based in the vicinity of Paso Robles, c. 160 km south of Monterey Bay, and on the inland side of the Santa Lucia Range. Though this span includes only the most recent archaeological sites analyzed in this work, it provides some detailed context, and can be used to make some general points.

First, even within the last 600 years, Griffin's (2007) reconstruction shows that the Salinas River often runs low, and goes dry at Paso Robles during extreme drought. Though downriver may get more rain, extreme drought at the very least would decrease the total amount of freshwater available to people living on the coast. The percentage of extreme drought years was also high: 16% of the last 600 years were years with no flow.

Second, Griffin noted that consecutive-year droughts cause the most problems for modern water storage, but this would also hold true for the aquifer and annual river flow. Based on the tree rings, consecutive-year droughts cluster. In the time periods most relevant to my research, clusters occurred in the mid-1400s, early 1500s, and mid-1600s. Griffin identified "decadal droughts" in the 1470s, 1510s, and 1630s.

Finally, Salinas Valley climate correlates fairly well with records from California in general, and from southern California in particular. Considering the

wettest and driest individual years from AD 1645 onward, the wettest years in the southern Salinas Valley coincided with years when other data indicate California received heavy rainfall, while the south-central region of the United States had a mild drought. The driest years occurred when records indicate southern California and parts of Nevada and Baja California were also quite dry, and most of the rest of the continental U.S. also had mild drought conditions (Griffin 2007). If these dendroclimatological sequences were extended further back in time, or if another set could be developed closer to the coast itself, they could be quite useful for Central Coast paleoclimate reconstructions.

In 1998, researchers collected a core from Pinto Lake, near the Pajaro River, and analyzed pollen to study sedimentation and precipitation (Plater et al. 2006). The core was AMS dated using bulk sediment samples and spanned AD 650-present. While the authors focused mainly on events after European contact, they also categorized AD 650–900 and 1275–1750 as two periods of "reduced precipitation in the region" (Plater et al. 2006:82). The last 100 years of the first period and first 100 years of the last period overlap with the MCA as identified in California, but would otherwise suggest the Central Coast had good rainfall during much of the MCA.

Monterey Bay Ocean Cores

The best data for both ocean and continental climate in the Monterey Bay region come from recent work by Myers (2007), who analyzed multiple climate proxies from cores collected from the continental slope outside of Monterey Bay. Core OO-99-10 is closest to shore, OO-99-12 is slightly farther out, and GC-3 is in

deep water next to the Monterey Canyon channel (Figure 2.2). The study used alkenones to estimate SST (with a ±0.14ºC margin of error), biosilica and organic carbon to characterize upwelling, and magnetic susceptibility to determine detrital sedimentation rates, which are influenced by continental climate. Data could therefore be interpreted to describe both marine and terrestrial climate conditions over time. The remainder of this section is all drawn from Myers' work, as it reveals the greatest detail on local Monterey climate.

The dated cores contain recognizable evidence for the last glacial cycle, the Bølling, Older Dryas, Allerød, and Holocene regimes. Core OO-99-12 also reflects another drop in SST, possibly during the Younger Dryas, but dating calibrations are difficult around that time for reasons outlined earlier in the chapter, so this identification is tentative. Overall, SST during the last glacial maximum was about 4.2ºC colder than modern conditions, averaging 8.0-8.4ºC, which is similar to the SST studies from northern California, but more extreme than the ones from southern California. Overall, Myers (2007) noted the strong correlation in SST between Monterey Bay and other central and northern California cores. This further supports the argument that Santa Barbara is not the best proxy for Central Coast conditions.

The early Holocene (defined by Myers as 9650-6250 BC) had a warmer and wetter terrestrial climate, plus warmer SST, compared to glacial conditions. Evidence exists for a slight drop in SST at 7850 BC in the core nearest to the shore, as well as a possible increase in upwelling that continued through the middle Holocene. The

characterization of climate indicates a regime likely influenced by ENSO conditions (Myers 2007).

In both of the Monterey Bay cores farther from shore, SST was cooler during the middle Holocene interval (6250-1350 BC) than earlier, and about 1-2ºC cooler than today, findings which again coincide with other studies in northern California and Oregon. Productivity and upwelling were also quite high through much of this time span, and continental climate at 4050-2050 BC was drier, but cool. The terrestrial Monterey Bay area therefore probably had cool, drier, and more productive La Niña conditions during much of the middle Holocene. At 2550-2150 BC, SST at the GC-3 core farthest out increased quickly and stayed warm, while SST at the core closest to shore decreased before warming over the rest of the Holocene. Productivity proxies also became more variable 2550-2150 BC. Warm and wet terrestrial conditions and low terrestrial productivity occurred 1750-1550 BC (Myers 2007).

Another especially warm and wet terrestrial event was identified at 1250 BC. In the ocean, 1350 BC-present, SST was warmer and productivity lower compared to that of the middle Holocene. From 450 BC to present, evidence suggests a slow decline in upwelling. Overall, after 1250 BC, a wetter terrestrial climate with more flooding indicates the returned influence of ENSO events (Myers 2007).

Elkhorn Slough

The formation of the Elkhorn Slough estuary has been studied for over two decades. However, as technology has advanced, some earlier research is seen to have produced overly certain interpretations. Early in the slough's development, around

6050 BC, it was a high-energy tidal inlet at its mouth, similar to the artificially created one present today (Schwartz et al. 1986). Descriptions of what happened next vary. In general, researchers agree that at some point in the past, maybe twice, Elkhorn Slough had a much stronger freshwater regime than it does today, and possibly was entirely cut off from the ocean (Jones 2002b; Schwartz 2002; Watson personal communication 2011). However, major discrepancies exist among authors, and sometimes within one author's own works, on the timing of such events.

Schwartz et al. (1986) analyzed grain size and invertebrate and plant remains from several sediment cores to determine Elkhorn Slough's developmental history. Temporal placement of the cores was based on three radiocarbon and five amino acid racemization dates, and extrapolated to other cores based on stratigraphy. Schwartz et al. (1986) argued that, during 3050-2050 BC, a high-energy marine environment intruded further inland, incorporating McClusky Slough, which today lies between Elkhorn Slough and the Pajaro River. The slough then calmed, until by 1050 BC it was an "extremely quiet-water estuary" (Schwartz et al. 1986:297), and was probably cut off from the ocean for ~1000 years (Schwartz 2002).

Other sources suggest different timing, and Table 2.10 summarizes the conflicting interpretations. Jones and Jones (1992) dated a freshwater event in Elkhorn Slough to 1500 BC, based on a core collected by Dietz et al. (1988) and analyzed by West (1988). At the time, they could not estimate the length of the event. Later, an AMS date on the peat from the core led Jones and Waugh (1997) to argue a freshwater event began c. 3040 BC. They also suggested the freshwater intrusion

peaked at 1900 BC, but this is based on a conventional, and thus probably less reliable, date from West (1988).

Table 2.10. Interpretations of freshwater events in Elkhorn Slough. See text for details. *Indicates dates originally published as calibrated BP.

Source	Freshwater event	Archaeological hiatus
Schwartz 2002	1050-50 BC*	NA
Jones and Jones 1992	1500 BC	4000-1000 BC
Jones 2002	3000-2000 BC	4050-3050 BC*
Jones and Waugh 1997	3040-1000 BC[1]	3000-1000 BC
Watson personal communication 2011	Possibly two, not dated	NA

A date for the return of estuarine conditions is not available from the core, but Jones and Waugh suggested 1000 BC based on archaeological data, which I discuss below. Jones (2002b) subsequently reported that a freshwater event occurred c. 3050-1840 BC, essentially the same as Jones and Waugh (1997). These dates are probably more dependable than those originally provided by Jones and Jones (1992), as well as those from Schwartz et al. (1986), but the discrepancy between the interpretations needs further exploration. As it stands, while researchers obviously agree that there was at least one event when the slough was probably cut off from the ocean, they substantially disagree on the timing. Aside from the freshwater event, Schwartz (2002) described the high energy tidal environment as gradually calming from 3050 BC to historic times, due to sediment input from the rivers and wind.

Archaeological data have also been used to address the question of when Elkhorn Slough was closed off from the ocean. Jones (2002b) referenced several

archaeological sites around Elkhorn Slough that display a hiatus in radiocarbon dates 4050-3050 BC, which he suggested implied that the sites were abandoned during that time span. He interpreted the gap as occurring simultaneously with the freshwater event he identified in the pollen core, despite a lack of overlap in dates. Jones and Jones (1992) noted that one of the Elkhorn Slough sites, MNT-229, might have an occupational hiatus of a much longer duration, c. 4000-1000 BC, and that a similar hiatus is found at nearby MNT-228 and MNT-234. Jones and Waugh (1997) also maintained that estuarine conditions returned by 1000 BC, because of radiocarbon dates from the Elkhorn Slough archaeological sites. An occupational hiatus of 4000-1000 BC would overlap with the timing of both the freshwater event and occupational hiatus that Jones (2002b) identified, though not with the data from Schwartz (2002). Jones and colleagues have argued that the slough closure, and resulting decrease in its resource richness, may have instigated the temporary human abandonment of the area (Jones 200b2; Jones and Jones 1992; Jones and Waugh 1997).

Most recently, Beth Watson (personal communication 2011) noted that earlier cores often dated bulk sediment samples, because that was the only way to acquire enough carbon for conventional radiocarbon dating, and then interpolated dates between the samples, assuming a linear deposition rate. However, the environmental context of early cores was not always clear, and this is highly problematic, because a variable intertidal or subtidal environment can produce non-linear depositional rates (Watson personal communication 2011). Jones and Waugh's (1997) AMS date of 3040 BC may be the most reliable indicator of a freshwater event in progress at that

time, but the length and extent of the event is unclear. Furthermore, Milliken et al. (1999) pointed out that the difficulties of reconciling pollen core with archaeological data might be a result of over-generalization. As they argued, "we cannot reconstruct the entire history of salt and freshwater estuaries at the mouth of Moro Cojo, Elkhorn Slough, or the former bay in the lower Salinas Valley on the basis of a single pollen core in the upper reaches of Elkhorn Slough" (Milliken et al. 1999:150).

Watson's more recent 12 cores seem to tell "similar stories" to the earlier ones, but are higher resolution for the last 5,000 years. The cores used AMS dates on organic material, and then extrapolated a depth-at-age model (Watson et al. 2011). Despite the AMS dating, the necessary use of the depth-at-age model for describing the slough's history makes Watson hesitant to assign definite dates to events seen in the cores until further AMS dates can be run. Her future work creating a master chronology based on x-rays and radiocarbon dates (Watson personal communication 2011) could help significantly in clarifying Elkhorn Slough's history.

To summarize Watson's work, Elkhorn Slough's "background conditions" have been brackish to marine for much of its history, but with intervals of more freshwater. During two spans, Watson's cores transition abruptly from estuarine sediments to freshwater peat, which was widespread in the slough, but not in all areas (Watson personal communication 2011). Other cores in the farther inland reaches of the slough also have freshwater peat levels wherein no marine species were evident (Hornberger 1991). The abrupt transitions into peat layers suggest slough closures are probably the best explanation, though that explanation has yet to be fully tested

(Watson personal communication 2011). Overall, Watson's cores might indicate two freshwater events, rather than just one as identified in earlier work.

The possible causes of such closures, as well as freshwater influxes, can be elucidated by modern observations. In historic times, storms, shifts in river mouth locations, tectonic movement, and erosion all influence the slough's drainage system. Both the Pajaro and Salinas Rivers have drained through Elkhorn Slough in the past, though currently the Pajaro enters the Pacific Ocean to the north of the slough, and the Salinas to the south. The old Salinas River channel can be seen between the current mouth and Elkhorn Slough, extending parallel to the Monterey Bay shoreline. Before the middle of the nineteenth century, the Salinas entered the slough and continued north, joining with the Pajaro before reaching the ocean (Schwartz 2002; Schwartz et al. 1986). Elkhorn Slough was thus a "minor tributary to the much larger Pajaro-Salinas River system (Schwartz 2002:21).

Shortly thereafter, the Pajaro separated to form its own present-day river mouth, and the Salinas did the same in the early twentieth century (Caffrey and Broenkow 2002; Patch and Jones 1984; Schwartz 2002; Schwartz et al. 1986). At that time, Elkhorn Slough debouched into the ocean four kilometers north of Moss landing. In AD 1946, jetties were installed to create Moss Landing Harbor, the slough was artificially opened to the ocean at Moss Landing, and the slough has subsequently remained tidally influenced (Caffrey and Broenkow 2002; Patch and Jones 1984; Schwartz 2002; Schwartz et al. 1986). Unfortunately, while the river

mouths probably wandered before historic times as well, the details and dates of such shifts are undetermined.

Synthesized Monterey Bay Climate Chronology

The Monterey Bay cores are clearly the best source for climate data, simply because of their time depth and their location in my study region. They are, however, coarser in resolution, particularly in more recent times, than would be most useful for archaeological analyses. In Table 2.11, I compile the evidence from those cores with other data from the geographically closest regions, to create a basic Holocene climatic sequence for the Monterey Bay region. I have decided not to use San Francisco Bay data at this time, because the interacting influence of the combined Sacramento and San Joaquin watersheds make it difficult to determine the applicability to Monterey Bay. I also do not include Elkhorn Slough freshwater events, because their dates are currently unclear. However, a freshwater event c. 3040 BC would have occurred during a span when the terrestrial climate was cool and dry, and marine productivity generally high or variable.

So far, no clear *climatic* evidence for the Medieval Climatic Anomaly exists in the Monterey Bay area. The best indication is decreased inflow to Pinto Lake AD 650-900 and 1275-1750, which both overlap only partially with the MCA. The upper Salinas drainage dendroclimatological sequence demonstrates that multi-year droughts have occurred regularly over the last 600 years, and cause substantially decreased water flow in the Salinas River (Griffin 2007). Unfortunately, those records as yet do not extend back to the MCA.

Table 2.11. Climate Reconstruction for the Monterey Bay area. Dates before AD 1 have been converted to BC from BP as originally published. Thickness of row does not indicate length of time. Sources: 1. Griffin 2007; 2. Myers 2007; 3. Jones and Kennett 1999; 4. Plater et al. 2006; 5. My inference based on other sources noted in this table; 6. Masters and Aiello 2007; 7. MBAF 1997; 8. Barron et al. 2003; 9. Barron and Bukry 2007; 10. Ingram 1998.

Dates	Terrestrial Climate	Marine Climate	Region	Source	Comments
mid-AD 1600s	Clusters of consecutive droughts	Upwelling declines gradually but significantly over time, SST warmer and productivity lower than "middle" Holocene	Salinas Valley	1. for droughts; 2. for marine and general terrestrial climate	
early AD 1500s	Clusters of consecutive droughts		Salinas Valley		
mid-AD 1400s	Clusters of consecutive droughts		Salinas Valley		
AD 1500-1700	Warm, higher rainfall, ENSO influence, continues except for droughts identified above (resolution probably not high enough to identify droughts in the cores), and AD 650-900 and AD 1275-1750 may have lower precipitation	SST 2-3ºC cooler than today	Monterey Bay and Big Sur Coast	3. for marine climate; 2. and 4. for terrestrial climate	
AD 1300-1500		Bay: SST less variable than today. Open coast: SST highly variable, extreme high and low temperatures	Monterey Bay and Big Sur Coast		
AD 1-1300		SST 1ºC cooler than today on open coast	Big Sur Coast		Not applicable to sites within the bay
450-0 BC		Upwelling declines gradually but significantly over time, SST warmer and productivity lower than "middle" Holocene	Monterey Bay		Conditions in core extend until present
1250-450 BC		SST warm and productivity lower than "middle" Holocene	Monterey Bay	2.	
1250 BC	Warm, wet, possible large flood events	Potentially very low productivity, but flooding may affect proxies	Monterey Bay		
1350-1250 BC	Warm, higher rainfall, ENSO influence	SST warmer and productivity lower than in "middle" Holocene, continues for most of the remaining sequence	Monterey Bay		

(continued on next page)

Table 2.11. (continued)

Dates[1]	Terrestrial Climate	Marine Climate	Region	Source	Comments
1550-1350 BC	Possibly cooler and drier again, as climate oscillates while transitioning to late Holocene conditions	Most likely SST warming, productivity increasing after low event, but staying lower than "middle" Holocene	Monterey Bay	5.	Northern CA SST increased 1ºC quickly at 1450-1250 BC and remained there[8], modern upwelling conditions develop[9]
1750-1550 BC	Warm, wet, possible large flood events	Potentially very low productivity, but flooding may affect proxies	Monterey Bay	2.; 6. and 7. for sea level data	1950-1550 BC period of very low upwelling and wet climate in San Francisco Bay[10]
2050-1750 BC	Drier and cool, especially during 4050-2050 BC	Productivity more variable, ENSO influential again and through rest of Holocene	Monterey Bay		
2150-2050 BC		Undefined, SST probably continues to warm			
2550-2150 BC		SST shift, still cool but begins warming again, productivity more variable	Monterey Bay		Northern CA cores also show ocean at least 1ºC cooler than today 6250-1250 BC[8]. Stronger upwelling 6050-3050 BC, weaker 2850-1650 BC[9]
6250-2550 BC		SST 1-2ºC cooler than today, upwelling and productivity high, ENSO suppressed; sea level 10-15 m below present at 8000 BP, reaches modern 5000 BP	Monterey Bay		
7850-6250 BC	Warm and wet	Warmer SST, upwelling increasing	Monterey Bay		Northern CA cores show SST at 12-13ºC 9650-6250 BC, similar to today[8]
7850 BC		Small drop in SST, upwelling starts to increase	Monterey Bay		
9650-7850 BC		Warmer SST, ENSO influential	Monterey Bay		

As shown in Table 2.8, multiple parts of California were affected by the MCA, which suggests the Central Coast region was as well. San Francisco Bay, the Santa Barbara region, and both the central and southern Sierra Nevada mountains all underwent arid conditions during that AD 800-1400 time span which is supposed to encapsulate the MCA. As discussed through this chapter, problems exist with using each of these regions as proxies for Monterey Bay. I therefore only include the Pinto Lake material in this climate reconstruction, and do not otherwise incorporate dates or conditions for the MCA, because the data do not support such an interpretation at this time. Based on the information in Table 2.8, the most overlap in evidence for low rainfall appears to be c. AD 1000-1300, so that may be when the Monterey Bay area was most likely affected. On the other hand, that span directly contradicts the Pinto Lake data. In Chapter 3, I discuss some of the cultural upheavals that occurred during the time of the MCA, which may represent people struggling with terrestrial climate stress.

Ocean Circulation, the Reservoir Effect, and Radiocarbon Dates

Some samples used in radiocarbon dating derive from contexts where the ^{14}C content may be depleted and thus register as older than its true age. Oceans are a major source of this "reservoir effect," which requires a correction to acquire an accurate date. The "reservoir age" is the difference in age between a biological sample from a reservoir context and one from a contemporaneous atmospheric context, such as a shellfish versus charcoal. This difference is not necessarily constant

through time or space. Globally, oceans average a reservoir effect of 200-400 years, but local upwelling can increase those ages (Stuiver et al. 1986).

To correct for the reservoir effect, change in atmospheric ^{14}C ($\Delta^{14}C$) through time has to be measured. This is compared to the $\Delta^{14}C$ of the ocean, to see how the ocean reacts to the atmospheric $\Delta^{14}C$ forcing (Stuiver et al. 1986). After correcting for the reservoir effect for oceans in general, a specific correction (ΔR) also has to be made for the region, to account for how upwelling in the region might require even more of a correction (Stuiver et al. 1986).

The eastern Pacific tends to have strong upwelling, so ΔR values are usually high, because older carbon is being drawn up from deep water. Along California, deep-water upwelling creates a ΔR of 225 ± 35 ^{14}C years on average but ranging from 220±40 to 290±35 from southern to northern California (Ingram 1998). San Francisco Bay estuary has much lower reservoir ages than the coastline, perhaps because of the freshwater input, while Elkhorn Slough in Monterey Bay has anomalously high ΔR at 403±48 (Ingram and Southon 1996). Point Pinos in Pacific Grove is only 243±52, and Carmel Bay on the open coast is 216±53 (Ingram and Southon 1996).

Recently, researchers have begun dating charcoal and shell from the same stratigraphic contexts in archaeological sites to determine how ΔR values may have changed over time in a given location, and to create local reservoir correction values (Daniels 2009). Both San Francisco Bay (Ingram 1998) and the Santa Barbara Basin (Kennett et al. 1997) have evidence for significant diachronic variability. In Table

2.12, I show the more extreme ΔR values over time from the West Berkeley Shellmound in the San Francisco Bay area; high ΔR values were 400-800 ^{14}C years, and low and really low ΔR values were -170-60 ^{14}C years (Ingram 1998).

Table 2.12. Notable relative ΔR levels for San Francisco Bay over the last 4000 years. See text for numeric equivalents of ΔR values. Data from Ingram (1998).

Time span	ΔR values
50 BC-AD 750	High
350-150 BC	Low
850-750 BC	High
1550-850 BC	Low
1950-1550 BC	Really low
2150-1950 BC	High

High values probably indicate increased upwelling relative to today, and low values weaker upwelling. The 1950-1550 BC period of especially low upwelling was also a particularly wet climatic period in the San Francisco Bay, while the 50 BC-AD 750 period of high upwelling corresponds to a drier atmospheric climate identified at Mono Lake (Ingram 1998). Coastal upwelling and precipitation may therefore be linked, possibly through ENSO events (Ingram 1998), though I must reiterate that connecting coastal and Sierra Nevada climate is problematic.

Summary

Any area's local climate can be influenced by cycles in the earth's orbit, weather systems, ocean circulation, melting glaciers, etc. Adjacent regions might respond similarly to broader climatic forcing, but even if they experience comparable

effects, the timing can differ significantly. In many cases, when one area has undergone substantial paleoclimatic research, the results are then assumed to hold true for a much broader area. West et al. (2007:14) pointed out that many "bio/geochronologic schemes … have been developed elsewhere and have been applied by some to California with little recognition of the variation that occurs at global, regional, or landscape scales." As more detailed paleoclimatic data are collected, the variability among regions becomes clearer, as does the importance of local topography and its interaction with weather systems.

California as a whole is in many ways a transitional zone between Pacific Northwest and American Southwest weather patterns. Moreover, central California climate alternates between correlating with the southern and northern parts of the state. This makes it a particularly important region for which to collect local paleoclimatic data, and unfortunately, such information is still scarce.

The great diversity in timing and direction of climatic shifts over time in different areas supports my argument that regional paleoclimatic proxies should be used with care. As a result, my reconstruction of Monterey Bay area Holocene atmospheric and oceanic climate is confined to sources from that area. I have assigned a possible time span when the MCA may have affected the Central Coast, but it is simply based on when the most other California areas experienced low rainfall. The region is desperately in need of further paleoclimatic research.

Still, I have compiled what Monterey Bay area climatic history we have because environmental conditions, both atmospheric and oceanic, affect the

distribution of resources on the landscape. I expect that the relative productivity of the ocean compared to the terrestrial environment influences foragers' subsistence decisions, both based on the overall abundance of resources and on the nutritional content of the foods available. Poorer terrestrial conditions, for example, can lead to leaner animals and a scarcity of carbohydrate- and fat-rich plant foods. Foragers thus might turn to oily cold-water fishes as excellent sources of calories and fats. In Chapter 8, I describe the results of proximate composition analyses on several local fish species, so that in the discussion in Chapter 9 I can incorporate both climatic and nutritional data. In the next chapter, I summarize what we currently know about the culture history of the California Coast, emphasizing subsistence and in some cases its relation to climate.

CHAPTER 3

Culture History of the California Coast

Major research themes in California archaeology have emphasized relationships among subsistence, the environment, population sizes, and social complexity. Archaeological data have challenged assumptions about why people would eat shellfish, small seeds, and small fish, as all of these appear earlier in prehistory than researchers originally expected. Debates continue as to why large game hunting appears to increase over time, why some species of marine mammal are hunted much later on some parts of the coast than others, and what relationship prestige might have to the acquisition of large prey.

Many California archaeologists have adopted the use of behavioral ecological principles to explain the patterns of human subsistence we see in the archaeological record. Most commonly, archaeologists apply behavioral ecology by assigning an economic value to different resources, and testing whether archaeological material indicates the higher valued resources were more commonly exploited. I provide a more detailed treatment of this theoretical approach in Chapter 4, along with some criticisms of the current ways in which it is applied.

In this chapter, I place Monterey Bay's cultural history in the broader context of California's coast and the above research themes, highlighting both the similarities and differences among the Northern, Central, and Southern Coast regions over time. I emphasize the Santa Barbara Channel area, because it has been the focus of extensive

archaeological research, perhaps more than any other part of California. Furthermore, both Monterey Bay and the Santa Barbara Channel have rich marine environments and an abundance of shellfish and fish remains in archaeological sites over time, thus making a comparison of their diverse histories particularly interesting. The northern California coast has a very different environmental context, but it provides another example of contrasting cultural development. In Figure 3.1, I show the major sites and geographic regions discussed in this chapter.

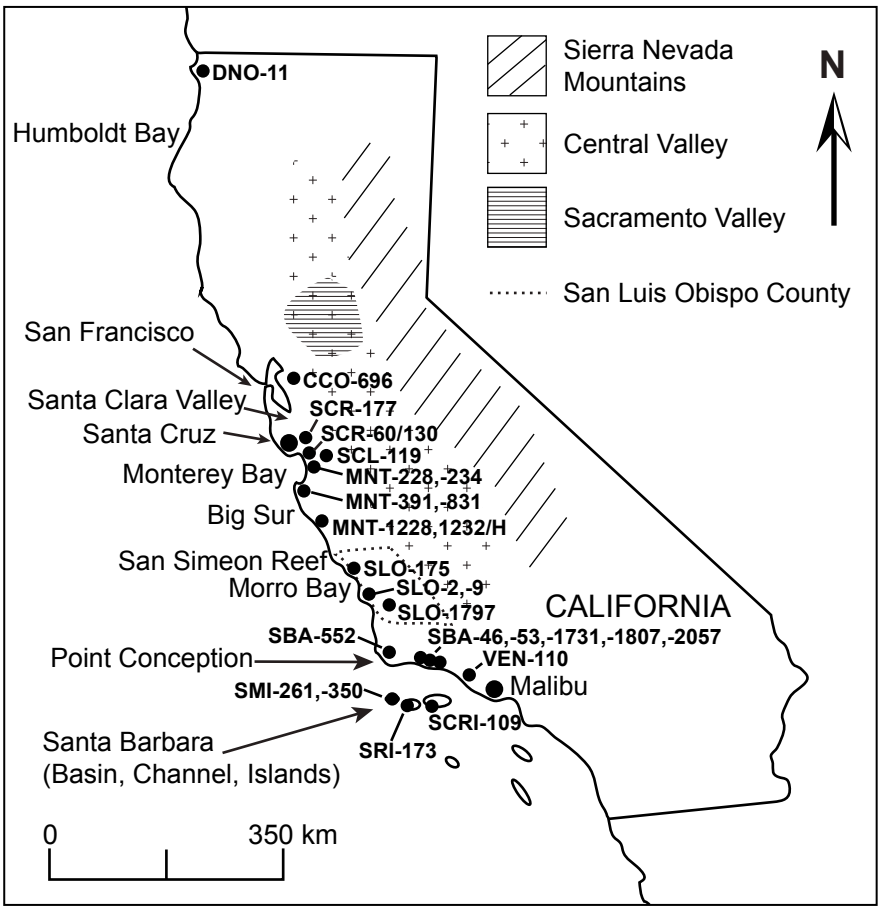


Figure 3.1. Important sites and geographic regions of the California Coast, as discussed in this chapter.

Culture Sequences

Initial attempts to classify central California prehistory occurred in the early twentieth century and focused on San Francisco Bay sites (see Breschini 1983). Not too much later, Heizer and Fenenga (1939) developed the first major classification, emphasizing the lower Sacramento Valley. In their Central California Taxonomic Sequence (CCTS), they defined Early, Transitional (or Middle), and Late Horizons, mostly based on burial methods and associated artifacts (Heizer and Fenenga 1939). The sequence was thought to extend at least south to Diablo Canyon (Breschini 1983), thereby covering approximately the middle third of the state. Researchers assumed the Sacramento Valley was the cultural core for central California, and sites throughout the rest of the region were therefore described and defined based on their resemblances to the taxonomic categories of the CCTS (Breschini 1983; Moratto 1984). Beginning in the 1970s, archaeologists identified several contemporaneous "Patterns" in central California during the Early Horizon: the Windmiller Pattern (lower Sacramento Valley), Berkeley Pattern (San Francisco Bay), and Sur Pattern (Monterey Bay and Big Sur coast), as well as early cultures from Santa Cruz County and the Santa Clara Valley (Breschini 1983).

In 1959, Meighan proposed that, except for the very earliest sites, California prehistoric culture could also be defined as an Archaic developmental stage. Based on Willey and Phillips' (1955) historical-developmental taxonomy, the Archaic stage required lithic technology, including groundstone, used by hunter-gatherer groups that did not yet practice agriculture. The concept that all hunter-gatherer groups

evolve through the same stages, in the same order, in any environment, was an inherent part of this taxonomy. People were thought to have entered the Americas only able to hunt and gather a few kinds of resources, then over thousands of years, learned about their environment and developed more specialized subsistence economies (Caldwell 1958). The assumption that people started out as mainly hunters had significant implications for the study of the peopling of the Americas and early cultures, as I will discuss below.

Fredrickson (1974) later expanded on the Archaic term, dividing it into the Lower, Middle, and Upper Archaic Periods, followed by the Emergent Period. He defined the Lower Archaic based on millingstones and an emphasis on plant foods; the Middle Archaic on the mortar and pestle, increase in hunting, and subsistence diversification; the Upper Archaic on greater sociopolitical complexity; and the Emergent Period as a time when people were significantly modifying their environments, storing food, participating in complex exchange and religious practices, and in many cases organizing themselves in ranked societies (Fredrickson 1974). For the Central Valley, Rosenthal et al. (2007) later compiled newer radiocarbon dates to adjust the dates for those periods, but retained the same terminology.

The Archaic sequence is still used occasionally in California archaeological research (e.g., Jones and Klar 2007), though regionally defined cultural sequences are more common now that we have better localized datasets, and the term is no longer associated with an evolutionary stage of development. While at certain times

similarities existed across broad geographic ranges, each region clearly has its own history. In Table 3.1, I summarize the current understanding of cultural taxonomies for California's coastal and Central Valley regions, compared to Fredrickson's (1974) original Archaic system.

I focus much of this chapter on the Central Coast and comparisons with the Santa Barbara Channel area. Therefore, I organize my discussion using Jones et al.'s (2007) cultural sequence for the Central Coast, though I discuss how Breschini and Haversat (2011) have proposed a somewhat different chronology for the Monterey Peninsula. The Santa Barbara Channel chronology is close enough to the Central Coast's that they can be treated simultaneously with the Jones et al. (2007) system. The Northern Coast does not line up quite so neatly, but I note where the defined patterns overlap with multiple Central Coast periods. In each section, I first describe broader patterns, then cover major topics of research, and conclude with a discussion of what we know specifically about the Monterey Bay area.

The division of California's Central Coast prehistory into periods is typically based on the introduction of new artifact types or significant shifts in relative proportions of artifacts already being used. These divisions also generally coincide with changes in subsistence and settlement patterns, and several regional authors have invoked "resource intensification," a subject I address more critically in Chapter 4.

Table 3.1. Major cultural taxonomy sequences developed for California as a whole, three coastal regions, and the Central Valley. The San Francisco Bay area uses such a diversity of chronological systems that it is not included here. See Milliken et al. (2007:Figure 8.4) for an excellent figure showing the many different classification schemes.

<table>
<tr><th>Years</th><th>General California (Fredrickson 1974)</th><th>Northern Coast[1] (Hildebrandt 2007)</th><th>Central Valley (Rosenthal et al. 2007)</th><th>Central Coast (Jones et al. 2007)</th><th>Santa Barbara Channel (Arnold and Graesch 2004)</th></tr>
<tr><td>Historic</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2"></td><td rowspan="4">Emergent Period
AD 500-1800</td><td rowspan="4">Gunther Pattern
AD 500-historic</td><td rowspan="2">Emergent
AD 1100-historic</td><td rowspan="2">Late Period
AD 1250-1769</td><td rowspan="2">Late Period
AD 1300-1782</td></tr>
<tr><td rowspan="2">Transitional Period
AD 1150-1300</td></tr>
<tr><td>AD 1000</td><td rowspan="3">Upper Archaic
550 BC-AD 1100</td><td rowspan="2">Middle-Late Transition
AD 1000-1250</td></tr>
<tr><td></td><td rowspan="3">Middle Period
600 BC-AD 1150</td></tr>
<tr><td>0 BC/AD</td><td rowspan="2">Upper Archaic
1000 BC-AD 500</td><td rowspan="3">Mendocino Pattern
2500 BC-AD 500</td><td>Middle Period
600 BC-AD 1000</td></tr>
<tr><td>1000 BC</td><td rowspan="4">Middle Archaic
5550-550 BC</td><td rowspan="2">Early Period
3500-600 BC</td></tr>
<tr><td>2000 BC</td><td rowspan="3">Middle Archaic
3000-1000 BC</td><td rowspan="3">Early Period
5500-600 BC</td></tr>
<tr><td>3000 BC</td><td rowspan="4">Millingstone
8000-3500 BC</td></tr>
<tr><td>4000 BC</td><td rowspan="3">Lower Archaic
6000-3000 BC</td><td rowspan="5">Borax Lake Pattern
8000-6500 BC</td></tr>
<tr><td>5000 BC</td><td rowspan="3">Lower Archaic
8550-5550 BC</td></tr>
<tr><td>6000 BC</td><td rowspan="2">Millingstone[2]
c. 7000 BC to 5500-5000 BC</td></tr>
<tr><td>7000 BC</td><td rowspan="4">Paleoindian
10,000-6,000 BC</td><td rowspan="3">Paleoindian[2]
11,000-7000 BC</td></tr>
<tr><td>8000 BC</td><td rowspan="3"></td></tr>
<tr><td>9000 BC</td><td rowspan="3">Paleoindian
>8000 BC</td></tr>
<tr><td>10,000 BC</td><td rowspan="2">Paleoindian
11,550-8550 BC</td></tr>
<tr><td>11,000 BC</td><td></td></tr>
</table>

1. This is the chronology for the northern part of northwest California. 2. Chronology derived from Glassow et al. 2007. For the Millingstone, they use an end date of 5000 BC, while acknowledging that some archaeologists consider it to end at 3500 BC.

Peopling of the Americas

Much archaeological research on late Pleistocene and early Holocene in the Americas has centered on whether humans arrived from an inland or coastal route, and how early people used marine resources. Linguistic, dental, and genetic evidence all suggest that people migrated into North America from Asia in the late Pleistocene (Greenberg *et al*. 1986). By the 1960s, archaeologists most commonly believed that humans had migrated into the Americas using an ice-free corridor between the Laurentide and Cordilleran Ice Sheets (e.g., Haynes Jr. 1969). Early peoples in North America were thought to have specialized in hunting large game, and to have followed megafauna like mammoths across the Bering Land Brige and through the ice-free corridor (Adovasio and Pedler 2005). They then slowly became accustomed to their new environment, and incorporated other foods into their diets. In California, since the earliest sites indicated the exploitation of widely varying marine and plant foods, Meighan (1959:297) argued that they must have developed from an "older and simpler cultural stratum" from farther east. For several decades in California, the environment had been described as so rich that early foragers hardly had to work to survive, thus explaining away the supposed lack of cultural change through time (Jones and Raab 2004).

In the 1960s, all of the uncontested evidence for the earliest North Americans came from Clovis sites, which were geographically wide spread and dated to 11,500-11,000 ^{14}C years bp (Haynes Jr. 1969). Radiocarbon dates were not calibrated at that time, and the Clovis horizon has since been adjusted to 13,400-13,000 BP (Fiedel

1999), or 11,450-11,050 BC. In the 1970s, Fladmark (1979) compiled substantial paleoenvironmental and archaeological data to argue that a Pacific Coast migration route should not be discounted, but his ideas did not receive wide support among North American archaeologists. Furthermore, sites presented as possible pre-Clovis occupations did not hold up to scrutiny (Jablonski 2002).

In the 1990s, the discovery of the Monte Verde site challenged the existing ice-free corridor hypothesis, as it dated to 12,500 ^{14}C years bp, well before Clovis, and was located on the coast of Chile (Erlandson 2002). Fiedel's (1999) radiocarbon calibrations later put the site's occupation at c. 12,050-11,650 BC. Erlandson (2002) subsequently argued that the technology necessary for a maritime pathway was not excessive, given that evidence for sea faring capabilities among anatomically modern humans extended back tens of thousands of years. Moreover, Dixon (2001) noted that similarities between the marine environments of northeastern Asia and northwestern North America were similar, so people would not have needed to develop new technology. Research into a coastal migration route subsequently increased.

Testing the coastal migration hypothesis required finding more early evidence of marine resource use along the Pacific Coast, a difficult endeavor given sea level rise since the Pleistocene and coastal erosion (Erlandson 2002). Still, terminal Pleistocene sites are cropping up, including in California, where the earliest coastal site, SRI-173 on Santa Rosa Island, dates to c. 10,000 BC (Erlandson et al. 2007b).

As evidence for early use of marine resources increased, archaeologists also had to rethink their expectations of early peoples' subsistence. Ethnographic studies

had suggested that the perceived struggle of the hunter-gatherer lifestyle was probably due to modern foragers being pushed into marginal habitats, rather than representative of foraging in all contexts (Lee and DeVore 1966). Anthropologists started to argue that early peoples were probably extremely capable, knowledgeable about their landscape, and not dedicated solely to hunting (Lee and DeVore 1966).

While archaeologists in California had originally assumed hunters from the interior populated the region (e.g., Wallace 1978), the subsequent research identified a diversity of subsistence strategies during the Pleistocene and early Holocene (see Erlandson et al. 1999). Jones (1991) noted that excavations of more than 700 archaeological sites within 35km of the California coast revealed an obvious early use of marine resources, especially shellfish. Early peoples in California seemed to favor estuarine habitats in particular, as well as bay shores and lacustrine areas (Breschini and Haversat 1991a; Hildebrandt 1997; Jones 1991, 1997). Erlandson et al. (1999:255) suggested that "coastal environments…encourage diversified subsistence patterns, and optimal subsistence choices differ considerably from many land-locked environments."

The early habitation of coastal areas and use of marine resources in California is striking, especially considering that the earliest sites could well be underwater from sea level rise. Marine habitats were therefore probably not simply a second choice to be exploited only when depletion of terrestrial resources forced a switch (Jones 1991). Instead, as I discuss more in the section on Millingstone Period subsistence, archaeologists started analyzing why coastal resources might be valuable.

Though early sites continue to be found, and arguments for a coastal route have become more common (e.g., Erlandson, Graham, et al. 2007; Erlandson, Rick, et al. 2007; Faught and Freeman 1998; Jones 1991; Moratto 1984), knowledge of very early Holocene fishing practices on the Pacific Coast and how they relate to later cultural developments is still limited. Multi-component sites are frequently mixed, the sites are small, or they are not well dated (Rick and Erlandson 2000). The earliest layers at several coastal shell middens do not appear to have milling tools for plant processing (Erlandson and Moss 1996; Glassow 1992), which contrasts with later Millingstone occupations. Most early Holocene sites in the Channel Islands have faunal assemblages dominated by red abalone (e.g., SRI-173) and rocky shore shellfish (SMI-350, SCRI-109), with few artifacts of any type and no grinding tools (Erlandson 1991b).

Recent surveys of more inland sites on the Channel Islands have discovered early occupations with very high numbers of flaked stone tools that were probably used for hunting birds and mammals (Erlandson et al. 2011). Three sites on Santa Rosa and San Miguel Islands dated between 10,300 and 9250 BC, with crescents and stemmed projectile points suggesting a connection with the Western Pluvial Lakes Tradition from western continental North America (Erlandson et al. 2011). By contrast, Daisy Cave (SMI-261), a later stratified shell midden dating to c. 7950-6650 BC, had both faunal remains and preserved fishing gear made from marine sea grass, all of which pointed toward an emphasis on marine resources (Connolly et al. 1995; Erlandson 1991b; Erlandson and Moss 1996). Erlandson et al. (2011) argued that

highly mobile foraging groups used the inland sites on Santa Rosa and San Miguel islands for seasonal activities, and exploited marine resources from the coastal locales.

The earliest possible site in the Monterey Bay area identified so far is the Scotts Valley site, SCR-177. It may date to 9500 BC [10,000 ^{14}C years bp] or even earlier, though the radiocarbon dates from the site were both bulk samples, comprising multiple pieces of charcoal for each date, and were not stratigraphically concordant (Cartier 1989). Other older sites in the area date to the Millingstone Period, which is discussed next.

Millingstone Horizon: 8000-3500 BC

The Millingstone Horizon was first identified and defined on the Southern Coast of California (Wallace 1955, 1966, 1978). Though Wallace (1955) used the term "horizon," which usually refers to cultural evidence that is widely spread geographically but restricted in time, the Millingstone may cover thousands of years. It has been dated to as early as 8000 BC at SLO-2 and SLO-1797 on the San Luis Obispo coast (Jones et al. 2007), and 7920 BC at CCO-696 to the east of San Francisco Bay (Milliken et al. 2007). On the later end, the Millingstone has been extended into the "Late Holocene" in some parts of southern California (Fitzgerald and Jones 1999), which Glassow et al. (2007) define as beginning at 1500 BC, though they also recommend that the termination of the Millingstone in the northern Santa Barbara Bight be dated to 5500-5000 BC.

Since the original definition of the Millingstone Horizon, archaeologists have also identified Millingstone sites in central and northern California, especially along the coast, but not limited to it (Fitzgerald and Jones 1999; McGuire and Hildebrandt 2004). Though originally referred to as "Milling Stone," I follow Jones and Klar (2007) in spelling it as one word, and Jones and Waugh (1997) in calling it the Millingstone *Period* when referring to its manifestation on the Central Coast. They consider the Millingstone Period on the Central Coast to end at 3500 BC, when major changes in archaeological material signify the transition into the Early Period (Jones and Waugh 1997).

As evidenced by the term Millingstone, sites from this period include a prevalence of milling equipment, especially handstones and millingslabs (or *manos* and *metates*), a scarcity of projectile points, and abundant shellfish remains, suggesting that people relied heavily on nuts or seeds and marine resources (e.g., Colten 1991; Erlandson 1988, 1991a; Glassow et al. 2007; Jones et al. 2004; Wallace 1966, 1978; Warren 1967). Fitzgerald and Jones (1999:71-72) defined Millingstone assemblages as being "marked by dense accumulations of milling slabs, handstones, crude core and flake tools, low frequencies of projectile points and bifaces, and cairn burials."

I described above how the early cultural evolutionist explanations of human subsistence assumed that foragers started off as specialized large game hunters in very mobile groups, and then evolved through other stages of cultural development as they became more comfortable with their environment. As archaeologists started

realizing that hunter-gatherers were smart and capable, the cultural evolutionary arguments gave way to explanations that highlighted external environmental factors to which foragers had to adapt in particular ways. Shellfish and small seeds were still considered sub-optimal resources, and therefore exploited only when other resources were relatively less abundant (see Erlandson 1991a). Cohen (1977, 1981), for instance, contended this was because of population overcrowding, which would either require more resources to feed people, or could result in the overexploitation of large game, necessitating the inclusion of other resources in the diet. Additionally, archaeologists argued that coastal areas were settled later than inland areas because they provided resources of lower value (Cohen 1981; see Hildebrandt et al. 2009; Osborn 1977).

In California, the presence of many of the earliest archaeological sites on the coast (Erlandson, Graham, et al. 2007; Erlandson, Rick, et al. 2007), along with the Millingstone Horizon's emphasis on a wide variety of plants and marine resources, challenged these previous descriptions of marine resource value and the evolution of human subsistence (Erlandson 1991a; Rick and Erlandson 2000). Eventually, behavioral ecology in general, and optimal foraging theory in particular, was employed as a way to explain changes in resource use through time. It emphasized the interaction between humans and their environment, and the dietary value of different resources, and was particularly invoked to explain the "intensification" (in very simple terms – the increased use) of what were considered lower ranked foods (e.g., Broughton 1994, 1997, 2002; Codding and Jones 2007b; Erlandson 1997;

Hildebrandt and Levulett 1997; Jones et al. 1999; Jones and Ferneau 2002; Jones and Waugh 1997; Wohlgemuth 1996).

Millingstone Subsistence

The adoption of an optimal foraging theory approach to California subsistence required a more specific understanding of the resources themselves, and why they might be valued. Shellfish are localized, predictable resources that do not require specialized technology to harvest or process, are generally low-risk (Erlandson 1988), and can be harvested by nearly anyone (Erlandson 1988; Jones 1991). With plant foods such as high-calorie seeds or nuts to provide energy, shellfish could be an excellent easy source of complete protein (Erlandson 1991a; Glassow and Wilcoxon 1988), or even a sufficient source of calories, especially in less-depleted beds (Bettinger et al. 1997; Jones and Richman 1995).

Based on the archaeological evidence, marine taxa were high-ranked dietary choices long before population pressure or resource stress developed (Erlandson 1991a; Rick and Erlandson 2000). Furthermore, shellfish, nuts and seeds, and even fish are part of a resource suite that requires certain kinds of technology and skills to exploit, but skills that would be easily transferrable from one location to the next. Fish species found in the intertidal zone might change from north to south, but the same fishing technology would still catch dinner.

Using nets to capture small schooling fishes was originally thought to begin late in the Holocene, when high human population density and overexploitation of other resources necessitated technological adaptations (see Rick and Erlandson 2000

for summary). However, the presence of small clupeids (herrings or sardines) in Santa Barbara Channel sites at SBA-2057 by c. 6400 BC and SBA-1807 by 6750-6350 BC (Rick and Erlandson 2000), and clupeids and atherinids (silversides) at MNT-234 in Monterey Bay by c. 6300-5800 BC (Milliken et al. 1999), all indicate that net fishing started much earlier. Though the latter two sites had smaller faunal assemblages, net fishing at SBA-2057 probably produced significant yields.

The emphasis on shellfish and plant foods in Millingstone sites might also reflect a less distinct sexual division of labor than in historic periods (Erlandson 1991a). The overwhelming association of both male and female burials with milling tools instead of hunting technology also points towards less gender segregation in subsistence activities (McGuire and Hildebrandt 2004). After 550 BC, male burials have a much higher proportion of projectile points/bifaces to milling equipment, suggesting the development of greater gender differentiation in subsistence activities (McGuire and Hildebrandt 2004).

Based on Myers' (2007) work presented in Chapter 2, atmospheric climate in the Monterey Bay area probably shifted from warm and wet to drier and cool slightly less than halfway through the Millingstone, c. 6250 BC (Table 3.2). These conditions, however, were accompanied by high terrestrial productivity, and marine climate in the Monterey Bay area was also cooler and more productive (Myers 2007). I emphasize, again, that these cooler, drier, and more productive conditions run counter to much of the evidence for paleoclimate in western North America, reinforcing the need for local climate data.

Table 3.2. Simplified climatic data for the Central Coast compared with the cultural chronology.

Dates	Terrestrial Climate	Marine Climate	Culture Sequence
450 BC – AD 1700	Warm, higher rainfall, but clusters of consecutive droughts in AD 1400-1600s.	Upwelling declining, SST warmer and productivity lower than 6250-2550 BC. SST might be cool AD 1-1300, highly variable AD 1300-1500, and cooler again AD 1500-1700.	Late Period AD 1250-1769
			Middle-Late Transition AD 1000-1250
			Middle Period 600 BC-AD 1000
1250-450 BC		SST warming and productivity lower than 6250-2550 BC	Early Period 3500-600 BC
1350-1250 BC	Warm, higher rainfall		
1550-1350 BC	Possibly cooler and drier again		
1750-1550 BC	Warm and wet, possible floods, low productivity	Potentially very low productivity	
2550-1750 BC	Drier and cool, especially during 4050-2050 BC, higher productivity	SST still cool but begins warming, productivity variable, ENSO influential again through rest of Holocene	
6250-2550 BC		SST 1-2ºC cooler than today, upwelling and productivity high, ENSO suppressed	
7850-6250 BC	Warm and wet	Warmer SST, upwelling increasing	Millingstone Period 8000-3500 BC
7850 BC		Small drop in SST, upwelling starts to increase	
9650-7850 BC		Warmer SST, ENSO influential	Paleoindian >8000 BC

Millingstone Period in the Monterey Bay Area

The earliest Millingstone Period sites in Monterey Bay, from north to south, are SCR-60/130 at Harkins Slough, which has an earlier component dating to c. 5450-4850 (Culleton et al. 2005); MNT-234, the Moss Landing Hill site at Elkhorn Slough, dating to c. 6000 BC (Milliken et al. 1999); and MNT-831 in Pacific Grove, dating back to 5200 BC (Breschini and Haversat 2006).

Harkins Slough and Elkhorn Slough are less than 7 km apart, and sites in these locations both had significant numbers of millingslabs and handstones. At SCR-60/130, the majority of radiocarbon dates from the site reflected occupation during the Millingstone Period, centered around 5000 BC, with a smaller number dating to the Early Period (Culleton et al. 2005). Shellfish and faunal remains and some burials could be attributed to the Millingstone component, but "no formal artifact [could] be definitively assigned" (Culleton et al. 2005:95). Archaeologists recovered high numbers of groundstone artifacts, many of which came from one part of the site. Unfortunately, in that area, handstone and millingslab toolkits did not seem to segregate by depth from mortars and pestles, making their temporal relationship unclear. Much of the other groundstone was recovered during trench excavation and only had the most general provenience. As a result, despite the temptation to sort the groundstone artifacts into Millingstone and Early Periods, Culleton et al. (2005:89) decided that such attribution would be "entirely speculative." SCR-60/130, therefore, has a dated Millingstone component, and typical Millingstone artifacts, but the two are not correlated.

At MNT-234, Milliken et al. (1999) listed 18 handstones and three millingslabs, all recovered during backhoe excavation, which normally would provide less obvious provenience. However, the artifacts came out of a brown paleosol layer in the site that otherwise dated to the Millingstone Period, so they were reasonably assigned to that time span (Milliken et al. 1999).

For the Monterey Peninsula, Breschini and Haversat (2005, 2006) argued that a near-complete lack of sites dating to before 4000 BC, as well as a paucity of millingstones, indicated that the Millingstone Horizon might not be represented in that area. Sites do date to the same years as the Millingstone Period, but a lack of assemblages with high proportions of both millingslabs and handstones made them reluctant to use the term Millingstone. While 38 "grinding slabs" were uncovered at MNT-831, only one *mano* was found. However, numerous "faceted handstones" were tested for protein residue, and results suggested they were used to process plants and wood (Breschini and Haversat 2006).

Based on extensive radiocarbon dating of Monterey Peninsula sites, and what they see as a relative lack of milling artifacts, Breschini and Haversat (see 2011) have recommended a different cultural chronology than that provided for the Central Coast in Table 3.1. I provide a comparison between Jones et al. (2007) and Breschini and Haversat (2011)'s proposed chronologies in Table 3.3. Though this chapter is organized with the Jones et al. chronology for ease of comparison with the Santa Barbara Channel area, I maintain both the Jones et al. and the Breschini and Haversat

sequences in the rest of this dissertation to investigate whether the fish remains provide support for either chronology.

Dietary information comes primarily from these coastal sites. Faunal remains from Elkhorn Slough and Pacific Grove suggest a heavy emphasis on shellfish supplemented with fishing and fowling, and lastly hunting (Breschini and Haversat 1995; Breschini and Haversat 2006; Milliken et al. 1999), with accompanying high percentages of rabbits at CA-MNT-831 (Porcasi 2006).

Table 3.3. Comparison of Jones et al.'s (2007) cultural chronology for the Central Coast, and Breschini and Haversat's (2011) for the Monterey Peninsula.

Years	Jones et al. 2007	Breschini and Haversat 2011
Historic		
AD 1000	Late Period AD 1250-1769	Late Period AD 700-1769
	Middle-Late Transition AD 1000-1250	
0 BC/AD	Middle Period 600 BC-AD 1000	Middle Period 200 BC-AD 700
1000 BC		gap[1] 1200-200 BC
2000 BC	Early Period 3500-600 BC	Early Period 4000-1200 BC
3000 BC		
4000 BC		
5000 BC	Millingstone 8000-3500 BC	Archaic, or not yet locally defined
6000 BC		
7000 BC		
8000 BC		

1. The "gap" refers to a span of time where no radiocarbon dates occur from sites on the Monterey Peninsula.

Results from recent analyses of human remains from SCR-60/130 dating to c. 5050 BC demonstrate early dependence on marine resources (Newsome et al. 2004). Stable isotope data from seven burials display $\delta^{13}C$ and $\delta^{15}N$ levels that indicate 70-84% of the diet comprised marine mammals, marine fish, and shellfish (Newsome et al. 2004).

To the south on the Big Sur coast, and slightly later at 4400-3300 BC, MNT-1232/H also has isotope data from one human bone, showing much greater emphasis on terrestrial resources than is indicated by the archaeofauna (Jones 2003). Jones (2003) argued that this was similar to the Santa Barbara Channel, where faunal assemblages produced abundant shellfish remains, but human bone stable isotope analyses indicated more plants in their diet earlier in time (see Walker and DeNiro 1986). Temporal constraints on Walker and DeNiro's isotope data are less specific, however, and it is unclear whether they are comparable to the Big Sur remains. Jones (2003) also contended that in the Big Sur area, people probably made seasonal rounds and only depended heavily on marine resources during the short period of time when they were actually on the coast. This would reflect a more mobile population than the subsequent Early Period, when a decrease in diet breadth and a greater correlation between midden fauna and human bone isotopic signatures suggests that mobility decreased (Jones 2003).

Though the Monterey Bay and Big Sur isotopic data differ, it is difficult to generalize for the Big Sur coast based on analysis of one human skeleton, and more research clearly need to be performed to fully test Jones' (2003) hypothesis about

mobility. If the pattern holds, it highlights the need to reconstruct human behavior in each area individually. Additionally, plant food productivity of each region needs to be considered. Wohlgemuth's (2010) productivity maps indicate the Big Sur coast is currently somewhat productive, compared to the non-productive strip along the Monterey Bay coast. Greater inclusion of plant resources in a Big Sur diet would thus make sense, if productivity were similar in the past. In the meantime, at least in the Monterey Bay area, the isotopic signatures in human bone seem to agree fairly well with both the faunal and artifactual data.

Northwest California

Millingslabs and handstones are found in northwestern California sites dating to 8000-3500 BC, but their relationship to the Millingstone Horizon is debated. The Borax Lake Pattern that covered this time span also included large projectile points and several other types of flaked stone tools (Hildebrandt 2007). The similarity among artifact assemblages at Borax Lake sites, and the types of artifacts found, might represent foraging groups that moved frequently to new resources. So far, archaeologists have not been able to recover faunal and botanical remains due to poor preservation (Hildebrandt 2007).

Early Period: 3500-600 BC

Two major technological shifts marked the end of the Millingstone Horizon and beginning of the Early Period along the California coast. First, mortars and pestles appeared by 4300-3500 BC in a few sites in Santa Barbara, and by 3700 BC in

San Mateo and Monterey Counties in central California (Jones 1996; Rick and Glassow 1999). The mortar and pestle became the dominant milling technology across California much later, during the Middle Period (600 BC-AD 1000), and is discussed further in the next section. Second, the ratio of ground stone to flaked stone tools on both the Santa Barbara and Central Coasts reversed at the end of the Millingstone, a pattern often interpreted as reflecting an increase in hunting. Though the timing may have been different in the two areas, this shift occurred on the Central Coast c. 3500 BC (Jones 1996). Jones (2003) saw the major changes that occurred at this time as being mainly a result of population pressure and people becoming more sedentary, at least in the Big Sur area.

On the Central Coast during the Early Period, the open coast was more densely settled compared to the Millingstone Period, and residential sites had more extended occupations (Jones and Waugh 1997). People seem to have been relatively healthy with good levels of nutrition, based on human osteological evidence from MNT-391 on the Monterey Peninsula (Jones and Waugh 1997). Artifacts used for subsistence included stemmed spear or dart points, and bowl mortars, pestles, and milling equipment for plant processing (Jones 2002b). Fishing would have been done with nets and small, bipointed bone gorges (Jones et al. 2007). In the Santa Barbara region, faunal remains indicate that at 3700-3100 BC, fishing practices had continuity with previous periods, with a focus on bay/estuarine and nearshore species at SBA-53 (Rick and Glassow 1999). Fishes from similar habitats were also identified at SLO-175 (Rick and Glassow 1999), between Santa Barbara and Monterey.

The Early Period includes the thousand-year span that Breschini and Haversat (2011) have identified as a "gap" in radiocarbon dates: 1200-200 BC. Only four out of over 550 reliable samples date to within that time and all four are on the southwestern Monterey Peninsula. The area in which the gap appears to occur includes the southern Monterey Bay and the greater Monterey Peninsula (Breschini and Haversat 2011).

Overall, artifacts and faunal remains from the Central Coast point towards hunting and fishing becoming relatively more important compared to shellfish collecting in the Early Period, though with little change in what kinds of fish were being caught. Hunting and shellfish harvesting have been major topics of discussion about this period, as well as how mobile people were on the Central Coast.

Northwestern California had very different settlement and subsistence strategies at this time. In the northern part of the region, the Mendocino Pattern replaced the Borax Lake Pattern around 2500 BC. Sedentary villages appeared along rivers and lakes by 1000 BC, especially in the southern half of the region, but not on the outer coast until 2000 years later (Hildebrandt 2007; Hildebrandt and Levulett 2002). This is in striking contrast to both the Central and Southern Coasts of California, which had groups emphasizing marine resources much earlier. While further survey is needed, early villages have so far not been found on the coast in the places where uplift has exceeded sea level rise (Hildebrandt 2007), suggesting the lack of evidence may reflect past behavior rather than sampling. Subsistence

emphasis during this interval appears to have been mainly terrestrial resources and freshwater and anadromous fishes (Hildebrandt 2007).

Hildebrandt and Levulett (2002) maintained that maritime adaptations probably occurred late on the Northern Coast because of highly productive terrestrial and riverine environments in that region. In particular, northern California had major salmon runs, which decline in number and strength as latitude decreases (Hildebrandt and Levulett 1997). Additionally, large terrestrial mammals were more abundant in the north, and archaeologically, rabbits become relatively more abundant in sites to the south, testifying to a less productive terrestrial environment (Hildebrandt and Levulett 1997). As a result, Hildebrandt and Levulett (1997, 2002) argued, in more southern parts of California, inland habitats are less productive compared to the north *and* compared to the coast, making marine habitats the better choice.

The Hunting Question

In many regions of California, including the coast, Central Valley, and Sierra Nevada, faunal assemblages from archaeological sites show higher numbers of large mammal remains compared to small game, beginning after 3050 BC and especially 2050-50 BC (Hildebrandt and McGuire 2002). The trend is unexpected, because human populations were probably growing during this period, and should therefore have been depleting higher-ranked resources. Though archaeologists agree that large game hunting increased, they continue to debate the reasons behind it.

Two main arguments have been put forth to explain the phenomenon. In a greatly simplified summary of the first, the hunting of large animals is connected to a

costly signaling strategy, whereby males might be inclined to "show off" to attract more mates (Hildebrandt and McGuire 2002, 2003; McGuire and Hildebrandt 2005; McGuire et al. 2007). This view is explained in more depth in Chapter 4, as part of a discussion of advances in the use of behavioral ecology in California archaeology. The second argument is that environmental data can explain the increase, because the timing and trend of increased artiodactyl hunting can be correlated with improved climatic conditions at the start of the "Late Holocene," c. 3050 BC [4000 BP]. Cooler and moister conditions would have allowed artiodactyl populations to expand, increasing rates of encounter and leading to greater exploitation (Broughton and Bayham 2003).

Broughton and Bayham (2003) originally cited mainly Great Basin paleoclimate research, which lessened the strength of their argument for the rest of California, based on the regional diversity I discussed in Chapter 2. McGuire and Hildebrandt (2005) also pointed out that with wetter climate, plant biomass should have increased along with artiodactyl populations, yet the archaeological record suggests people focused on harder-to-process plant foods. Later, Broughton et al. (2008) used general circulation and physical climate modeling, paleoclimate proxies, and archaeological data to connect climatic conditions with artiodactyl abundances during the Holocene in the western United States. Though a much more extensive treatment of the relationship between paleoclimate and artiodactyls, it still focused mainly on the Great Basin. In general, the debate over reasons for increased large game hunting in California and the Great Basin remains unresolved.

Shellfish Harvesting

In addition to hunting, people may have begun harvesting shellfish more heavily in the Early Period on the coast (Jones 1996, 2003). Shellfish assemblages from several sites in Big Sur show that the dominant shellfish species, California mussel (*Mytilus californianus*), decreased in size over time, c. 4000 BC-AD 1000. Jones (1996, 2003) argued that because shellfish grow well in colder water, and SST data from the Santa Barbara Channel showed that SST was cold 6000-3400 BC, the shrinking mussel size was not due to deteriorating environmental conditions. Instead, he used experimental data to create curves for shellfish sizes based on "plucking" and "stripping" collection strategies, and determined that increased human gathering caused the size shift, as people switched from plucking only larger mussels to stripping all shellfish from one patch (Jones 1996, 2003).

In Chapter 2, I explained why paleoclimatic data from the Santa Barbara Channel is not a reliable proxy for the Central Coast, but more appropriate proxies still support Jones' argument. Central and northern California data indicate SST should have been cooler until 1350 BC, and again AD 1-1600 (Barron et al. 2003; Jones and Kennett 1999), which leaves only ~1400 years when shellfish growth might have slowed due to warmer ocean conditions. However, the shellfish were smaller in mean size for almost 5000 years. The lack of correlation between SST and shellfish size, plus the comparisons between experimental and archaeological shellfish size curves, suggest that Jones' (1996, 2003) argument for exploitation strategy is probably correct.

However, a stripping strategy might not represent people needing to work harder for their subsistence (Whitaker 2008). For California mussels, the meat-to-shell ratio is higher in smaller individuals, and the overall meat weight is higher in large individuals. Recent modeling of California mussel population structures under different types of harvesting showed that stripping mussel beds approximately every 24-36 months would maximize the trade-off between the meat-to-shell ratio and the total meat weight (Whitaker 2008).

During the transition from the Millingstone to the Early Period on the Big Sur coast, as men began to hunt more and both men and women probably spent more time and effort on subsistence activities, Jones (1996) contended that women's processing labor may have become more important. He identified the increase in processing archaeologically by the shift to a stripping strategy for harvesting shellfish, the greater emphasis on fish, and the use of mortars and pestles, whether for acorns or other resources (Jones 1996).

Human Evidence for Diet

So far, limited isotopic analyses of human burials along the coast demonstrate that diets became more generalized over time, but started with very different emphases depending on the area. As I have described before, the Big Sur Coast has a more productive edible plant community than the Monterey Bay area, which may have influenced some of the differences in subsistence. The Santa Barbara region is more similar to Big Sur (Wohlgemuth 2010).

In the Monterey Bay area, two human burials at SCR-60/130 dating to c. 2550 BC suggest the marine component of the diet decreased over time. Compared to the Millingstone Period burials described earlier, these individuals ate a higher proportion of terrestrial foods, but their diet probably still comprised 55% marine resources (Newsome et al. 2004).

On the Big Sur Coast, isotopic analyses on an earlier human bone reflected a surprisingly terrestrial and plant-based diet. The results from an Early Period human bone at MNT-1228, dating to 3700-2900 BC, showed a higher proportion of marine resources and meat and overall greater generalization (Jones 1996). Newsome et al. (2004) pointed out that based on the carbon and nitrogen values, Big Sur individuals were eating fewer marine foods than those from Harkins Slough, and that the latter data are most comparable to the four Late Period (AD 950-1700) Big Sur burials.

Santa Barbara Channel data are somewhat harder to compare, because the dates are so general. However, people appear to have increased their use of marine foods over time (Walker and DeNiro 1986), which is most similar to the Big Sur pattern. In terms of specific carbon and nitrogen isotope values, however, the Harkins Slough individuals from all time periods seemed to be more similar to Channel Islands people than to those from the Santa Barbara mainland (Newsome et al. 2004).

Population and Mobility on the Central Coast

Jones and Waugh (1997) argued that increased human population density led to territorial circumscription and the greater use of vertebrates in relation to shellfish that they see in the archaeological record. In contrast, for the span of 2200-500 BC,

Hildebrandt (1997) described the presence of bay mussel in several inland Santa Clara Valley sites. The movement of estuarine resources from Elkhorn Slough and San Francisco Bay inland suggested seasonal provisioning and that people were still relatively mobile. The Santa Clara Valley sites were occupied mainly from spring through fall, based on seed and acorn macrofossils, and a lack of migratory waterfowl. Additionally, the diverse resources at Elkhorn Slough may have made it particularly attractive in the winter, as fish, shellfish, and waterfowl were all available for exploitation (Hildebrandt 1997). However, based on high site density and diverse habitats in the slough area, Jones (2002b:63) pointed out that "there is no reason to assume that the slough's use was seasonally restricted," a shift from his earlier (1997) argument that the slough would mostly have been exploited in the summer. Jones (1997) suggested the richness of the slough may be more relevant in earlier and later periods, when the slough may have been most productive, as opposed to during the Early Period, during part of which it might have been cut off from the ocean.

Some evidence indicates that Elkhorn Slough was abandoned by human settlement c. 3000-1000 BC, perhaps because a freshwater incursion 3040-1000 BC lessened its productivity (Jones and Jones 1992; Jones and Waugh 1997). Chapter 2 covered potential problems with the dating of this event in more detail. If such a freshwater infusion did indeed drastically lessen the estuary's productivity, it is unclear why people continued to travel to the coast from the Santa Clara Valley for some 2000 years to collect estuarine shellfish.

Overlapping with this span is Breschini and Haversat's (2011) radiocarbon date gap at 1200-200 BC, which suggests the southern Monterey Bay area, including the peninsula, might also have been mostly abandoned for part of the Early Period. In contrast, the open coast to the south of Monterey Bay was continuously occupied through the Early Period, as was Morro Bay, farther south along the coast but with similarly rich fisheries as Elkhorn Slough (Jones and Waugh 1997).

Middle Period: 600 BC – AD 1000

The Middle Period on most of the California coast is defined by the appearance of *Olivella* saucer beads beginning around 1500-500 BC and lasting until AD 600-1300 (Jones 2002a). Single-piece circular shell fishhooks also appeared on the California coast during the Middle Period. In the Channel Islands region, direct AMS dates on fishhooks indicate they were in use by 550 BC, and possibly as early as 1550 BC (Rick et al. 2002). In the Monterey Bay area, the earliest shell fishhooks known so far date back to c. 150 BC (Gary Breschini, personal communication 2010). Circular fishhooks were by far more common in the Santa Barbara area than anywhere else, and were made mainly from abalone in the beginning, shifting toward mussel shell and even bone later on (Strudwick 1986).

Major subsistence changes also occur between the Early and Middle Periods. Mortars and pestles became the dominant grinding technology, and according to Jones (1996), may represent greater use of acorns. Pinniped remains peaked in abundance during the Middle Period, and the potential overexploitation of northern

fur seals and sea lions has been the subject of major debate. I discuss both of these topics in more detail below.

The Middle Period as defined on the Central Coast overlaps with two patterns in northwest California, which are discussed in the preceding and succeeding sections.

Were Mortars and Pestles Used for Acorns?

The presence of mortars and pestles in Middle Period California archaeological sites is often interpreted as evidence for acorn exploitation, a result of subsistence intensification and adaptation to climatic changes (see Jones 1996). Given the need to extract tannic acid, acorns require significant time and labor investment to process into edible food, but have a high caloric content and are also storable. Glassow (1992) argued that acorns should therefore enter the diet once other foods become difficult to acquire, and the presence of mortars and pestles has been used to argue for human population pressure. However, Wright (1994) listed ethnographic evidence showing that native Californians used mortars to grind tobacco, berries, seeds, and nuts in addition to acorns. She questioned whether groundstone artifacts can indicate specific food choices, and instead believed those artifacts are better considered representative of processing strategies (Wright 1994). Furthermore, using estimates based on the energy required to exploit various plant foods in other regions, Wohlgemuth (2010) determined that toxic nuts ranked above small seeds. As a result, archaeologists should probably consider acorns a more desirable resource than they traditionally have.

Since most interpretations of plant use are currently based on artifactual data, greater emphasis needs to be placed on analyzing plant remains directly. Two studies have addressed acorn use in California using paleobotanical remains, both in the central California region, and with varied outcomes. Wohlgemuth (1996) directly tested the hypothesis that people began using acorns more intensively during the Middle Period, by identifying plant remains from several sites in the Coast Ranges and Central Valley just north of San Francisco Bay. In all of the analyzed sites, mortars and pestles became the dominant grinding technology c. 850-550 BC. After the Early Period, when small seeds were more abundant than acorns, acorns became far more abundant in the Middle Period. The Middle Period also had the lowest large seed diversity, indicating the emphasis on acorns was particularly high (Wohlgemuth 1996). Afterward, small seeds increased in relative abundance again, though the proportion of acorns remained high. The lack of small seeds during the Middle Period does not appear to be due to preservation, and may reflect that people emphasized another resource during that time, or that the sites with acorns were only used seasonally (Wohlgemuth 1996).

In contrast, Hildebrandt's (1997) study of sites in the southern Santa Clara Valley showed acorns as by far the most abundant large seed present throughout the Early, Middle, and Late Periods, and more abundant than any other individual taxa. This contradicts the overall idea that people mainly intensified acorn use in the Middle Period. Wohlgemuth's (2010) descriptions of edible plant productivity, however, suggested that the southern Santa Clara Valley is mostly unproductive for

edible plants, while north of San Francisco Bay ranges between unproductive and very productive. The difference in acorn use may therefore partly be a result of available plants on the landscape and the accessibility of more productive habitats. Furthermore, Hildebrandt (2007) described how acorn macrofossils are found in early Holocene components from both northern and central California, but are connected with handstones and millingslabs, *not* mortars and pestles.

On the whole, recent archaeological investigations into acorn use in California show little direct relationship between acorn evidence and mortar and pestle technology. In fact, milling gear types are probably more closely related to a group's degree of sedentism than what material the milling gear is used to process (Hildebrandt 2007). Further paleobotanical studies are in order, and archaeologists could also start trying to recover starch and other residues from the grinding equipment itself, which is done routinely in other parts of the world (e.g., Dickau et al. 2007; Pearsall et al. 2004; Piperno et al. 2004).

Pinniped (Over)exploitation

Evidence of pinniped exploitation and consumption in California dates back to at least 6050 BC, with faunal remains from SBA-552 (Glassow 1992), and 5050 BC in Monterey Bay based on isotopic analysis of human bone from SCR-60/130 (Newsome et al. 2004). Significant numbers of pinniped bones have been recovered from coastal California archaeological sites, and seem to be especially abundant in Middle Period sites from both Santa Barbara (Glassow 1992) and Monterey Bay

(Gifford-Gonzalez et al. 2005). Over time, along the coast of both California and Oregon, faunal remains show a shift in which pinniped species are most abundant.

Why this shift exists has been a subject of debate since the early 1990s. Hildebrandt and Jones (1992; Jones and Hildebrandt 1995) have framed it as humans switching from exploiting migratory to resident breeders as the former became overharvested. They defined migratory breeders as the sea lions and northern fur seals, eared seal species that breed and give birth onshore, and could be acquired with relatively low cost while in rookeries. Resident breeders included harbor seals and sea otters, which can breed and give birth in the water, have less sexual dimorphism than migratory breeders, and do not form large harems. Migratory breeders would therefore be easier prey when both were present (Hildebrandt and Jones 1992; Jones and Hildebrandt 1995).

Jones and Hildebrandt (1995) argued that the increase in resident compared to migratory pinnipeds represents a prehistoric "tragedy of the commons," where individuals are best served by exploiting a communal resource at levels that lead to its eventual destruction. Migratory breeders only persist late in the sequence (post-AD 500) near sites with offshore rocks for rookeries or haulouts (Hildebrandt and Jones 1992, 2002; Jones and Hildebrandt 1995). People may have harvested gregarious otariid breeders from onshore rookeries until those pinniped populations either went locally extinct or moved to offshore rocks, then switched to either resident breeders or complex boat technology. Then, according to Hildebrandt and Jones (2002; Jones and Hildebrandt 1995), in some places a human population movement or shift in resource

focus allowed migratory breeders to rebound, as indicated by abundant migratory breeder remains in a few locations during the Late Period.

Lyman (1995) maintained that Jones and Hildebrandt (1992) did not provide enough evidence of low human occupation intensity to argue for reduced predation pressure. He also argued that a high ratio of female to male pinniped bones in the site demonstrated that people were not hunting "optimally," since this would reduce the population's reproductive capacity (Lyman 1995).

Though northern fur seals are not present in the Monterey Bay area today, zooarchaeological material from multiple sites includes large quantities of their remains dating to 150 BC-AD 750 (Gifford-Gonzalez and Sunseri 2009). At Elkhorn Slough, the combination of a high percentage of northern fur seal individuals younger than weaning age at MNT-234, and isotope data showing the adults foraged in mid-latitudes but far offshore, suggests that a northern fur seal rookery was present nearby (Gifford-Gonzalez and Sunseri 2009). Some marine mammalogists have argued that the pinniped remains resulted from young individuals stranded on the California coast after being swept away from the Farallon Islands off San Francisco by strong currents before they could swim well (see Gifford-Gonzalez 2011). However, the age ranges found archaeologically do not match those expected if all the individuals had stranded, and northern fur seals in historic times have shown they can form breeding colonies in new areas and adapt to changing conditions (Gifford-Gonzalez 2011). The northern fur seals were also not simply traveling down from Alaska to feed, as the

stable isotope analyses of their remains describe a population separate from those in the Pacific Northwest and eastern Aleutian Islands (Newsome et al. 2007).

Fur seals mainly disappeared from the record by AD 750, before the Medieval Climatic Anomaly, and may have been overexploited for both nutritional needs and for the exchange value of their furs (Gifford-Gonzalez and Sunseri 2009). The presence of pinnipeds in Monterey Bay probably influenced people's choices of subsistence activities, and fishing practices cannot be reliably interpreted without understanding which species of pinnipeds were available at different time periods, and whether or not they could have been caught on land.

Monterey Bay Area

The Middle Period was a time of cultural florescence in central California, when sites were especially large and numerous (Jones 1993; Jones and Ferneau 2002). As in the Early Period, artifacts included stemmed projectile points, bowl mortars, and pestles, plus an assortment of bone tools. Notched net sinkers made their first appearance during the Middle Period (Jones 2002b; Jones et al. 2007), as did circular shell fishhooks (Gary Breschini, personal communication 2010).

Along the Central Coast, people occupied and exploited most habitats, with an overall emphasis on marine resources including fish, shellfish, and marine mammals, supplemented with deer and rabbit (Jones and Ferneau 2002). This is fairly similar to the Point Conception area of southern California, where shellfish remained the most abundant taxon by weight, though they decreased in importance, but fish increased and pinniped abundance peaked (Glassow 1992).

Ocean upwelling was reasonably strong throughout this period, and the high density of fish bones and abundance of anchovy suggests fishing was worth the effort (Jones and Kennett 1999). Gobalet and Jones (1995:820) said that at Elkhorn Slough, "a prehistoric starry flounder fishery must have been extensive but localized at CA-MNT-234," based on the large quantities of that species' remains. Otherwise, MNT-234 and other Elkhorn Slough sites provide assemblages that mostly comprise species that are still the most common today (Gobalet and Jones 1995).

Based on evidence from both the coast and the Santa Clara Valley, population levels appeared to rise and territorial circumscription became more evident during the Middle Period (Jones and Ferneau 2002; Hildebrandt 1997). Hildebrandt (1997) argued that human transport of estuarine resources to inland sites decreased during the Middle Period and Middle-Late Transition, as people in the Santa Clara Valley started exploiting more local lacustrine and wetland resources. While overall shellfish abundance, and bay mussels in particular, decreased over time, the *numbers of shellfish taxa* increased. Seasonal indicators also suggest year-round habitation at inland sites, unlike earlier periods, which were only occupied spring through fall (Hildebrandt 1997). Interestingly, despite the size and apparent residential stability of Middle Period coastal sites, most were abandoned by the end of the Middle-Late Transition.

On the Big Sur coast and southward, oxygen isotope analyses of California mussel shells show season of harvest based on water temperature, and provide insight into settlement strategies that appear to stay the same from the Middle Period until

historic contact (Jones et al. 2008). Coastal sites have mussels from all seasons of the year, while inland sites have mainly mussels from the spring and early summer, with a few from late summer and early fall. The authors proposed that two groups may have existed with different settlement strategies, one staying on the coast year-round, while the other visited it in spring and early summer, but returned to inland sites to harvest acorns and other nuts (Jones et al. 2008).

Jones et al.'s (2008) conclusions should perhaps be considered tentative, since the coastal sites mainly represent the Middle Period and Middle-Late Transition (with only three shells from the Late Period), and the inland sites are Late Period, except for eight shells from one Middle Period site. However, it is a provocative pattern, and one that would also be interesting to test in the Elkhorn Slough and Santa Clara Valley area. So far, Jones (2002b) suggested otolith data from two sites on Elkhorn Slough, MNT-228 and MNT-234 indicated a lack of occupation during the winter during the Middle Period. Unfortunately, identifying seasonality from otolith edge readings has been recently questioned, and is deemed less reliable than previously thought (Andrews et al. 2003).

Middle-Late Transition and Late Period: AD 1000-1250 and AD 1250-1769

The shift between the Middle and Late Periods is defined by major artifactual and cultural changes in bead types, pottery and projectile points, seaworthy plank canoes in the south and redwood dugout canoes in the north. Manifestations of the Medieval Climatic Anomaly (MCA) vary in precise calendrical timing according to

region, but occur within AD 800-1400, for California as a whole (Jones et al. 1999). Far northern and southern California both have evidence for offshore exploitation of the marine environment using oceangoing canoes, large sedentary villages, and marked social differentiation, in contrast to the Monterey Bay area.

In southern and central California coastal areas, archaeologists have identified transitional periods between the Middle and Late Periods (see Table 3.1). In the Santa Barbara area, the Transitional Period lasts from AD 1150 to 1300. On the Central Coast, AD 1000-1250 is called the Middle-Late Transition, which Jones et al. (2007) defined based on the concurrent use of type G1, G2, and K beads. However, they also noted that the concept of an MLT Period in the Monterey Peninsula and Santa Cruz areas is debated (Jones et al. 2007), and I address that controversy below.

Northwest California

On the Northern Coast of California, sedentary villages appeared on the outer coast c. AD 500, fully 2000 years after they arose along regional rivers, and were widespread by AD 1000. Gunther Pattern sites have houses built with redwood planks, which are well separated from the middens, and distinguishable cemetery areas (Hildebrandt and Levulett 2002). As discussed before, Hildebrandt and Levulett (1997, 2002) argued that the late emphasis on marine resources was due to the relatively high productivity of terrestrial and riverine habitats, and that people eventually spread into the coastal areas as a result of population pressure. North of Humboldt Bay, when marine-focused economies did develop by AD 1000,

oceangoing canoes were used to exploit marine mammals (Hildebrandt 1984; Hildebrandt and Levulett 2002).

Artifacts and faunal remains found in Gunther Pattern components (post-AD 500) north of Humboldt Bay reflect the emphasis on marine resources. Composite harpoons are associated with sites in areas with offshore habitats for marine mammals, and where ethnographic accounts report the use of large canoes (Jobson and Hildebrandt 1980). Faunal assemblages from those areas have relatively high proportions of marine to terrestrial mammals (Hildebrandt and Levulett 2002). Netsinkers are also common in some sites and are ethnographically described as being used for fishing and catching diving ducks. Though analyzed faunal assemblages are somewhat rare, deeper water rockfish are more common at DNO-11, the Point St. George site to the north (Hildebrandt and Levulett 2002).

Hildebrandt (1984:203) argued that the exploitation of offshore marine mammals using large oceangoing canoes must have required "substantial capital investment and labor," as well as the organization of a large group of people. Status differentiation can be seen in the uneven distribution of burial goods, and rank was probably inherited, based on the items found with children's burials (Hildebrandt and Levulett 2002).

Santa Barbara Channel and the Chumash

In the greater Santa Barbara area, the archaeology of the Chumash – a complex maritime hunter-gatherer group present at European contact – reveals major cultural developments during the late Holocene and especially around the time of the

Medieval Climatic Anomaly. Increased physical violence, as evidenced by traumatic cranial injuries, began in the Middle Period and may have stemmed from competition over scarce resources during unfavorable climatic periods (Arnold 1992; Walker 1989). A long emphasis on nearshore and estuarine fish species suddenly shifted to include many more offshore, pelagic fishes, as evidenced at sites such as VEN-110, SBA-46, and SBA-53. Population pressure and over-harvesting of shellfish and bay or estuarine fishes may have influenced the switch to less easily available species (Rick and Glassow 1999). Around AD 800-1000, improvements in the plank canoe, or *tomol*, made crossing the channel much easier (Arnold 2001a, 2001b).

Similarities between *tomol* construction and that of Polynesian sewn-plank canoes, as well as between Chumash and Polynesian composite fishhooks, led Jones and Klar (2005) to argue that Polynesian contact may have occurred in the early AD years. The *tomol* was in use by AD 625, and composite fishhooks by AD 300-900 (Jones and Klar 2005). Linguistic similarities in some relevant Chumash and Polynesian words also support the argument for contact (Jones and Klar 2005, 2009). However, Arnold (2007) has challenged the linguistic evidence, and maintained that the chronology of settlement in Polynesia would not allow for contact with the Chumash. It is clear that the *tomol* development happened shortly before a number of changes occurred in Chumash sociopolitical organization (Arnold 1992, 1993, 2001a, 2001b), but whether those changes were due to *in situ* independent development, or influenced by Polynesian contact, remains to be seen.

Characteristics of this phase in Chumash history include a highly uniform chert microblade industry based on Santa Cruz Island, and specialized *Olivella biplicata* callus bead production limited to the northern Channel Islands (Arnold 2001a, 2001b; Arnold and Graesch 2004). Though these activities had both occurred in the previous time span, production and exchange volume increased drastically during AD 1150 to 1300 (Arnold 2001a, 2001b; Arnold and Graesch 2004). *Olivella* shell beads were used as currency (Arnold 2001b), and northern Channel Island Chumash seem to have produced almost all of the shell beads found in southern California (Moratto 1984). Exchange was probably facilitated by *tomol* transportation of commodities from and to the Channel Islands.

Though archaeologists agree that the Chumash at European contact were sociopolitically complex, they debate over why and when that complexity developed. Arnold (e.g., 1992, 1993) maintained that warmer SST AD 1150-1250 caused *marine* subsistence stress, which in turn supported increased exchange to buffer food shortages, and provided an opportune time for emergent elites to gain control of a major means of exchange, in this case plank canoes. By AD 1200, she argued, burial evidence reflects a decrease in interpersonal violence, the emergence of hereditary status, and acquisition of food resources from a greater variety of habitats (Arnold 2001b). However, Raab and colleagues (Raab et al. 1995; Raab and Larson 1997) pointed out that long-term elevated SST might result in a shift in species distribution rather than drastically lower fish abundance. Instead of marine subsistence stress, they argued that higher temperatures and low precipitation during the MCA instead

caused *terrestrial* resource stress, to which ancestral Chumash had to respond (Raab et al. 1995; Raab and Larson 1997). In a similar vein, Jones et al. (1999) stated that droughts during the MCA caused population-resource imbalances, prompting cultural transformation and reorganization that played out differently in various regions of CA and the Southwest.

Both Arnold's and Raab and colleagues' arguments above, however, were based on Pisias' (1978) core, which as described in Chapter 2 probably represented a much shorter period of time than originally thought. Kennett and Kennett's (2000) core, to review, indicated cooler SST AD 450-1450, stronger upwelling AD 950-1550, but greater variability overall AD 450-1300. Their interpretation that ocean conditions were still productive across those spans is supported by archaeological data from SBA-1731, one of the few sites on the mainland coast with later deposits stratified and relatively unaffected by gophers. Dating to AD 500-1600, faunal assemblages at SBA-1731 reflect abundant fish and marine mammals over that period, suggesting ocean conditions did not significantly deteriorate (Erlandson and Rick 2002; Glassow et al. 2007).

Kennett and Kennett (2000) argued that Chumash social complexity instead developed as a combination of competitive and cooperative responses to environmental variability. Both tactics are often brought to bear in times of resource scarcity. Increased population densities might constrain mobility and strain resources, thus promoting competition, but at the same time, lessen the costs of transporting goods, thereby encouraging cooperation. According to Kennett and Kennett (2000),

the proliferation of sedentary villages seen in the archaeological record reflects a certain degree of territoriality, and their locations near perennial streams would make sense in a context of highly variable and unpredictable climatic conditions. They also maintained that an assortment of osteoarchaeological data supported their idea that people were experiencing poorer health and struggling more to survive (Kennett and Kennett 2000).

Direct evidence from Santa Barbara Channel area human bones does reflect both increased violence and nutritional deficiencies over time. Sublethal cranial injuries increased slowly beginning c. 3050 BC, and Walker (1989) argued that the consistency of size, shape, and distribution of those injuries represents violent but non-mortal interpersonal disputes, which may have stemmed from competition over scarce resources. Lambert and Walker (1991) showed that lethal violence increased sharply AD 300-1150, based on a higher proportion of buried individuals with projectile points embedded in their bones.

Regarding nutrition, frequencies of dental caries from burials on Santa Rosa Island were much higher between 2050 and 1050 BC than they were after AD 130, suggesting a decrease in carbohydrate intake, and a lessened importance of plant foods in relation to marine fish through time (Lambert and Walker 1991; Walker and Erlandson 1986). Stable isotope analyses of burials on the mainland coast and interior also suggest increasing emphasis on marine foods, as $\delta^{15}N$ and $\delta^{13}C$ values are much higher in later sites than earlier ones (Walker and DeNiro 1986). Dental hypoplasias, which reflect times when a child's growth is interrupted by malnutrition or disease,

increased in frequency significantly between the Early and Middle Periods, then stayed relatively similar until c. AD 1500, at which point they increased again (Lambert and Walker 1991). On Santa Rosa and Santa Cruz Islands, Lambert (1993) interpreted decrasing stature and greater frequencies of periosteal lesions and dental hypoplasia as signaling higher rates of infectious disease and nutritional deficiencies over time. The greatest change in most of these health markers occurred during the Santa Barbara Channel's Middle Period, 1400 BC-AD 1150 (Lambert 1993).

Overall, growth problems and fewer carbohydrates suggests that resources in general were becoming less abundant in relation to human population size, thereby leading to greater focus on fish and resulting in nutritional problems. Since this trend started in the Middle Period, the emergence of social complexity in the Santa Barbara Channel area was probably not a response to sudden resource stress during the Medieval Climatic Anomaly.

Evidence also exists for social differentiation in the Santa Barbara Channel region as early as the Middle Period. The distribution of grave goods, especially shell beads, in burials from a Middle and Late Period cemetery at Malibu indicates social stratification even in the earlier graves (Gamble et al. 2001). People who were buried without grave goods had more enamel hypoplasias, and therefore probably worse living conditions compared to those buried *with* grave goods, and interestingly this stratification was more pronounced AD 950-1150 than it was AD 1775-1805. Gamble et al.'s (2001) evidence indicates that at least in Malibu, the hallmarks of ethnographic Chumash social complexity did not develop all at once during the Santa

Barbara Channel's Transitional Period. On the other hand, given that there is evidence for both nutritional deficiencies *and* social stratification beginning earlier than the Transitional Period, it is possible that they did still develop together, even if they were not precipitated by a dramatic climate shift.

Part of the discrepancy among the above researchers' arguments is due to which cultural behaviors they are emphasizing. Arnold and Graesch (2004), for example, responded to previous critiques by pointing out that the real hallmarks of sociopolitical and economic complexity that the Chumash exhibited at contact began in the Transitional Period. Before the Transitional Period, they said, no "reliable sign" existed of "chiefdomlike organization, complex socioeconomic relationships, or hereditary wealth and leadership on the Channel Islands" (Arnold and Graesch 2004:6). On the other hand, some studies have centered on when the first signs of social differentiation, nutritional stress, etc., began. With that focus, as Glassow et al. (2007:203) said, more recent research has shown that "the hallmarks of historically documented complexity [of the Chumash] are rooted in significant technological and demographic transformations beginning 4,000 years ago."

Both of these arguments could be correct. While certain traits of complex organization in the area may have begun during Santa Barbara Channel's Early or Middle Periods, the stresses of the Medieval Climatic Anomaly may have encouraged further degrees of complexity. In either case, the question still remains as to why Monterey Bay peoples appear to have dealt with population growth and climatic stress in a completely different way.

Central Coast and Inland

Jones (1993) originally proposed the Middle-Late Transition (MLT) for the Central Coast because of the difficulty identifying a break between the Middle and Late Periods. The MLT is now considered to last from AD 1000 to 1250 (Jones et al. 2007), and would overlap with the Medieval Climatic Anomaly (AD 800-1400 in California), so one might logically expect different human behavior during this period. However, Breschini and Haversat (2005) contended that, on the Monterey Peninsula, radiocarbon date clustering and continuity in *Olivella* type G bead use from AD 785 to at least AD 1320 indicate that the Late Period should instead begin c. AD 660, cutting out the MLT entirely. As discussed in Chapter 2, a scarcity of local paleoclimatic research in the Monterey Bay area means that no direct evidence exists there for the MCA. Breschini and Haversat's (2005) point may indicate that people on the Monterey Peninsula, at least, were little affected by poor terrestrial climate.

At the same time, while artifacts do not show abrupt shifts, major disruptions in settlement patterns and altered subsistence strategies between the Middle and Late Periods must be acknowledged. In general, the MLT in Monterey Bay reflects a change from large, year-round habitation sites to much smaller seasonal sites identified as coastal processing stations (Jones 1993). Numerous coastal sites inhabited in the Middle Period were abandoned during the Middle-Late Transition (Jones 1993; Jones and Ferneau 2002), or perhaps by AD 660 on the Monterey Peninsula (Breschini and Haversat 2005), and not reoccupied. By AD 1000, people no longer transported estuarine resources to the Santa Clara Valley, as inland groups

became fully sedentary and increased their exploitation of lacustrine habitat (Hildebrandt 1997; Jones and Ferneau 2002).

Archaeological data also show that, over time, people increased their use of resources that were more difficult to obtain or process, in at least some areas of the Central Coast and directly inland. Those living in Santa Clara Valley sites focused on wetland resources from nearby San Felipe Lake and apparently no longer transported bay mussels from the coast. Faunal assemblages from those sites also reflect decreased terrestrial game acquisition and increased lacustrine resource use over time (Hildebrandt 1997). Several archaeologists identified greater exploitation of smaller fish such as anchovies on the Central Coast (see Jones and Ferneau 2002; Jones and Kennett 1999), which Jones and Kennett (1999) believed represents dietary stress.

In the San Francisco Bay area, several types of evidence indicate people exploited more difficult to procure or handle resources over time, sometimes beginning much earlier than the MLT, but persisting through it. Wohlgemuth (1996) inferred that central Californians incorporated a wider variety of small seeds into their diet in the Late Period (Wohlgemuth 1996). Artiodactyl abundance declined compared to sea otters over the last 4,000 years (Broughton 1994), and percentages of sturgeon decreased compared to smaller fishes c. 900 BC–AD 1400 (Broughton 1997). The corresponding decrease in average age or size of sturgeon implies that the declining abundance was due to humans overfishing the sturgeon rather than marine environmental conditions (Broughton 1997). In the western and southern San

Francisco Bay during the MLT, people shifted from exploiting oysters and clams to more labor-intensive species like horn snails (Hylkema 2002).

Jones and Kennett (1999) maintained that changes in settlement patterns and subsistence along the Central Coast were influenced more by terrestrial drought than by decreased marine productivity. Because SST along Big Sur was slightly cooler than modern conditions, and the frequencies of fish remains per unit volume from archaeological sites did not show significant changes during the MLT and first 200 years of the Late Period, Jones and Kennett (1999) inferred that the ocean was still productive. While this may be an appropriate interpretation for the Central Coast in general, I argue that, because the ocean conditions of the Big Sur coast are not necessarily representative of Monterey Bay, simply looking at the density of fish remains in an archaeological site does not provide enough specificity to truly determine the nature of the marine environment people were exploiting. Instead, it is necessary to look in detail at which fish taxa people were exploiting, and whether these changed through time.

Jones and Ferneau (2002) have suggested that changes beginning in the MLT, c. AD 1000, and extending into the Late Period, represent what they call a "deintensification." In their view, population densities peaked during the early centuries of the MCA and then declined as drought conditions created food and water shortages. With fewer people on the landscape, they could become more mobile again and be more selective about which resources to exploit (Jones and Ferneau 2002). This may be represented at SLO-9, a site on the southern end of Morro Bay that

shows evidence of people exploiting fewer types of marine resources again, and focusing on those more easily harvested and processed (Codding and Jones 2007b). Along the San Simeon Reef between Big Sur and Morro Bay, more common but smaller and shallower sites also suggest human populations were fairly low and settlement strategies more mobile in the Late Period (Joslin 2010).

To Jones and Ferneau (2002), this deintensification – lower population leading to more mobility, decreased diet breadth, reduced exchange – could explain why major Middle Period sites like MNT-229 next to Elkhorn Slough appear to have been abandoned during the MLT. People may have moved to places with higher terrestrial productivity and fresh water at a time when many water supplies may have run dry, because they *could* move, rather than simply expanding their diet breadth to include more seeds and nuts in a diet already heavily dependent on fish (Jones and Ferneau 2002). On the other hand, coastal sites, and especially estuaries, would make good refuges if marine resources were still abundant and freshwater was available. This might be displayed in sites around Morro Bay, and at SLO-9, which was still occupied year-round in the MLT (Codding and Jones 2007b; Joslin 2010).

This possibility of deintensification does not extend to the whole coast, as it clearly did not occur in the Santa Barbara Channel, San Francisco Bay, or Northern Coast areas. Monterey Bay is in a complicated position, being close to the San Francisco Bay, but far enough to have its own, noticeably different cultural developments. Currently, research looking at the relationship between Monterey Bay and inland areas suggests a continued decrease in mobility during the Late Period. In

nearby Santa Clara Valley, sites emphasize local wetland resources rather than coastal ones, suggesting reduced access to Elkhorn Slough and a high degree of sedentism (Hildebrandt 1997). A lack of mobility is also exhibited by Sunseri's (2009) research on relationships between coastal and inland groups, which suggested that people controlled local resources, thereby increasing their need for exchange. Bone processing for marrow grease extraction escalated during the MLT, implying that people were working harder for their subsistence, and substantial exchange of a variety of goods seems to have been a major tactic for buffering against resource stress. However, although MNT-234 on the coast and SCL-119 inland may have specialized in the production of certain resources, social differentiation has not yet been identified archaeologically in this region as it has in northern and southern California (Sunseri 2009).

So far, then, the San Luis Obispo coast has provided more evidence for deintensification than the Monterey Bay area. I use fish remains in this dissertation to assess whether deintensification can be identified in marine subsistence during the Middle-Late Transition and Late Period along the Monterey Bay coastline.

By the Late Period on the Central Coast in general, the number of inland sites increased, displaying more stable occupations and a decreased reliance on fish. In contrast, the coastal sites are fewer, less visible – aside from abalone processing sites – and display less emphasis on marine resources, according to Jones and Ferneau (2002). Arrow points replaced the larger spear and dart points in the lithic assemblages, and bedrock mortars replaced bowl mortars (Jones 2002b). Human

isotope data from Big Sur suggests diets were more generalized, with more meat and marine resources than earlier periods in that area (Jones 1996). Based on Jones' (1996) figure, interestingly, the individual with the highest marine diet dated to the Middle-Late Transition, when terrestrial resources might have been less abundant. Four burials from the Late Period show slightly less emphasis on marine foods than the MLT individual, but still more than those from the Early and Millingstone Periods in that region.

Coastal California at Contact

Ethnohistoric and ethnographic accounts of the Santa Barbara Channel area and northwest California are fairly substantive, whereas those from Monterey Bay are relatively poor. This may be partly because the northern and southern regions were home to groups with more complex organization and other traits that explorers seemed to find more impressive than those along the Central Coast.

Northern Coast

By European contact, population density was high in northwestern California and people lived in permanent villages along coasts and rivers (Hildebrandt 2007; Hildebrandt and Levulett 1997). Communities had a strong sense of individual and family property rights, including for resource acquisition. Productive fishing places and beaches could be jointly owned, but hunting areas were always private (Whitaker 2008). Goods could be accrued, leading to differential wealth and power, and stratified social structures (Hildebrandt 2007; Hildebrandt and Levulett 1997).

Wealth acquisition can be directly related to the large redwood dugout canoes found especially with the groups north of Humboldt Bay. The Tolowa, Yurok, and Wiyot used oceangoing canoes the most, described as being up to 12.2 m long (Gould 1968) and large enough to transport marine mammals within them (Hildebrandt 1984). Construction of a canoe could take an entire year, requiring a significant labor force, which the canoe's owner was required to feed (Gould 1968). Given how expensive canoes were, they were typically owned only by wealthy village headmen (Gould 1968; Hildebrandt 1984).

The groups that used oceangoing canoes more extensively also made greater use of marine resources (Hildebrandt 2007). By contrast, cultures south of Humboldt Bay had more varied diets and emphasized acorns to a greater degree. They were also more mobile, with a seasonal round between the coast and the interior. All groups caught anadromous fish, especially salmon, but as with other aquatic resources, this was more prevalent north of Humboldt Bay (Hildebrandt 2007).

Santa Barbara

The Chumash at contact extended across the Santa Barbara Channel mainland, islands, and slightly north of Point Conception. Population densities were high, estimated at 20,000 people for the area, 14,000 of whom lived in coastal areas, especially around productive marine habitats with good boat launch locations (Arnold 2001a). Most individuals lived in villages of 150-250 people (Arnold 2001a), but five particularly large coastal "towns" may have held 6,000 people among them (Fages 1937 [1775]). A distinct hierarchical structure existed, with hereditary chiefs who had

some control over communities incorporating multiple villages (Arnold 1992, 2001a; Arnold and Graesch 2004). Chiefly power included that over war, and war appeared to be commonplace between villages (Fages 1937 [1775]).

Exchange was an integral part of Chumash interaction (Arnold 1992; Fages 1937 [1775]). The *tomol* facilitated the transport of goods between the mainland and islands, including trade with the Gabrielino-Tongva on the more southern Channel Islands (Arnold 2001a; Arnold and Graesch 2004). As on the Northern Coast, canoes were expensive to build, and elites controlled their construction and use (Arnold 1992). Though most exchange happened within the Santa Barbara area, a major trade route extended from the coast all the way into the American Southwest. For example, coastally produced *Olivella* shell beads are found in Colorado (Arnold and Graesch 2001). *Olivella* beads that source to either the Santa Barbara area or the Gulf of California are found in numerous sites all the way out to Oklahoma (Kozuch 2002).

Continuing from the Transitional Period, strings of shell beads were used as currency in the Chumash area, with their production specialized and limited mostly to the northern Channel Islands (Arnold 2001a; Arnold and Graesch 2001). Microlith production was also specialized and standardized, and they were made almost entirely on eastern Santa Cruz Island. Both of these goods were produced in "massive quantities" (Arnold 2001a:17).

Subsistence practices emphasized marine resources, especially on the islands, (Arnold 1992). Fages (1937 [1775]:35) noted that fish were extremely abundant, and could feed "all the settlers which this vast stretch of country could receive." Unlike

the rest of California, where people tended to use nets, weirs, and poison, the Chumash mainly used fish pots (Menzies 1924), and circular shell fishhooks (Kroeber 1971) made mostly from mussel and red abalone (Arnold and Graesch 2001). The *tomol* made fishing in open water possible, and the Chumash were known to capture such large pelagic fishes as swordfish (Davenport et al. 1993; Pletka 2001).

Overall, the Chumash were well established in large villages with complex economic structures and sociopolitical organization by the time Europeans arrived. Similar to the Northern Coast, they had a strongly maritime-oriented diet, facilitated by the use of oceangoing canoes. All of these traits contrast with the Central Coast at contact.

Central Coast

While ethnohistoric accounts of central California exist, Jones and Ferneau (2002:207) described the record as "woefully incomplete and biased." In depth studies of the Central Coast cultures did not occur until the 1900s, after Missionization and disease drastically decreased the indigenous populations (Jones and Ferneau 2002). I include here a discussion of the ethnographic and ethnohistoric sources for the Central Coast, but with the understanding that almost all of our data come from contexts in which indigenous lifeways were already dramatically affected.

Early historic records suggest European observers considered Central Coast Native Americans to be simpler, less industrious, and less impressive than groups on the Northern and Southern Coasts. An account by Fages (1937 [1775]:65), for example, expressed how "…these unhappy people…undergo great hardship,

especially in winter, lacking even the few fish which during the rest of the year they obtain more through its abundance than by their own industry." Central Coast "tribelets" did have relatively less sociopolitical complexity, smaller villages, and simpler boats. However, some accounts depicted a surprising degree of differential wealth, ascribed status, and complex organization (Jones and Ferneau 2002).

About 50 tribelets existed between southern San Francisco Bay and Monterey Bay, and each of those could comprise multiple villages (Ginn 2009), which were divided into clans and thence into moieties (Jones 2002b). Villages and village groups were autonomous, but chiefs could hold leadership positions over multiple villages, and chiefly status was hereditary (Harringon 1942; Jones and Ferneau 2002; Milliken 1988). Fages (1937 [1775]:67) explained that Monterey Bay peoples did "not have fixed places for their villages, but wander here and there wherever they can find provisions at hand," though archaeologists have argued for fairly permanent settlements with some seasonal movement (Breschini and Haversat 1992; Ginn 2009; Jones and Ferneau 2002; Jones et al. 2007). For the Elkhorn Slough area, Milliken (1988) contended the ethnohistoric data reflect two different political groups of 250-350 people each, who used the slough as a boundary between their territories.

Native Americans in the Monterey Bay area used rafts and boats made of tule reeds balsa (Jones 2002b; Jones and Ferneau 2002), as did groups all along the California coast, except for the two areas described above (Kroeber 1971). Tule balsas were used mostly close to shore and in quiet water, which also lent itself to fishing with nets and seines rather than with hook-and-line (Kroeber 1971). Though

not for use on the open ocean, they could still transport people to nearshore rocks to catch sea lions (Kroeber 1953). Tule balsas were clearly quite functional in the tasks for which they were used, and certainly facilitated catching fishes from habitats such as kelp forests.

Subsistence at contact included a very wide variety of foods (Ginn 2009; Jones 2002b; Jones and Ferneau 2002; Jones et al. 2007; Milliken 1988). In 1770, Juan Crespí reported "so many large sea shells that many double-hundredweights' worth could be gathered" (Crespí 2001 [1770]). Shellfish were a major part of the diet according to Menzies' account of the Vancouver expedition in 1790-1794. Women collected shellfish while men hunted small game with bows and arrows (Menzies 1924 [1794]). Women also harvested plants and prepared food, while men hunted, trapped, and fished for a variety of mammals and birds (Milliken 1988). Acorns were another major food source, though Kroeber (1953) mentioned seeds were commonly used right on the coast. Ethnographic informants said fishing techniques included spears and poison, and bonfires would be used to fish at night (Harrington 1942). Nets and weirs or poison were apparently more common along the California coast than fishing by hook and line, except in the Santa Barbara area (Kroeber 1971). Finally, while Native Californians did not begin agriculture before European contact, they did use fire to manage the landscape and their resources. On the Central Coast, they burned land to encourage grass and flowers to grow, so they could collect seeds, provide habitat for rabbits, and flush game out for hunting (Silberstein et al. 2002).

Long-distance connections with other regions are evident from both goods and the trade routes on which they traveled. For example, shell disk beads of both *Olivella* and clam were used as currency along the whole Central and Southern Coast (Harrington 1942; Kroeber 1942, 1953; Milliken 1995). Shell beads do occur in the archaeological record, but the timing of initial use as currency is unclear. Sunseri (2009) argued that they might have been prestige goods without specific function as currency. In either case, their long-distance exchange is rooted at least as far back as the Middle Period, as isotopic analyses of Middle Period and Middle-Late Transition beads in Monterey Bay show they came from both northern and southern California (Sunseri 2009). Beads and other goods were transported along major trade routes connecting the coast to interior, and different areas of the coast. In the Monterey Bay area, for instance, a major trade route connected Elkhorn Slough and the Pajaro Valley to the Central Valley (Sunseri 2009).

The combination of hunting and gathering with some degree of complex intra- and inter-group relationships is somewhat unusual. Jones et al. (2007:129) stated that, "The greatest conundrum in Central Coast ethnohistory is reconciling apparent bandlike subsistence practices with early accounts of ascribed political power, highly formalized leadership statuses, economic redistribution, and widespread warfare."

Summary

The three regions of coastal California I have discussed clearly utilized the marine environment in varying ways. In some cases, such as the development of

oceangoing canoes, the degree of wealth and status differentiation, and the increasing use of marine resources over time, the northern and southern areas were most similar. However, Monterey Bay and the Santa Barbara Channel both had a much more heavily marine subsistence to start with, and exploited nearshore fish and shellfish to a considerable extent early in the human occupation of the coast.

Despite similarities between the Monterey Bay and Santa Barbara Channel areas, their historical trajectories differed. Difficult climatic regimes during the Medieval Climatic Anomaly are employed in Santa Barbara Channel research to help explain why the local indigenous groups developed into a complex society (e.g., Arnold 1992, 1993, 2001b; Kennett and Kennett 2000; Raab and Larson 1997; Raab et al. 1995). Fishing conditions, whether good or bad, have been part of these arguments, and evidence from burials shows that consumption of marine foods increased over time (Lambert and Walker 1991; Walker and DeNiro 1986; Walker and Erlandson 1986). One argument holds that poor ocean conditions may have led to subsistence stress, and subsequently encouraged the development of buffering tactics such as increased exchange, controlled by emergent elites (e.g., Arnold 1992, 1993). Another maintains that variability in both the marine and terrestrial environment led to cultural responses resulting in a high degree of sociopolitical complexity (Kennett and Kennett 2000). In both of these cases, the quality of fishing is an integral part of the ocean's environment.

Though similar climatic stresses probably affected the Central Coast, and though Monterey Bay has just as abundant marine life, if not more, indigenous

societies did not reach a level of complexity comparable to Santa Barbara by European contact. Sunseri (2009:219) pointed out that we should not assume groups would respond in parallel ways, since people live in diverse "historical and ecological circumstances." That Native Californians in the Monterey Bay adapted to their circumstances in a different way than the Chumash is part of what makes the area interesting.

Despite the prevalence of marine resource use throughout California's prehistory, specific discussions of how fishing fits into the cultural developments of the Central Coast are scarce. In this dissertation, I show how detailed understanding of ocean exploitation over time and space can elucidate how people adapted to their changing ecological and cultural contexts. In the next chapter, I provide a theoretical framework for analyzing and understanding human subsistence strategies.

CHAPTER 4

Human Behavioral Ecology and Dynamic State Variable Modeling

In North America, both ethnographic and archaeological research on hunter-gatherer subsistence are often studied through the use of human behavioral ecology (HBE), an application of evolutionary ecology to human behavior that focuses on how behavioral choices maximize reproductive success (fitness). Evolutionary ecology concentrates on the interaction between organisms and their environment, and characterizes actions and decisions in terms of a currency. The currency may change depending on the research question but must be related to fitness, or is assumed to be a proxy of fitness. By assuming that evolution will select for behaviors that maximize a certain currency and hence reproductive success, HBE researchers can make predictions about human behavior in a given situation. In particular, behavioral ecology is interested in determining the underlying functional basis of specific behaviors (Cronk 1991).

In this chapter, I first outline the basic principles and mechanisms on which evolutionary ecology is based and how those manifest in human behavioral ecology. The application of evolutionary ecology to humans is controversial, but Bright et al. (2002) reasonably suggested that, rather than assuming evolutionary ecology cannot be used for humans because we are "different," we should ask *how* humans are different, and which observations of the animal community can inform studies of humans and which cannot. When human behavioral choices and their outcomes

cannot be explained by HBE predictions, it provides a strong case for seeking causation in other areas of human existence.

After the broader discussion of HBE, I cover tests and critiques of optimal foraging models, especially those where ethnographic and experimental research has begun to highlight places where assumptions should be challenged. I then summarize the HBE theoretical approach as used in California archaeology, which has become more sophisticated over the past twenty years, but still needs to incorporate methodological advances in ecology. Therefore, in the final part of this chapter, I introduce a more nuanced approach to optimal foraging called dynamic state variable modeling, which was developed and has been used in ecology since the late 1980s. However, this approach has not yet been applied in archaeological studies. In Chapter 8, I develop and apply a dynamic state variable model to examine subsistence choices in coastal California.

Evolution

Evolutionary change is produced by natural selection acting on existing genetic variation in a population, at least some of which must be heritable, thereby increasing the proportion of individuals best adapted to the current environmental circumstances (Krebs and Davies 1993). Individuals compete for food, mates, and shelter from predation and other adverse conditions; better competitors have more offspring, thereby increasing the proportion of their traits in the population. As a product of such evolutionary change, organisms will " be adapted to their

environment" (Krebs and Davies 1993:9). Despite a long history of debate about the importance of group selection and kin selection (see S. West et al. 2007 for discussion of history and terminology issues), most researchers at least agree that selection is *strongest* at the individual level (Cronk 1991), and that many adaptations that superficially appear to be group selection can also be explained at the level of individual selection (e.g., Williams 1992).

Although the appropriate measure of Darwinian fitness is the long-term representation of an individual's genes in the gene pool (Clark and Mangel 2000), fitness is often defined as the total reproductive output of an individual. Since the actual number of offspring varies significantly based on situation, fitness is normally calculated as the expected number of descendants (Smith and Winterhalder 1992).

Optimal reproductive strategies vary according to many factors, but the sex of an individual has long been recognized as playing a disproportionate role (Krebs and Davies 1993). Males produce numerous, small gametes, whereas females produce comparatively fewer, larger ones. As a result, males are limited in their reproductive success by the number of females with which they can breed, while females are limited by available resources and the rate at which they can convert those resources into offspring. Principles of behavioral ecology thus predict that females invest in parental effort, while males put energy into seeking mating opportunities (Krebs and Davies 1993). Therefore, behavioral ecologists see each species' reproductive patterns as partly the outcomes of these two disparate and sometimes conflicting strategies. Anthropologists have occasionally applied this concept to humans, to

address such topics as foraging behavior and food sharing (e.g., Bird 1999; Hawkes 1991).

In fact, theorists view all biological strategies that maximize fitness as a balance among tradeoffs (Hawkes 1993; Hill and Kaplan 1999; Krebs and Davies 1993). Growth and reproduction represent one such tradeoff: larger individuals have lower mortality rates, so they have longer time-spans within which to reproduce, but investing energy into growth detracts from their current reproductive output and it may be very risky to become large (Mangel and Stamps 2001). Significantly investing in just a few offspring will result in a lower mortality rate for those offspring, but will also lessen the total reproductive output of the parent (Hill and Kaplan 1999; Krebs and Davies 1993). One of the main reasons the optimal balance between growth and reproduction will vary by species, according to Hill and Kaplan (1999:406), is that each species has different mortality rates, due to "predation, disease, intraspecific violence, accidents, [and] starvation." For example, a captive study comparing chimpanzees and bonobos found that chimpanzees displayed higher infant mortality accompanied by younger age at first birth and shorter inter-birth intervals, versus the lower infant mortality and longer inter-birth intervals of bonobos (de Lathouwers and van Elsacker 2005).

Human Behavioral Ecology (HBE)

HBE is included in evolutionary ecology and is defined by Winterhalder and Smith (1992:3) as "the study of evolution and adaptive design in an ecological

context." Evolutionary ecologists believe natural selection works on variation in both genetic and behavioral traits, since both can affect an individual's fitness and the survival of its genetic line (Winterhalder and Smith 1992; Smith 1983).

Optimality models bridge the gap between the theory of natural selection and what happens in nature by significantly simplifying systems and comparing specific strategies to one another (Smith and Winterhalder 1992). Such models usually concentrate on an actor faced with a set of choices and constraints (Cronk 1991) and are used to predict the actor's optimal behaviors, which can then be tested (Shennan 2002). They can be used to explain why variants exist and why selection favors certain variants over others. Though optimality models, by their simplifying nature, will exclude some factors that may influence behaviors, they are still frequently successful in their predictions (Clark and Mangel 2000; Smith and Winterhalder 1992).

In HBE, the environment to which behaviors are adaptive includes social and cultural circumstances (Cronk 1991). Researchers have used HBE to explain subsistence choices (Broughton 1994, 1997, 2002; Burger et al. 2005; Butler 2000, 2001; Codding and Jones 2007b, 2010; Codding, Porcasi, and Jones 2010; Hawkes and O'Connell 1985; Hawkes et al. 1982; Kaplan and Hill 1992; Keegan 1986; Sih and Milton 1985; Winterhalder and Bettinger 2010), food sharing (Bliege-Bird and Bird 1997; Hawkes 1992; Kaplan and Hill 1985), processing and transport (Bird et al. 2002; Burger et al. 2005; Metcalfe and Barlow 1992), reproductive decisions (Borgerhoff Mulder 1992), mobility (Bonzani 1997), inheritance patterns (Mace

1998; Smith et al. 1987), parental investment (Bird 1999; Borgerhoff Mulder 1992; Hawkes et al. 1997), sexual division of labor (Bird 1999; Bliege-Bird 2007), and costly signaling (Hildebrandt and McGuire 2002, 2003; McGuire and Hildebrandt 2005; McGuire et al. 2007) among other behaviors (Bright et al. 2002; Mace 1993; Mace and Houston 1989; Winterhalder 1997).

Though many applications of HBE to subsistence focus on foraging, anthropologists have applied the theory to other subsistence strategies such as pastoralism and horticulture, by measuring tradeoffs between sedentism and mobility (Cronk 1991). Mace (1993), for instance, used optimality modeling to predict under what conditions herding, farming, grain storage, or some combination of these strategies would be adopted among African pastoralists. Here, I focus on applications of HBE to food-related research questions, first reviewing the most frequently used models in anthropology, then discussing some of the problems with the way these models are constructed and ways to address them.

Optimal Foraging Theory (OFT)

OFT denotes a specific application of the principles of behavioral ecology to resource acquisition, usually of food, using mathematical or graphical models to predict strategies that result from balancing tradeoffs such as those mentioned above (Smith 1983). According to OFT, selection will favor subsistence strategies that maximize an individual's fitness (Kaplan and Hill 1992; Smith 1983) by one of a number of means. OFT requires defining actors, decisions, currencies, and constraints

(Kaplan and Hill 1992; Shennan 2002; Smith and Winterhalder 1992). Frequently studied decisions include prey choice, patch choice, habitat choice, time allocation to foraging in a patch, when a forager will change resource patches, and foraging group size (Clark and Mangel 2000; Cronk 1991; Mangel and Clark 1988; Pyke 1984). Anthropological models do not directly measure fitness but, consistent with early development in behavioral ecology, have traditionally used the rate of caloric return as a proxy for fitness, in which case calories are the defined currency.

For each resource, energy is gained from the prey, and energy expended includes the caloric expense of searching for, pursuing, and handling the prey (Boone 2002; Bright et al. 2002), though in some models, search time is not included. Bright et al. (2002) defined search time as that time spent looking for prey, and handling time as including both pursuit and processing time. Pursuit time is measured from the moment when an acceptable prey is discovered until it is caught, while processing includes any actions necessary before the prey can be consumed (Bright et al. 2002). Prey items are ranked according to their profitability, the total rate of return from acquiring the prey per unit of time (e.g., calories/hour).

The OFT models most applied in archaeology analyze prey choice (diet breadth), patch choice, and central place foraging decisions. The classic diet breadth model is a rate-maximizing one, which aims to predict which resources a predator will include in its diet by ranking prey species according to their rates of energetic return.

Charnov (1976a) originally crafted the prey choice model in equation form, first by calculating the net rate of energy intake ($\Re$) as follows, where,

λ_I is the rate of encounter for prey type *i*,

E_i^* is the expected energetic return for prey type *i*,

h_i^* is the expected handling time for prey type *i*, and

P_i is the probability a predator pursues prey type *i* when encountered:

$$\Re = \frac{\sum \lambda_i E_i^* P_i}{1 + \sum \lambda_i h_i^* P_i} \tag{4.1}$$

P_i values are then chosen to maximize the long-term rate of energetic return and three important predictions emerge (Clark and Mangel 2000; Mangel 2006). First, prey types are ranked by their individual profitabilities $\frac{E_i}{h_i}$. Second, prey choice has a sharp boundary, in that prey are either always included in the diet or always excluded, i.e., P_i =1 or P_i =0 respectively. Prey type *i* is included if $\frac{E_i}{h_i} > \Re$. Third, the encounter rates with excluded types do not affect the forager's prey choice.

The diet-breadth model describes the circumstances under which a forager is predicted to exploit specific resources. The forager is predicted to always take high-ranked resources upon encounter, but whether she takes low-ranked resources depends on the abundance of higher-ranked taxa (Broughton 1994; Hawkes & O'Connell 1992; Mangel 2006). If high-ranked taxa are abundant, then a predator has

a higher overall rate of return if it passes over the lower-ranked prey and continues searching for the higher-ranked ones. The scarcer higher-ranked taxa are, the more likely a predator will pursue lower-ranked prey, given the added search time and opportunity cost this scarcity entails. Based on this rate maximizing model, the forager takes lower-ranked taxa only when their energetic return per unit handling time exceeds the average rate of return of all higher-ranked prey items. As a result, the forager's diet breadth is predicted to expand when higher-ranked resources become less abundant. This model, while providing insights into prey choice, assumes that all prey are evenly distributed across the landscape and are encountered randomly within it (Boone 2002; Hawkes & O'Connell 1992; Smith 1983).

Patch choice models, on the other hand, acknowledge the spatially uneven distribution of many resources, and predict when a forager will switch patches (Mangel 2006). The Marginal Value Theorem, originally developed by Charnov (1976b), and graphically represented in Figure 4.1, is used to predict the optimal residence time in a patch. In this model, one assumes that foraging in a patch will deplete it, necessitating movement to another patch (Charnov 1976b; Smith 1983; Sosis 2002). Marginal rates of energetic return are measured as the rate of return for the last resource exploited before moving to another patch becomes more advantageous (Smith 1983). Exit from the current patch is predicted to occur when the marginal rate of return for the current patch becomes lower than the mean rate for all patches, when travel costs are incorporated (Smith 1983). Although the optimal

residence time can be calculated using elementary calculus, the prediction of the MVT can be captured using the geometry of the gain curve (Figure 4.1).

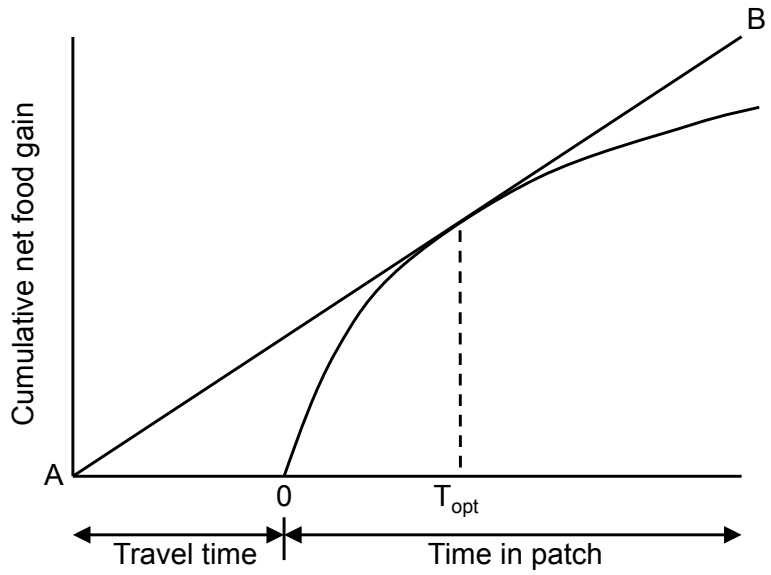


Figure 4.1. Marginal Value Theorem. Line A-B represents the average rate of return of all patches. T_{opt} is the optimum length of time to spend in a patch to maximize overall rate of return (adapted from Smith and Winterhalder 1985).

Central place foraging models focus on foragers who leave a "central place" to acquire resources and then return to that place again when finished foraging, as is common among humans (Kaplan and Hill 1992; Schoener 1979). Resources do not have to be limited to foods, and both prey and patch choice decisions can be affected by central place foraging behavior (Bettinger et al. 1997). These models predict that, as distance increases between the places of acquisition and use, optimal foraging behavior will change. For example, larger prey items are usually needed to justify longer travel times (Bettinger et al. 1997; Kaplan and Hill 1992), though Schoener's

(1979) original equations show that this is only true if larger prey items do not require more time to pursue or transport.

Processing to remove the less valuable pieces of a prey item will also increase with distance from the central place, to lessen transportation costs. Frequently, the major tradeoff in a central place foraging model is between processing time and transport time (Bettinger et al. 1997). Other transport costs include the weight of the resource being transported, terrain variation, and specific caloric costs of travel per unit distance (Brannan 1992). For resources with parts of differential utility, such as shellfish or nuts, Metcalfe and Barlow (1992) found that the most important predictors of the degree of in-field processing were transport time and its relationship to field processing time and effort.

These OFT models typically assume that foragers have complete information about their environment. While some researchers criticize this assumption (e.g., Sih and Milton 1985), it is more likely to be correct for humans than for any other species (Kaplan and Hill 1992). Humans can communicate and pass information quickly and across long distances, allowing individuals to track environmental changes in detail over large areas (Kaplan and Hill 1992).

Archaeological Applications of OFT

As noted above, in ethnographic studies, net rate of energetic return is often used as a proxy for fitness. Since archaeologists cannot directly observe prehistoric human behavior or prey caloric yield, prey size is frequently employed as a substitute for rate of return, along with consideration of factors like available technology or ease

of capture (Broughton 1994, 1997, 2002; Butler 2000, 2001; Butler and Campbell 2004; Kopperl 2003; Nagaoka 2001, 2002a, 2002b; Whitaker 2010). However, ethnographic and experimental research has expanded our understanding of rates of energetic return and prey rankings significantly over the last several years (Bird et al. 2004; Bliege-Bird 2007; Bliege-Bird and Bird 1997; Hawkes et al. 1982; Jones 2004; Jones and Richman 1995; Lindström 1996; Simms 1985; Sosis 2000, 2002; Ugan 2005). Such research is discussed in more detail in the next section, but reveals the importance of taking into account such traits as prey mobility or nutritional content when ranking resources.

Archaeological applications of OFT approaches are further complicated by the fact that archaeologists usually cannot distinguish between individual foraging events. Broughton (1994) argued that, since archaeological cases represent the aggregate outcome of multiple foragers, foraging events, and exploited patches, we should consider these as the results of a "collective predator" exploiting one large patch.

If a taxon in an archaeological assemblage is known to be found in numerous patches in documented history, the specific patch from which humans acquired it cannot be determined (Yesner 1985). Coyotes, for example, can be found in practically any habitat, from open areas to forest, coasts or inland. As a result, patches must be defined so as to be relevant to the research question and to group taxa into reasonable sets. Using more specific, smaller patches can actually cause more overlap in which species are available, thus making patches impossible to identify archaeologically (Yesner 1985). Therefore, most archaeologists using patch choice

models define general patch types from which a range of species could be exploited. For example, Kopperl (2003) described riverine and marine patches, Butler (2001) divided fishing patches into freshwater and marine, and Nagaoka (2001) simply used "inland" and "coastal" patches. Broughton (2002) recently defined patches by dividing species into categories of similar acquisition techniques, placing terrestrial mammals, estuarine fishes, and waterfowl into three distinct categories.

Most frequently, prey and patch choice models are used archaeologically to assess the presence of resource depression. At least three types of resource depression are identified, which have different effects on the prey population and archaeological signature:

1) *Exploitation depression* refers to cases in which predation causes a decrease in prey populations (Lyman 2003). Assuming people initially target larger individuals, and that they continue to exploit that same resource, then overexploitation will lead to an overall decrease in the size and/or age of captured prey, because they will be harvested before they have reached full size (Butler 2001; Broughton 1994). In some cases, human exploitation does not affect the prey population numbers, but does cause lower rates of encounter with prey.
2) *Behavioral depression* refers to prey taxa changing their behavior to lower rates of encounter with predators, such as by being more alert or changing the time at which they themselves forage (Broughton 2002).

3) *Microhabitat depression* occurs when prey animals spatially shift where they breed, feed, etc., away from the predator (Lyman 2003). For example, nesting seabirds may move from mainland to island colonies to protect their young from exploitation. Unlike exploitation depression, this behavioral change could potentially lead to an increased relative proportion of adults available to humans, and therefore a higher mean age and size of captured individuals (Broughton 2002).

Because OFT predicts that foragers will take higher-ranked prey first, and exploitation depression is the most common form studied, archaeologists typically identify resource depression by a declining proportion of high-ranked to low-ranked taxa and a decrease in mean prey age and/or size over time in archaeofaunal samples.

The most common method for assessing resource depression is to look for changes in species proportions using taxonomic abundance indices, usually displayed as:

$$\frac{\sum \text{NISP high-ranked taxa}}{\sum \text{NISP high-ranked taxa} + \sum \text{NISP low-ranked taxa}} \qquad (4.2)$$

Archaeologists have employed such abundance indices to argue for resource depression of sturgeon, elk, and geese in San Francisco Bay (Broughton 1997, 2002), mammals along the lower Columbia River (Butler 2000), moas and fur seals in New Zealand (Nagaoka 2001, 2002), serranid fishes in Mangaia (Butler 2001), sea mammals and salmon in Alaska (Kopperl 2003), and nearshore fishes in the Santa Barbara Channel (Rick and Glassow 1999).

Though these studies interpreted declines in abundance indices as representing decreasing rates of return, Codding, Bird, and Bliege Bird (2010:3206) recently marshaled ethnographic data to show that "the effect of large prey hunting on [an abundance index] is mostly a function of hunting bout success while the effect of small prey is mostly a function of foraging time." Maintaining a high abundance index over time can only occur when the acquisition of large game is reliable (Codding, Bird, and Bliege Bird 2010). The authors also suggest that risk of failure needs to be more formally considered in abundance index interpretations (Codding, Bird, and Bliege Bird 2010). While I do not use traditional abundance indices here, the dynamic state variable model I develop in Chapter 7 incorporates the probability of success or failure when foraging, and also produces results that highlight the importance of this variable.

Species richness, evenness, and diversity are other mathematically based approaches used to describe and assess change in an ecological community or a zooarchaeological assemblage. Richness represents the number of taxa present, whereas evenness refers to how individuals are distributed among the different taxa. Diversity indices combine richness and evenness to quantify heterogeneity, what Reitz and Wing (1999:105) describe as, "the amount of uncertainty of predicting the identity of an individual picked at random from the community." While these indices can be used to examine diet breadth and how it changes over time, the taxonomic abundance index above, as used archaeologically, specifically compares two ranked groups of resources.

In addition, many archaeologists invoke *resource intensification* as an explanation for patterns in the archaeological record. While resource depression refers to a change in the prey population levels due to human behavior, intensification describes an increase in foraging effort. As Broughton (1997:846) stated, resource intensification is "classically defined as a process by which the total productivity or yield per areal unit of land is increased at the expense of declines in overall caloric return rates, or foraging efficiency." In such a case, higher productivity results from putting in more effort per unit time and area (Butler and Campbell 2004). However, Butler and Campbell (2004) noted that, on occasion, researchers have used intensification to mean changing subsistence practices to acquire more resources with the same effort.

Though often undefined in California archaeological literature, resource intensification in regards to mobile prey seems to most frequently describe putting more effort into exploiting declining prey populations, whether that decline results from human or environmental factors. Intensification of plant use, however, typically refers to increasing the productivity of a given area of land, such as by influencing habitat to encourage better plant growth. For example, Wohlgemuth (1996) discussed how small-seeded plants grow well in disturbed areas, and thus burned or cleared habitat can support higher populations of those species.

Tests and Critiques of Optimal Foraging Theory

Though frequently used in anthropological and ecological studies of subsistence, OFT has been criticized for oversimplifying the factors underlying subsistence behavior. Of course, all science must simplify, hence it is important to ask what we can learn from such simple models and their extensions (e.g., Clark and Mangel 2000; Winterhalder 2002). When assessed with ethnographic data, diet breadth models are most accurate in predicting which resources out of a selection of similar goods will be exploited, and least accurate when comparing different broad food categories (Kaplan and Hill 1992). Such research has revealed a number of potentially confounding factors. Most importantly, prey body size is only one of many variables that people consider when choosing which resources to exploit. Others include the following.

1) *Nutrition.* Currencies other than calories may be more appropriate for determining why foragers rank particular resources higher than others (Kaplan and Hill 1992; Martin 1983; Outram 2004; Sih and Milton 1985). Many humans and nonhuman primates have been observed to pass over resources with higher caloric values in favor of foods with lower caloric but higher protein and fat content (Kaplan and Hill 1992; Keegan 1986; O'Connell and Hawkes 1981; Sih and Milton 1985). Animal research has shown that nutrients can affect food preferences, individual growth and maintenance (Pyke 1984). For example, the Aché hunter-gatherers chose dietary items that were suboptimal in terms of caloric return, but, according to researchers, probably selected those foods because they provided a better balance of

nutrients (Kaplan and Hill 1992). Behavioral ecologists have noted similar behavior in animals, such as moose around Lake Superior, which ate aquatic plants with low caloric value to obtain sufficient sodium (Krebs and Davies 1993).

Though including nutrients may make models more complex (Hawkes and O'Connell 1985), they play a very important function in human biology. Adult humans require 2200-2900 kcal of energy per day (Gebhardt and Thomas 2002), and a mixture of fat, protein, and carbohydrates (Otten et al. 2006:70). However, foragers in strongly seasonal environments seldom have a "balanced diet" day to day and instead store energy in the form of adipose tissue when they are able to consume more than maintenance levels of calories (Speth and Spielmann 1983). For hunter-gatherers in strongly seasonal contexts, carbohydrates are rare on the landscape, and fats are an important source of easily digested calories (Outram 2004; Speth and Spielmann 1983). Fats are especially important in lean seasons, because consumption of very lean meat, in combination with low carbohydrate intake, can lead to increased hunger, protein poisoning, and even death (Speth and Spielmann 1983). Essential fatty acids (EFA) require external sources because they are not created by the body, and deficiencies can lead to major developmental pathologies (Alfin-Slater and Aftergood 1980). EFA are particularly relevant to this dissertation, because oily cold-water fishes, along with nuts, seeds, and leafy green vegetables, are a major source.

In fact, research findings are emerging that suggest polyunsaturated fatty acids (PUFA) and other nutrients found in aquatic foods probably played a major role in the evolution of the human brain. Long-chain DHA (docosahexaenoic acid) is the main

PUFA found in vertebrate brains and is far more common in aquatic than terrestrial foods (Brenna 2010; Crawford 2010). Iodine, iron, copper, selenium, and zinc are also brain-selective nutrients, meaning that they are necessary for successful brain development (Cunnane 2010). These are also found in much higher levels in aquatic foods, and Cunnane (2010:35) described shoreline habitat as having "the richest source of brain-selective nutrients available in any known ecosystem." Overall, human brains require a certain selection of fatty acids and minerals to develop and operate, and the modern human brain probably did not evolve until hominids started using easily harvested food sources from a habitat that provided these nutrients in abundance – the shoreline (Crawford 2010; Cunnane 2010; Cunnane and Crawford 2003; Muskiet and Kuipers 2010). Clearly, nutritional content cannot be ignored as a factor in human subsistence choice.

Nutrient levels can be incorporated into models as constraints, even if we cannot determine exactly how much of a nutrient a human individual needs to ingest daily. Pyke (1984) noted that adding nutritional requirements as constraints significantly changes some predictions of OFT. In particular, rather than moving down a clearly ranked list of foods, foragers instead display "partial preferences," and a food type will be taken partially based on its own abundance, not just that of more preferred resources.

2) *Environmental Conditions.* Foragers also may take into account environmental conditions on a daily basis. When patches are ranked by rate of caloric return, ethnographic studies typically find that foraging groups emphasize the

highest-ranked patches, but also forage in lower-ranked patches. For example, studies of the Inujjuamiut of Arctic Canada suggested they considered the weather's effect on patch profitability when exploiting what were defined as lower-ranked patches (Kaplan and Hill 1992). Ifaluk fishers from the Caroline Islands, in the Federated States of Micronesia, sometimes fished in lower-ranked patches, but only when profitability in the higher-ranked patch was expected to be low, such as when the previous day's rate of return from the high-ranked patch was lower than the expected mean rate of all patches combined. Therefore, each decision of where to fish was based on recent experience of patch profitability, which varied (Sosis 2002). In Australia, Alyawara hunters usually picked patches on average more productive for hunting, but still spent time in less profitable patches. Decisions to hunt in places with lower average rates of return seemed to occur when environmental conditions were poor for hunting elsewhere (O'Connell and Hawkes 1984). In all of these contexts, researchers assumed the foragers were still maximizing their caloric rate of return, but were using their knowledge of the environment to re-rank prey in the moment.

3) *Mass Capture.* Mass capture refers to catching multiple prey items at one time, such as fishing with nets, or driving bison into a trap. When it represents a more efficient foraging strategy, mass capture can move smaller prey from lower to higher ranks as food resources (Cannon 2000; E. Jones 2004; Lindström 1996; Madsen and Schmitt 1998; Schmitt et al. 2004). However, if processing multiple individuals at once does not decrease handling costs, mass capture may not result in increased rates of energetic return (Ugan 2005). Especially relevant to this dissertation is the mass

capture of small schooling fishes, given their predominance in Monterey Bay area archaeofaunas. These can be captured in bulk and eaten whole, thereby significantly reducing processing costs (Lindström 1996).

When the costs of manufacturing capture technologies are taken into account, fishes are often higher ranked by energetic return than are terrestrial resources (Lindström 1996). Moreover, netfishing can provide higher rates of return than hook and line or spear (Codding and Jones 2007b; Ugan et al. 2003).

Out of a wide range of foraging activities on the shore, the Meriam of Melanesia have a far higher rate of return from netting sardines than from any other type of fishing or shellfish collecting (Bliege Bird 2007). Using mathematical models, Ugan et al. (2003) argued that more total hours have to be spent fishing with a net to compensate for the time spent making it, so nets would be less justified when trying to capture small numbers of fish. However, Bettinger et al. (2006) noted that fishing technologies are not different versions of one another that can be compared as if they were ordered on a spectrum. Instead, various fishing methods allow access to diverse habitats, and each kind of method has its own cost-benefit function. As a result, the cost-benefit analysis of netting and hook-and-line fishing, for example, should be modeled separately and then compared, rather than ranking them against each other (Bettinger et al. 2006).

In summary, these analyses indicate that resources cannot be ranked simply by body size, even when working within models that assume maximization of rates of energetic return.

4) *Mobility of Prey.* Using body size as a proxy for energetic return is also problematic because the mobility of prey typically scales with body size, and mobility decreases a prey item's rate of return (Bird et al. 2009; Sih and Christensen 2001). This holds true even post-encounter. For instance (Bird et al. 2009:18), the Martu of Australia often hunted for highly mobile prey that have high variance in success rate, but they did *not* choose to go after those prey if they were encountered while out "foraging for daily provisions…[because] the risks from pursing these larger game are too costly." Risk, in this case, refers to the probability of failing to catch the prey. This type of ethnographic research shows that the probability of successfully catching prey *after* encounter, not just finding prey in the first place, is very important in forager decision-making about prey ranking (Bird et al. 2009). In fact, Bird et al. (2009) note that consideration of prey mobility and pursuit success leads to a complete lack of correlation between body size and post-encounter rate of return.

5) *Food Sharing.* Human food sharing is not easy to explain evolutionarily, and researchers have suggested sexual division of labor, genetic relatedness, risk, and uncertainty as reasons for sharing food in specific circumstances. In many ethnographic cases, male hunters acquired prey that ultimately provided a lower consumption rate of return for them than if they had taken other prey that were not customarily shared (Bliege Bird and Bird 1997; Hawkes 1993). Large hunted game in particular arere often shared beyond the hunter's immediate family, such as in the cases of the !Kung of northern Botswana and Namibia, Aché of Paraguay, Hadza of Tanzania, and the Meriam in Melanesia (Bliege Bird and Bird 1997; Hawkes 1993).

One argument for why food items may be shared is that it is a risk reduction strategy (for a mathematical treatment, see Mangel and Clark's 1988 example using lion behavior). If each individual or family shares when they have a resource in abundance, it can reduce the variance of food intake, such as with the Nata Baswara sharing their grain harvests (Cashdan 1985). In other anthropological examples, sharing may really be tolerated theft, when defense of a resource is more costly than letting others partake (Cronk 1991). It is difficult, unfortunately, to distinguish between tolerated theft and risk reduction (Cashdan 1997; Cronk 1991), since the calculation of benefits from tolerated theft will likely include consideration of future potential transactions (Cashdan 1997).

Food-sharing behavior may also result from the differing fitness-maximizing strategies of males and females (Hawkes 1993). Females, when foraging for their offspring, directly enhance their own fitness, whereas males will be best served evolutionarily by increasing their mating opportunities (Hawkes 1991, 1993). This stems from the fundamental difference in numbers of gametes produced between the two sexes. If males act to increase reproductive success, they will forage for food that is shared among the larger group, where more potential mates exist, rather than bring back resources that will only be consumed by their immediate family members.

6) *Gender and Foraging*. Based on ethnographic evidence, men and women often forage for very different resources (e.g., Bird et al. 2004, 2009; Bliege Bird 2007; Bliege Bird and Bird 1997; O'Connell and Hawkes 1981, 1984; Sosis 2000, 2002) and for varying reasons. Kaplan and Hill's (1992) work with the Aché

indicated that men often passed over higher-return plant resources to continue hunting, whereas women killed small burrowing animals when no men were present, but otherwise avoided hunting. Both men and women sometimes lowered their overall foraging energetic return-rates to exploit protein- and fat-rich resources (Kaplan and Hill 1992). In the Meriam groups of Melanesia, men and women acquired resources in ways that appeared to emphasize different combinations of the mean and variance in rates of return (Bliege Bird 2007). Meriam women focused on resources that they could reliably acquire, as seems common for women in other ethnographic studies. Social status for Meriam women is tied to the effort they put into provisioning their households, whereas competition is key to men's status. Bliege Bird (2007) therefore argued that the kinds of resources men and women exploited related to their efforts in constructing their gendered identities.

This kind of gendered division of labor may also result from competition (Bird 1999). In societies where mating opportunities are greater, and male parental investment is low, men may hunt because it signals to females that they are worthwhile mates. In contexts where men's mating opportunities are fewer, sexual division of labor would be less noticeable, and cooperation between men and women more prevalent, resulting in greater benefit for the children (Bird 1999).

Costly signaling theory acknowledges that, "in contests between individuals, the ability to provide an honest index (or signal) of each individual's quality or motivation can frequently be in the best interests of both signaler and recipient" (Bird and O'Connell 2006:163). An expensive display may indicate high genetic quality,

thus bringing social benefits to the individual showing off; for example, encouraging mating opportunities or discouraging predators from pursuit (Bird and O'Connell 2006; Krebs and Davies 1993).

Costly signaling is also one argument anthropologists have employed to explain why humans pursue large game (Bird and O'Connell 2006). Hunting is dangerous, and requires both strength and skill (Walker et al. 2002), so by exhibiting his skill, the hunter can signal to other members of the community that he is somehow desirable (Bird 1999; Bird and O'Connell 2006). Hunting also has a high rate of failure, and does not provision a hunter's family as well as capturing small game would, making it a costly activity in terms of food acquisition (Bird and O'Connell 2006). However, showing off by displaying hunting prowess can bring social benefits to an individual, even if they are indirect (Bird 1999). As Hawkes (1991:32) pointed out, when a hunter shares meat among the community, he can "attract the favorable attention of potential future mates and potential allies for future contests over mating access."

One potential ethnographic example of costly signaling comes from the Meriam, where men hunted for sea turtles during a season when the turtles can only be found on less-accessible reefs (Smith and Bliege Bird 2000). Turtle hunting required significant time, energy, and skill, and hunters contributed their catch to public feasts, which meant they received little direct benefit. Instead, turtle hunting seemed best explained as an honest signal of quality that resulted in greater respect and a good reputation (Smith and Bliege Bird 2000).

HBE in California archaeology

As considered in detail in Chapter 3, archaeologists have argued that several changes in subsistence over time in California may reflect resource intensification as well as possible resource depression. Broughton (1994, 1997; Broughton et al. 2007) explained the diachronic decline in sturgeon size and abundance, and artiodactyl, geese and cormorant proportions in San Francisco Bay archaeological sites as resulting from resource depression and reduced foraging efficiency. Cormorants also apparently succumbed to resource depression at Punta Gorda Rockshelter in northern California (Whitaker 2010). The potential overexploitation of marine mammal resident breeders along the California coast (Hildebrandt and Jones 1992, 2002; Jones and Hildebrandt 1995), and fur seals especially in Monterey Bay (Gifford-Gonzalez and Sunseri 2009), may be due to exploitation depression in the places where migratory breeders disappeared, or behavioral depression – possibly along with exploitation depression – in the areas where offshore rocks provided a safer haven.

Most discussions of intensification describe putting in more effort for lower rates of return, resulting in the exploitation of what are defined as less efficient resources: acorns (Basgall 2004; Jones 1996; Wohlgemuth 1996), smaller shellfish (Jones 1996, 2003), fishes and mammals compared to shellfish (Jones and Waugh 1997), offshore pelagic instead of bay and estuarine fishes (Kennett 2005; Rick and Glassow 1999), smaller rather than larger fishes (Jones and Kennett 1999), and lacustrine in place of terrestrial resources (Hildebrandt 1997). Along the Central Coast of California, the "de-intensification" proposed for the Middle-Late Transition

(Codding and Jones 2007b; Jones and Ferneau 2002) would have occurred after climatic and subsistence stress reduced human populations, allowing foragers to refocus on exploiting resources with higher rates of return.

However, many of the assumptions in these studies about what constitutes a less efficient resource are problematic. California archaeologists still emphasize caloric rates of return, and sometimes body size, when ranking prey, although progress has been made in beginning to consider other factors. Discussions of shellfish have particularly addressed reasons why larger-bodied resources may not always be higher ranked. Shellfish, for example, may be valued resources compared to larger animals due to their ease of harvest, predictability, and nutritional content (Bettinger et al. 1997; Erlandson 1988, 1991a; Glassow and Wilcoxon 1988; Jones 1991; Jones and Richman 1995). Within the category of shellfish, other traits might further influence ranking, including the total meat-weight versus meat-to-shell ratio discussed by Whitaker (2008). Jones and Richman (1995) measured rate of return for mussels experimentally, and Hildebrandt et al. (2009) provided data for several other shellfish species compiled from the literature.

Central place foraging analysis has been less prevalent than prey or patch choice models in California archaeological research. Bettinger et al. (1997) developed a central place foraging model to predict mussel and acorn transport in prehistoric California, but did not test those predictions. Their calculations of processing and transport costs predicted that all acorn processing will occur at central places, and that

mussel processing will be variable depending on collection method (plucking versus stripping) and distance from acquisition locale to central place (Bettinger et al. 1997).

In California archaeology, applications of central place foraging theory have been partly intertwined with the debate over costly signaling. These explanations for archaeological patterns come mainly from Hildebrandt and colleagues. Hildebrandt and McGuire (2002, 2003; McGuire and Hildebrandt 2005; McGuire et al. 2007) maintained that costly signaling and gender-based subsistence strategies could be behind the increase in large game exploitation noted in California sites dating to post-3050 BC. As social organization changed, people started being able to exploit distant patches, a behavior too high in caloric costs to justify itself using rates of energetic return, and also associated with symbolic representations of hunting found in the Coso rock-art complex, figurines, and ceremonial and stylized hunting items (Hildebrandt and McGuire 2002). Though challenged by other researchers (Broughton and Bayham 2003; Broughton et al. 2008; Codding and Jones 2007a), costly signaling may be able to explain this behavior, if male hunters were hunting at longer distances to increase their prestige, and subsequently their individual reproductive fitness, rather than simply trying to maximize their caloric rate of return (Hildebrandt and McGuire 2002, 2003; McGuire and Hildebrandt 2005).

Similarly, shellfish from California's Central Coast appear in a site 25 km inland, and their associated rates of return are most likely lower than those that could be acquired by hunting deer or even rabbit closer to the site (Hildebrandt et al. 2009). Moreover, the shellfish should have been processed before transport, in which case

their shells would not have appeared in the archaeological assemblage. Hildebrandt et al. (2009) argued that the shellfish might represent a chief showing his power to organize people and labor to bring large numbers of gaper clams inland for feasting events, another form of costly signaling.

Codding, Porcasi, and Jones (2010) considered the field processing of artiodactyls in a central place foraging context, but did not find evidence for increased acquisition costs along with higher deer abundance. As a result, they determined that the higher proportion of deer in their assemblages from the Pecho Coast of California was not due to costly signaling strategies (Codding, Porcasi, and Jones 2010).

Overall, while California archaeologists are pushing beyond simple body-size for assessing rates of return, the fundamental basis of behavioral ecology applications is still rate maximization. Moreover, fishes are considered lower-ranked than many other resources, and smaller fishes less efficient than large ones, despite ethnographic research showing the incredibly high rates of return that can be acquired from fishing and the relative predictability of catching prey.

Lupo (2007) pointed out the need for methodological progress in zooarchaeology, and specifically recommended further consideration of the forager's state (e.g., social status, energetic reserves, reproductive capacity) and context in predicting subsistence choices. One way to add forager state to optimal foraging models is through dynamic state variable modeling (e.g., Clark and Mangel 2000; Mangel and Clark 1988), which can also be used to address other problematic assumptions of rate maximizing models.

Advances in Modeling

Both the traditional prey and patch choice models, as used in archaeology, predict only one optimal subsistence choice for a forager, and that the choice changes only when there is a change *in the resource itself*. Additionally, such models focus on the maximization of one rate, typically caloric return per unit time. However, when optimal foraging theories focus on rate maximization in attempting to predict the course of action an individual will take, they lose the ability to compare the importance of different factors, to assess how much it will cost an individual to *not* reach the optimum, and to understand what effect an individual's current state will have upon its decisions (Mangel and Ludwig 1992). The state variable can be used for any organism, and describes the individual's physiological condition or knowledge of its surroundings (Houston and McNamara 1999). For example, it could comprise the number of eggs an organism has available to be laid (Mangel 1989), its energy reserves (Houston et al. 1988), foraging skill (Tinker 2004), or even level of household wealth (Luttbeg et al. 2000; Mace 1993).

Dynamic state variable modeling (DSVM), as developed by Houston et al. (1988), Mangel and Clark (1988), Houston and McNamara (1999), and Clark and Mangel (2000), allows archaeologists to incorporate state and context into analyses. It addresses some of the limitations of rate maximization models and has a history of successful application in animal ecology (e.g., Clark and Mangel 2000; Houston and McNamara 1999; Houston et al. 1988; Mangel and Clark 1988; Mangel and Ludwig 1992; Tinker 2004; Tinker et al. 2008, 2009), with a smaller presence in anthropology

(e.g., Anderies 1996; Luttbeg et al. 2000; Mace 1993; Mace and Houston 1989). DSVM can incorporate multiple variables and can be built as a nested set of increasingly complex models so that the influence of each variable can be determined (Clark and Mangel 2000).

Furthermore, while OFT often focuses on a static optimum of behavior, environments are by their nature stochastic, and models should consider this (Mangel and Ludwig 1992; Pyke 1984). DSVM is well suited to a stochastic environment. For instance, a forager might know that she has a probability of approximately 0.4 of catching a deer if she goes out to hunt for one. During the model's simulation run, each time the forager decides to go hunting, the computer picks a random number that determines whether she is successful. Subsequent foraging decisions are then based on that outcome.

As discussed earlier in this chapter, optimal foraging theory is based on the assumption that human subsistence choices positively influence reproductive fitness. Prey and patch choice models emphasize rates of energetic return as a proxy for fitness, and in archaeological research, another proxy, prey body size, is often used to approximate rate of return. This results in models that work to maximize a proxy of a proxy, rather than fitness directly. In dynamic state variable modeling, a relationship must be defined between a forager's state and its fitness, but the model can then be set to optimize fitness itself. This is particularly important, because fitness is ultimately the trait through which evolutionary processes work.

Rate maximization – the cornerstone of traditional OFT approaches – is only an appropriate proxy for fitness under specific conditions. Mangel (1992:420) demonstrated that in diet selection models, such outcomes occur when "metabolic rates are constant, physiological constraints and predation are unimportant, and expected future reproduction is equal to the value of the state variable." All of these factors are usually assumed under normal rate-maximizing models and if they hold true, rate maximizing and dynamic state variable models will predict the same behaviors. However, when any of those assumptions are false, a DSVM may provide very different predictions; it also might not, but must be tested in any given context (Mangel 1992). I decided to use DSVM in this dissertation for my optimal foraging predictions precisely because assumptions common in OFT – constant metabolic rates, no physiological constraints, and no predation (or other risks of death during foraging) –usually do *not* apply to human foraging contexts.

DSVM indicates that a forager's optimal decision can vary depending upon her level of energetic reserves, even without a shift in environmental or patch parameters. For example, faced with three patches with as-yet-undepleted resources, a forager may make different decisions on subsequent days about which patch to exploit, based solely upon how well fed she was on previous days. If she is flush with reserves, the optimal decision might be to not hunt or gather at all, since those activities can come with a slightly higher possibility of injury. A starving forager might take more risks, either mortality risks, or risk such as what Winterhalder et al. (1999:302) call "unpredictable variation in the outcome of a behavior."

Unlike traditional rate maximizing models, DSVM also allows the emergence of *partial preferences*. Using rate of energetic return limits influential factors to a single currency (in most cases, calories), but a dynamic state variable model can simultaneously incorporate several currencies. For example, the probability of mortality when visiting a patch is not quantifiable in calories, but may strongly influence a forager's decision making. Patches might therefore be considered optimal for different reasons, and lower-return patches might be exploited more often than caloric calculations would predict. As a result, a forager could decide to move between patches without depleting her resources, depending on which factor, or currency, was most important in a certain context with a certain state level. With no change in the environment, then, the forager may vary her exploitation of patches. DSVM are constructed to incorporate several such types of behavioral decisions in a forager's fitness optimization.

Ethnographic research demonstrates why assuming a lack of predation is inappropriate for human hunter-gatherers, especially when the concept is expanded to include any injury or death risk from foraging activities. During a 1985-1992 study, Hiwi hunter-gatherers of Venezuela had high adult mortality, with 11% of deaths in young adults coming from "accidents," including those occurring in hunting and foraging activities, though not from predation (Hill et al. 2007). Adult mortality was about 2.3% per year, so deaths from accidents while hunting and foraging must be very low, but did still occur. This is a higher mortality rate than the precontact Aché, Hadza, and !Kung, which ranged from 1.1 to 1.3% (Hill et al. 2007).

Hill and Hawkes (1983) described several methods of hunting by the Aché in Paraguay, which Walker et al. (2002:642) termed "dangerous techniques." For example (see Hill and Hawkes 1983), they used clubs to kill giant anteaters, while attempting to keep clear of claws that could kill them. Aché provoked white-lipped peccaries to charge them, because they would then climb a tree and keep shooting, but the peccaries can "bite viciously" (Hill and Hawkes 1983:151). Finally, the Aché hunted caiman, a kind of crocodile, by "feeling along in the mud with their feet, hoping to locate the body of a sleeping reptile," at which point they would spear it (Hill and Hawkes 1983:153). In a 225-day study, Hill (1988:168) observed among the Aché, "three serious wounds from animal bites…six poisonous snake bites, and several arrow wounds, all of which were incurred by hunting."

In Hadza groups, men collected honey by climbing tall trees, resulting in the occasional fall and serious injury (Bennett et al. 1973). Out of 491 Hadza people studied, Bennett et al. (1973) found 21 men, or 4% of their sample, with severe injuries due to falling from trees. Blurton Jones and Marlowe (2002:207) noted that they knew of "two recent deaths and two serious injuries," at that time, from recent honey-collecting incidents. Included in their identification of injuries from other sources, Bennett et al. (1973) found eight people injured directly by wild animals or from falling while escaping them (Bennett et al. 1973).

Regarding collecting marine resources, Acheson (1981:276) said, "the intertidal zone is not as dangerous as the open ocean, but even here people must retreat in the face of the incoming tide." Logically, fishing from a boat in open water

would be more dangerous than collecting tide pool fishes or setting nets in a calm estuary. Areas with rip tides or strong wave action could also be more hazardous.

These examples elucidate the problems in assuming a human forager will never encounter significant injury or death while gathering resources. A DSVM can include the possibility of mortality as a factor for the forager to consider when making a decision about which resource to exploit.

In summary, many of the assumptions made in rate maximizing models do not usually hold true in human foraging contexts. DSVM addresses some of the problems with rate maximizing, and provides a more sophisticated tool for exploring optimal foraging behavior. This kind of modeling can focus on fitness itself, incorporate the forager's state, add stochastic variation to a defined environment, and accommodate several types of currencies simultaneously. These variables can then be used to model a forager's range of optimal outcomes if she exploits specific taxa or patches. Because of its strengths, I chose dynamic state variable modeling as a framework for understanding my zooarchaeological results. Chapter 7 describes the model and its implications in detail.

Summary

The principles of natural selection can be fruitfully applied to behavior to craft hypotheses about how organisms are predicted to act to optimize their fitness. Ethnographic and archaeological applications of human behavioral ecology and optimal foraging theory have demonstrated that these approaches help with

understanding why people make certain behavioral decisions. It is important to remember, however, that human behavioral ecology does not say that people must behave optimally, but does provide a framework from which hypotheses for optimal behaviors can be determined (Shennan 2002). These hypotheses can then be tested ethnographically or archaeologically to see if peoples' behaviors actually indicate optimality. HBE should not be used as the only answer for why humans make certain choices, but it can help illuminate when human behavior diverges from biological expectations.

In the next two chapters, I describe the archaeological context of the sites considered for this dissertation and my zooarchaeological methods. In Chapter 7, I develop a dynamic state variable model to explore how predictions differ from those of rate maximization models. The DSVM predictions are eventually tested against the zooarchaeological results in Chapter 9.

CHAPTER 5

Archaeological Context

The Monterey Bay area's structure creates a variety of habitats, including sandy beaches and rocky shorelines, open coasts and protected areas in the bay, rivers and estuaries, and kelp beds off much of the outer coast. The high proportions of fishes, shellfish, and marine mammals in archaeological sites indicate marine resources played an important role in human subsistence on the coast. For this dissertation, I chose sites to provide a sampling of different habitats and cultural periods in the region. I describe in this chapter the sites from which I analyzed the ichthyofauna, as well as two sites previously analyzed only by others, SMA-18 (Hildebrandt et al. 2006) and SCR-60 (Culleton et al. 2005), which I use for further comparison. I summarize the excavations and interpretations of site use as gathered from existing site reports, especially emphasizing habitat, fishing technology, and faunal remains. I show the general site locations in Figure 5.1, and provide more detailed maps of the Elkhorn Slough and Carmel Bay areas later in the chapter.

Fish remains from seven of these assemblages were previously identified, but I have re-analyzed them for several reasons. First, in some cases the provenience of identified remains based on the site reports was difficult to determine, and for multi-component sites, I needed to be able to divide the assemblage according to my definition of the components. This was particularly true for some proveniences within the estuary site materials, for which more recent radiocarbon dates have challenged

the original interpretations of cultural period. Second, especially with the Pacific Grove sites (MNT-112 and MNT-113A-D), many remains had been put aside as "undifferentiated," but I found numerous identifiable specimens. Third, I wanted the ability to look at proportions of unidentifiable to identifiable remains, which was not always possible with the data from the site reports. Finally, I wanted to collect more detailed data relevant to processing and taphonomy, such as burning, fragmentation, and estimated size.

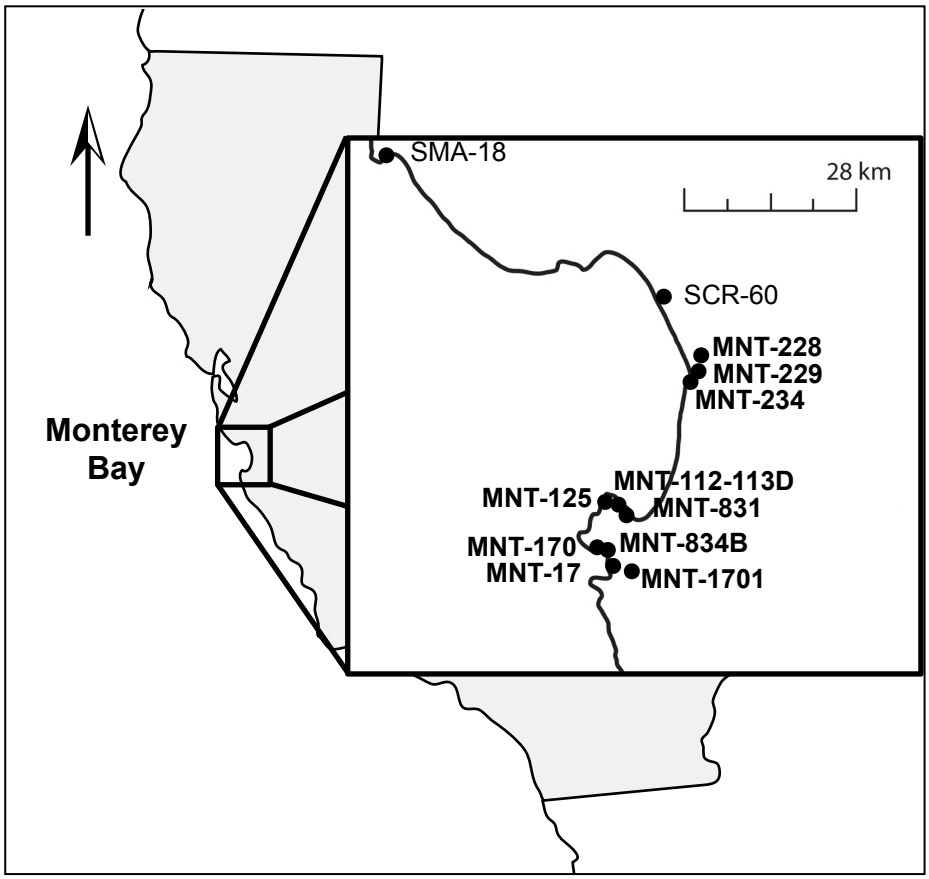


Figure 5.1. Monterey Bay archaeological sites analyzed for this dissertation in bold; data gathered from site reports in plain text.

In Chapter 3, I introduced two cultural chronologies, one by Jones et al. (2007) that was developed for the entire Central Coast of California using mainly shell bead typologies, and one by Breschini and Haversat (2011) that is founded on radiocarbon dates and dated site components, and more specifically addressed the Monterey Peninsula. Because Breschini and Haversat's chronology is based on a very local area, it makes sense that it would fit better with material from my sites that are located on the peninsula. However, I also have material from sites north of the peninsula, which may work better with the Jones et al. chronology.

For example, Breschini and Haversat (2005, 2006) suggested that the lack of millingslabs and handstones in Monterey Peninsula archaeological sites meant that early sites should simply be referred to the Archaic (or undefined), rather than calling them Millingstone Period sites. By contrast, sites in the Elkhorn Slough area have much more robust collections of millingslabs and handstones, and thus may represent different kinds of site use. Assemblages from early sites on Elkhorn Slough also seem to represent marine-oriented subsistence behavior (Breschini, personal communication 2011).

Given the different ecologies and local climatic responses along the Central Coast, as well as the divergent exchange relationships among precontact groups and their differing linguistic affiliations in at least the Late Period, there is no a priori reason to assume the cultural chronologies across my research area will be identical. I therefore reference both chronologies in this chapter, and treat each as an alternative hypothesis for cultural and subsistence change in the region. The sites that date to

periods where the chronologies differ are particularly interesting, and I consider in Chapter 9 whether my research results support one chronology over the other.

Estuary Sites

Elkhorn Slough is a large estuarine habitat in Monterey Bay. At various times in the past, both the Pajaro and Salinas Rivers have emptied into the Pacific Ocean via Elkhorn Slough, though currently their outlets are to the north and south, respectively (Figure 5.2). Elkhorn Slough connects with two other sloughs, Bennett and Moro Cojo, as well as the former Salinas River channel, before it reaches Monterey Bay. In the modern slough configuration, CA-MNT-228 is located on the northern Bennett Slough, about one kilometer from the coast. CA-MNT-229 lies on the southern edge of Elkhorn Slough, at its confluence with the other two sloughs, and only half a kilometer from the bay. Finally, CA-MNT-234 sits between Moro Cojo Slough and the old Salinas River channel, also less than half a kilometer from the coast. On a north-south line, MNT-228 and MNT-234 are both separated from MNT-229 by about 1.5 km. I describe them here from north to south.

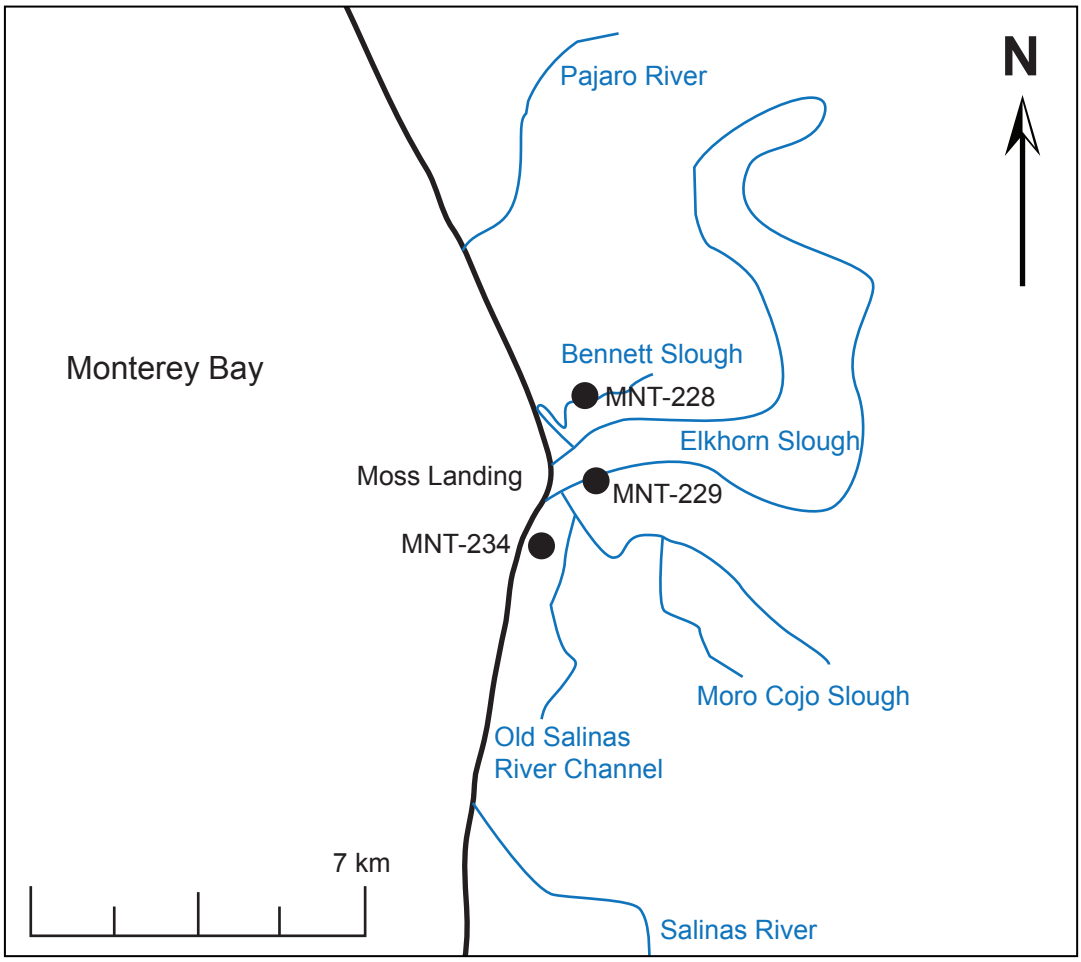


Figure 5.2. Greater Elkhorn Slough, with the three estuary sites analyzed for this dissertation.

CA-MNT-228

Caltrans excavated at MNT-228 in 1991 to determine how to expand, with the least impact to the site, the highway that runs through it (Jones et al. 1996). Based on both sediment structure and radiocarbon dates, MNT-228 is divided into two areas, labeled A and B. Most units were 1x2 m, and screened with 1/8 in mesh. I summarize the excavation methods in Table 5.1.

Table 5.1. Unit locations, sizes, and screening methods at MNT-228 (Jones et al. 1996).

Unit	Area	Size	Screen size	Screening method
1	B	1x2 m	1/8 in	Dry
2	B	1x2 m	1/8 in	Dry
3	A	1x2 m	1/8 in	Dry
4	A	1x2 m	1/8 in	Dry
5	A	1x2 m	1/8 in	Dry
6	A	1x2 m	1/8 in	Dry
7	A	1x2 m	1/4 in	Dry
8	A	1x2 m	1/4 in	Dry
9	A	1x2 m	1/8 in	Dry
10	A	1x1 m	1/8 in	Wet
11	A	1x2 m	1/4 in	Dry
12	A	1x2 m	1/8 in	Dry
13	A	1x2 m	1/8 in	Dry
14	A	1x2 m	1/8 in	Dry
15	B	1x2 m	1/8 in	Dry
16	B	1x2 m	1/4 in	Dry
17	B	1x1 m	1/8 in	Wet
18	A	1x1 m	1/4 in	Dry

Area A matrix was loamy sand, with one stratum of cultural material composed of "a dark gray, shell-rich midden" (Jones et al. 1996:73). Effects of rodent disturbance and farming were clearly evident, indicating the deposit was vertically mixed. Area B had a fine sandy loam matrix, typically found on marine terraces like this one. As in Area A, one main stratum comprised the cultural material (Jones et al. 1996).

Two components were present at MNT-228, a Millingstone or Archaic component in Area B and a Middle Period component in Area A. The dates, as shown in Table 5.2, are not always stratigraphically congruent. However, the two components appear to overlap only slightly along their edges, in Unit 15. Temporal components at the site thus appear to be horizontally discrete, implying that the ichthyofaunal samples are also spatially and temporally discrete (Jones et al. 1996).

Table 5.2. Radiocarbon dates from MNT-228 (Jones et al. 1996). These are reservoir corrected, calibrated dates, all on *Protothaca staminea* shells, except for Unit 5, 30-40 cm, which was on *Saxidomus nuttalli*. The first column of dates comes from Jones et al. (1996), and the second reports Gary Breschini's (personal communication 2011) recalibrated dates using a different local reservoir correction and calculating an intercept. For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Date with ΔR 325±35	Date with ΔR 225	Period
Unit 1, 30-40 cm	5453 BC	5553 BC	Millingstone/Archaic
Unit 1, 60-70	5215 BC	5314 BC	Millingstone/Archaic
Unit 2, 40-50	5291 BC	5386 BC	Millingstone/Archaic
Unit 3, 30-40	AD 453	AD 350	Middle
Unit 5, 30-40	AD 367	AD 252	Middle
Unit 5, 70-80	AD 571	AD 444	Middle
Unit 5, 80-90	AD 381	AD 249	Middle
Unit 8, 100-110	AD 634	AD 541	Middle
Unit 9, 40-50	AD 662	AD 569	Middle
Unit 9, 100-110	AD 445	AD 343	Middle
Unit 9, 110-120	AD 685	AD 615	Middle
Unit 9, 150-160	AD 553	AD 431	Middle
Unit 15, 100-110	AD 685	AD 623	Middle
Auger (Area B), 40-60 cm	5473 BC	5610 BC	Millingstone/Archaic

Previous excavations in 1989 uncovered one burial, a 50-year-old female without associated artifacts, and the 1991 project also discovered several isolated human elements. Flaked stone artifacts included 39 cores, 19 bifaces, 3 projectile points and a small assortment of other tools. Assemblages from the two components both indicate high levels of core reduction. Only ten pieces of groundstone were recovered, seven of which were pestles, the high proportion of which is similar to the Middle Period component at nearby MNT-229 (Jones et al. 1996). No fishing-related artifacts were identified.

The faunal assemblage comprised over 11,000 pieces of bone, of which 4855 were identifiable to genus or species, and 4160 of those that were fish. Mammal

specimens mainly represented gopher and ground squirrel, though deposits attributed to the Middle Period included 85 deer specimens, 37 rabbit, 35 sea otter, and 20 harbor seal. The 16 identified species of bird were mainly waterfowl that would have been easily accessible in the slough habitat.

People living at MNT-228 depended heavily on fishes, as suggested by both the number of specimens and calculated meat values. Based on the original analyses of fish remains by Dr. Ken Gobalet of California State University Bakersfield, people exploited freshwater, euryhaline (can survive in a wide range of salinities), and marine fishes. The high proportion of small schooling fishes in the Middle Period component indicates people probably fished with baskets and fine nets. Freshwater taxa are more common in Millingstone than in Middle Period deposits, and the Millingstone assemblage is more diverse, which may represent an "opportunistic fishery" (Jones et al. 1996:97). The Middle Period, in contrast, seemed to be "more specialized and heavily focused on a few species" (Jones et al. 1996:67).

Shellfish were also very common at MNT-228, and data suggest an emphasis on different taxa over time. Based on column samples, clams – and especially cockles – dominated the Millingstone Period, followed by mussel, whereas mussel far outweighed other species in the Middle Period. Jones et al. (1996) do not identify the mussels to species, though they note the existence of both outer coast mussel (*Mytilus californianus*) and bay mussel (*Mytilus trossulus*, or *Mytilus edulis*). I note in the rest of this chapter when mussels were identified to species, since this indicates what habitat people exploited.

Jones et al. (1996:104) argued that, "the Middle Period component clearly represents a residential base" (104), but was probably not occupied year-round, given the low frequency of formal artifacts. Otolith analyses suggested summer and winter occupation, but Andrews et al. (2003) later demonstrated the difficulties with using such a technique to estimate seasonality. The Millingstone component yielded so few artifacts that Jones et al. found it difficult to make any interpretations. However, they also contended that, "the high frequency of gathered foods (shellfish) and assemblage diversity suggest a residential base" (Jones et al. 1996:104).

CA-MNT-229

Because it is on the edge of Elkhorn Slough, MNT-229 would have been surrounded by marshland and grassland, the nearby coastal strand, and riparian corridors along the Salinas and Pajaro River channels, which would have shifted in location over time (Dietz et al. 1988). Oak woodland was a four to five kilometer trip eastward. Dietz et al. (1988:48) described grassland as, "a highly significant community in terms of both faunal and floral resources," that would have hosted tule elk, pronghorn antelope, and jackrabbit, among others. The slough itself also provides important resources, rich in shellfish, fishes, birds and marine mammals.

In the preliminary 1984 excavations, archaeologists excavated six 1x2 m units; Units 1 and 5 were screened with 1/4 in mesh, and the remainder (Units 2, 3, 4, and 6) with 1/8 in mesh (Dondero et al. 1984). During the full data recovery project in 1985, archaeologists used four kinds of units: 1) 1x2 m control units, dug in 10 cm levels, using 1/8 in screens, and from which all cultural materials were collected; 2)

1x1 m rapid recovery units, excavated in 20 cm levels, using 1/8 in screens again, but in terms of faunal material, only bones expected to be identifiable were retained; 3) surface transect units, excavated in the same fashion as the rapid recovery units, but frequently not to the bottom of the deposit; 4) shovel broadcasting units, with no screening and only identifiable materials kept (Dietz et al. 1988). Due to this diversity in recovery techniques, I have emphasized analysis of the 1985 control units and the 1984 units screened with 1/8 in mesh: Units 2, 3, 4, 6, 7, 11, and 15. I then included a small subsample of the other units for comparison. All of the deposits have a sandy matrix.

Though both Dondero et al. (1984) and Dietz et al. (1988) provided radiocarbon dates, I use the set published in Jones and Jones (1992), who recalibrated the original dates and corrected for isotopic fractionation and regional upwelling. The upwelling correction (ΔR) typically applied to California's Central Coast is 225±35 years, though Jones and Jones (1992) argued that, based on Big Sur data, correlating charcoal with abalone dates, 325±35 years is more appropriate. In Chapter 2, I discussed how ΔR varies over time and space, but given the relatively new explorations in that regard, I here report the dates as calibrated by Jones and Jones (1992), with the 325±35 correction factor. MNT-229, Jones and Jones argued, actually displays stratigraphic congruence with the new calibrations. Although they included dates on multiple specimens (e.g., multiple mussel shell pieces combined for one date), I have removed such dates from Table 5.3, because of their known problems (see Breschini and Haversat 2005).

Table 5.3. Radiocarbon dates on single specimens from MNT-229 (Jones and Jones 1992). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
Unit 11, 160-170cm	*Protothaca* shell	5040-4670 BC	Millingstone/Archaic
Unit 12, 100-120cm	Elk tibia	6100-5750 BC	Millingstone/Archaic
Unit 13, 120-140	*Protothaca* shell	5310-5130 BC	Millingstone/Archaic
Unit 14, 160-180	*Protothaca* shell	AD 450-670	Middle
Unit 15, 60-80cm	Elk radius	200 BC-AD 60	Middle
Unit 20, 60-80cm	Elk vertebra	197 BC-AD 53	Middle
Unit 21, 100-120, Feature 1	Charcoal	210 BC-AD 60	Middle
Unit 31, 0-20cm	*Protothaca* shell	AD 220-570	Middle
Unit 32, 40-60cm	*Protothaca* shell	6400-6090 BC	Millingstone/Archaic
Unit 32, 60-80cm	*Protothaca* shell	AD 540-710	Middle
Unit 32, 100-120cm	*Protothaca* shell	5240-5040 BC	Millingstone/Archaic
Unit 32, 120-140cm	*Protothaca* shell	5520-5310 BC	Millingstone/Archaic
Unit 40, 20-40cm	Deer metatarsal	AD 430-670	Middle

One burial was encountered during test excavations, and another nine in the data recovery portion of the project. One burial held two adult females, and one burial was in too poor of condition to determine age or sex. Two burials were of young individuals, one of 3-4 years and one 9-12 years. The remaining six burials were of adult males, one of whom was associated with over 3,000 beads.

Artifacts included numerous types of flaked stone, groundstone, and bone tools, pitted and grooved cobbles, and 3,638 shell beads. No fishing-related artifacts were identified.

Subsistence clearly focused on the estuary and surrounding grassland, though people also must have regularly traveled to the oak woodland areas to acquire deer. Elk, deer, various marine mammals and rabbits were the most abundant mammal species (Dietz et al. 1988; Sunseri 2009). Estuarine taxa dominate the shellfish assemblage, and birds are those that mainly live in freshwater habitats (Dietz et al.

1988). Based on previous analyses of MNT-229 ichthyofauna by Ken Gobalet (Dietz et al. 1988), most fishes could be found in the estuary or freshwater environments.

Dietz et al. (1988) interpreted the high diversity of tools and faunal remains, combined with a lack of formal cemeteries, other structures, or storage methods, as suggesting the site was a residential base occupied by relatively mobile groups, and only during parts of the year.

CA-MNT-234

Habitat around the Moss Landing Hill site, MNT-234, was similar to that at MNT-229, with grasslands around the slough, freshwater and coastal salt marshes, riparian corridors along the Salinas and Pajaro Rivers, and oak woodland 4-5 km inland (Milliken et al. 1999). Unfortunately, the reconstruction of river channels is not detailed enough yet to know where exactly they would have run during the occupation of MNT-234. The site rests on a vertical succession of stabilized Holocene sand dunes, built up on a Pleistocene terrace about 16 m above sea level. Currently, Moss Landing Marine Laboratories covers much of the site, which also previously housed a World War II coastal defense station and a dairy. The southeastern portion of the site underlies a twentieth century cemetery (Milliken et al. 1999).

Archaeological Consulting, Inc., performed the initial excavations in 1991, excavating five 1.22x1.245 m units in 10 cm levels, screening through 1/8 in mesh, and sorting all materials in the lab. The odd unit size was due to shoring up the sidewalls for safety in the sand matrix, using plywood forms measured in inches

(Breschini and Haversat 1995). Far Western Anthropological Research Group, Inc., later excavated 48 more 1x1 m, 1x2 m, and 2x2 m units in 1997-1998, and varying use of 1/8 and 1/4 in screens (Milliken et al. 1999). They described the deposits as including both silt-cemented and unconsolidated sands (Milliken et al. 1999).

Generally, the Moss Landing Hill site encompasses three important archaeological loci within one trinomial designation: 1) a large, rich midden deposit termed the Primary Midden, 2) a deposit in Area C north of the Primary Midden, especially dense in debitage, which Breschini and Haversat (1995) believed may have been a lithic workshop, and Milliken et al. (1999) assigned to the Millingstone Period, and 3) three more Millingstone Period occurrences, two in Area C west of the Primary Midden, which are horizontally discrete from the younger deposits in the rest of the site, and one that is underneath and substantially deeper than the Primary Midden. The Primary Midden is both vertically and horizontally extensive, about 150x100 m across, and over 3 m deep.

Radiocarbon dates from the Breschini and Haversat and Milliken et al. excavations are referable to Millingstone through Late cultural periods, implying long spans of occupation. Breschini and Haversat (1995) ran 11 radiocarbon dates, all on single shell samples from Unit 1. Milliken et al. (1999) published 43 more dates, two on type G1 *Olivella* beads paid for personally by Breschini and Haversat and Milliken. With multiple specimen samples removed, I show the MNT-234 shell dates in Table 5.4. While the dates are not all stratigraphically congruent, they indicate at least a 5000-year occupation, with some hiatuses.

Table 5.4. MNT-234 dates, arranged by provenience, excluding multiple specimen samples. All of the Unit 1 dates are from Breschini and Haversat (1995), and the remainder from Milliken et al. (1999). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
Unit 1, 80-90 cm	*Clinocardium* shell	AD 470	Middle
Unit 1, 180 cm	*Haliotis* shell	AD 425	Middle
Unit 1, 180 cm	*Saxidomus* shell	AD 145	Middle
Unit 1, 180-190 cm	*Clinocardium* shell	AD 115	Middle
Unit 1, 180-190 cm	*Clinocardium* shell	5065 BC	Millingstone/Archaic
Unit 1, 190-200 cm	*Clinocardium* shell	1255 BC	Early
Unit 1, 200-210 cm	*Saxidomus* shell	1485 BC	Early
Unit 1, 200-210 cm	*Saxidomus* shell	1525 BC	Early
Unit 1, 210-220 cm	*Clinocardium* shell	4780 BC	Millingstone/Archaic
Unit 1, 270 cm	*Saxidomus* shell	5110 BC	Millingstone/Archaic
Unit 1, 300-310 cm	*Saxidomus* shell	4900 BC	Millingstone/Archaic
Unit 5, 20-30 cm	*Olivella* shell bead	AD 1165	MLT/Late
Unit 5, 120-130 cm	*Olivella* shell bead	AD 1005	MLT/Late
N0/E10, 10-20 cm below unit surface	*Tresus* shell	AD 1340	Late
N0/E10, 130-140 cm below unit surface	Unidentified clam shell	2015 BC	Early
N4/E45, 10-20 cm below midden surface	*Tresus* shell	AD 1525	Late
N4/E45, 30-40 cm below midden surface	*Tresus* shell	AD 1685	Late
N8/E45, 70-80 cm below midden surface	*Prototheca* shell	AD 1645	Late
N4/E45, 90-100 cm below midden surface	*Tresus* shell	AD 1650	Late
N4/E45, 120-130 cm below midden surface	*Prototheca* shell	AD 1165	MLT/Late
N4/E45, 200-210 cm below midden surface	*Prototheca* shell	AD 1305	Late
N6/E45, 170-180 cm below midden surface	*Clinocardium* shell	AD 1710	Late
B-2, 0-10 cm	*Tresus* shell	1880 BC	Early
CC-1, 0-10 cm below paleosol surface	*Clinocardium* shell	5135 BC	Millingstone/Archaic
CC-2, 20-30 cm below paleosol surface	*Clinocardium* shell	5025 BC	Millingstone/Archaic
CC-4, 20-30 cm below paleosol surface	*Prototheca* shell	5970 BC	Millingstone/Archaic
CC-4, 50-60 cm below paleosol surface	*Prototheca* shell	5980 BC	Millingstone/Archaic
CC-4, 80-90 cm below paleosol surface	*Prototheca* shell	6060 BC	Millingstone/Archaic
Feature 11, in paleosol	*Clinocardium* shell	5265 BC	Millingstone/Archaic

More recently, 27 AMS radiocarbon dates on marine and terrestrial mammal bone produced a strikingly different distribution, reflecting a span of no more than 500 years, c. 2000 years ago (Gifford-Gonzalez and Sunseri 2009; Newsome et al. 2007). No cultural periods except for the Middle Period are represented by mammal bone dates (Table 5.5), which all come from the Primary Midden. As a result, Gifford-Gonzalez and Sunseri (2009) have argued the mammal bone assemblage from the Primary Midden can all be considered from the Middle Period. My own radiocarbon dates on Pacific hake vertebrae from MNT-234 accord with the mammal bone dates, though I discuss problems with this for the fish assemblage in my results in Chapter 8.

Despite the difficulties with the Primary Midden dating, the horizontally discrete Millingstone Component in Area C still just dates to the Millingstone Period, and one of my own radiocarbon dates supports that interpretation. My analysis of MNT-234 fish remains thus focuses on the Millingstone component identified in Area C. However, I still provide here a brief description of other materials found at the site, because there is evidence for both Millingstone and later components.

Archaeologists uncovered four human burials during excavations, one of which was a child of six or seven, along with hundreds of isolated human elements. All of the burials and most of the individual elements were not found in the Primary Midden, but rather in Areas A and C.

Table 5.5. MNT-234 dates on mammal bone, from Gifford-Gonzalez and Sunseri (2009). Four dates fall inside Breschini and Haversat's radiocarbon date "gap," but right on the edge, and may calibrate fully into the Middle Period if direct $\delta^{13}C$ values are measured (Gary Breschini, personal communication 2011).

Provenience	Material	Date	Period
Unit 1, 0-10 cm	*Callorhinus ursinus*	140 BC-AD 140	Middle
Unit 1, 50-60 cm	*Callorhinus ursinus*	AD 80-340	Middle
Unit 1, 140-150 cm	*Callorhinus ursinus*	200 BC-AD 150	Middle
Unit 1, 150-160 cm	*Callorhinus ursinus*	AD 100-380	Middle
Unit 1, 150-160 cm	*Canis latrans*	111 BC-AD 64	Middle
Unit 1, 150-160 cm	*Canis latrans*	39 BC-AD 143	Middle
Unit 1, 160-170 cm	*Callorhinus ursinus*	AD 100-380	Middle
Unit 1, 170-180 cm	*Canis latrans*	AD 18-181	Middle
Unit 1, 180-190 cm	*Callorhinus ursinus*	66 BC-AD 204	Middle
Unit 1, 180-190 cm	*Canis* sp.	AD 50-221	Middle
Unit 1, 190-200 cm	*Canis latrans*	261-94 BC	Middle/gap
Unit 1, 190-200 cm	*Callorhinus ursinus*	AD 70-330	Middle
Unit 1, 190-200 cm	*Callorhinus ursinus*	AD 70-330	Middle
Unit 1, 200-210 cm	*Callorhinus ursinus*	AD 50-320	Middle
Unit 1, 210-220 cm	*Callorhinus ursinus*	40 BC-AD 320	Middle
Unit 1, 200-210 cm	*Callorhinus ursinus*	20 BC-AD 240	Middle
Unit 1, 220-230 cm	*Callorhinus ursinus*	50 BC-AD 230	Middle
Unit 1, 220-230 cm	*Callorhinus ursinus*	340 BC-AD 20	Middle/gap
Unit 4, 40-50 cm	*Canis* sp.	104 BC-AD 85	Middle
Unit 4, 50-60 cm	*Canis* sp.	AD 236-401	Middle
Unit 5, 120-130 cm	*Canis* sp.	330-202 BC	Middle/gap
Unit 5, 130-140 cm	*Canis latrans*	104 BC-AD 71	Middle
Unit 5, 160-170 cm	*Arctocephalus townsendi*	162 BC-AD 244	Middle
Unit 5, 160-170 cm	*Canis latrans*	418-353 BC	Middle/gap
Unit 5, 160-170 cm	*Canis latrans*	202 BC-AD 25	Middle
Unit 5, 170-180 cm	*Canis latrans*	115 BC-AD 54	Middle

Although archaeologists excavated a very large volume of material, only 28 projectile points were recovered during the two excavations, though they represented 10 different types. Bifaces were the most abundant flaked stone artifact, numbering 86, but the assemblage also included numerous cores, core tools, and flake tools. Ground and battered stone artifacts comprised a selection of "handstones, millingslabs, pestles, mortars, and miscellaneous" (107), for a total of 87 pieces. Of the 48 pieces with proveniences, nearly 75% were from an identified Millingstone

component. Bone and antler artifacts included awls/pins, beads, whistles, a harpoon tip, and several pieces of "miscellaneous modified bone" (Milliken et al. 1999:114).

Nine fragments of *Mytilus* shell fishhooks were found, seven from Unit 1 in the Primary Midden, in the Feature 1 levels at 140-200 cm. This same unit and level yielded the densest concentration of fish bones. The other two fishhooks came from Unit 5, also in the Primary Midden, in the 150-160 cm level (Breschini and Haversat 1995). Circular shell fishhooks do not appear on the Central Coast until the Middle Period (Jones et al. 2007; Breschini and Haversat 2011). Nine netweights were also recovered at the site, three from a brown paleosol layer identified as a Millingstone component, one from Unit S102/E0 at 190-200 cm, and three without provenience (Milliken et al. 1999).

The faunal assemblage, based on analyses from both the Primary Midden from the Archaeological Consulting excavations, and the rest of the site from the Far Western project, indicates a heavy dependence on estuarine shellfish (including bay mussel), fishes, and marine mammals, especially northern fur seal (Gifford-Gonzalez and Sunseri 2009; Milliken et al. 1999). Identified bird taxa were nearly exclusively marine, but included a small selection of terrestrial birds of prey (Milliken et al. 1999). Given the dating issues with the Primary Midden, I will not discuss potential changes through time. Future analyses by Gifford-Gonzalez of the Area C Millingstone deposits may provide a comparison for the mammal assemblage.

Ken Gobalet identified over 20,000 fish bones from MNT-234, which was still a relatively small proportion of the approximately 157,600 specimens recovered

(Milliken et al. 1999). Nearly all of the identified taxa can be caught in an estuarine environment. Based on the previous definition of components using shellfish dates, it appeared a dominance of freshwater taxa gave way to a fishery focused on flatfish and small schooling fishes (Milliken et al. 1999). Though the dates are problematic, the relative increase in small schooling fishes fits well with my results, and other data from the Central Coast. On the other hand, as I present in Chapter 8, the horizontally discrete Millingstone component that I analyzed had no freshwater fishes.

Overall, at MNT-234, the Millingstone component appears to represent a residential base used by foragers on a seasonal round (Breschini and Haversat 1995; Milliken et al. 1999). The later components, as identified in the Primary Midden and elsewhere in the site, have surprisingly sparse, though diverse, artifact assemblages, and little milling equipment. Milliken et al. (1999:152) noted that this contrasts with other Middle Period residential sites in the Monterey Bay region, which have typically yielded high numbers of mortars and pestles, robust artifact assemblages, and substantial features. Sunseri (2009) has since argued that the MNT-234 assemblage represents a Middle Period residential site where people focused on northern fur seal pelt production for exchange.

Pacific Grove Sites

Sites in the Pacific Grove area are all along the southern curve of Monterey Bay, and are very close to the shoreline. Sandy beach and rocky habitats are both easily accessible, and kelp forests are found just offshore. Rocky intertidal zones and

kelp forests are both very productive habitats, so the people living at these locales were near a rich selection of marine resources.

CA-MNT-112 and MNT-113 through -116, or 113A-D

These sites all occur along a less than one-kilometer stretch on the southern Monterey Bay coastline, and excavation units for the large 1977 excavations were placed along a pipeline trench being dug on Ocean View Boulevard (Dietz and Jackson 1981). Despite using the original individual number designations for each of these sites, Dietz and Jackson (1981) recommended that MNT-112 through -116 be treated together for management. Breschini and Haversat (2002, 2006) noted that since the excavations, MNT-113 through -116 have been considered MNT-113A through -113D, based on the lack of boundaries between them. I discuss them here using the A-D designations, though it is important to note that my main source is the original site report, which used MNT-113 through -116. Ken Gobalet performed previous analyses on fish remains for all of these sites.

At all of these sites, excavators dug mainly in 10 cm levels, but used larger levels in contexts with historic fill or sterile soil. The sediment matrix was typically sandy in all deposits. Features with dense deposits of abalone were frequent, as were those with thermally fractured rock or battered cobbles (Dietz and Jackson 1981). In Table 5.6, I summarize the excavation methods as they pertain to each unit. I also note the numbers of identified fish remains that came from each site, as listed in the original site report, since I did not analyze all of the materials from every site.

However, of the proveniences I analyzed, my total sample sizes were generally higher than the original, because I was able to identify more specimens.

Table 5.6. Summary of excavation units and recovery techniques from CA-MNT-112 through CA-MNT-113D (Dietz and Jackson 1981). NISP=number of identified specimens.

Site	Nº Units	Levels*	Max. Depth	Units 1/4 in	Units 1/8 in	Fish NISP
MNT-112	9	10-30 cm	200 cm	1-4, 7	5, 8	248
MNT-113A	8	10-20 cm	140 cm	1-6	7-8	31
MNT-113B	9	10 cm	140 cm	1-5, 7	6, 8	97
MNT-113C	12	10 cm	150 cm	2, 4-6, 8-10	1, 3, 7, 11-12	268**
MNT-113D	27	10 cm	190 cm	1-10, 13-14, 16-18, 20-21, 23-26	11-12, 15, 19, 22, 27	50***

*Levels noted here are those used in the excavation of midden deposits and not the upper fill, which was occasionally removed in larger volumes.
**Only Units 1 and 2 were sorted and analyzed for faunal remains.
***Bone was only found in Units 1, 2, 3, and 24, and only Unit 24 was sorted and analyzed.

The sites are each described individually next, but because of their proximity to each other, and that four of them are now considered part of one larger site, the radiocarbon dates are compiled together in Table 5.7. Dietz and Jackson (1981) provided both uncalibrated and MASCA corrected dates, almost all on abalone shell. Because of the more recent research on the reservoir effect and local upwelling, I have instead included here recalibrated dates from Gary Breschini, who used a ΔR of 225 years.

MNT-112. At MNT-112, Unit 8 is the only one with faunal remains screened through 1/8 in mesh. One particularly large feature spread across Units 3, 5, and 8, at 40-70 cm, and contained a high number of fish bones. Both this feature, and another one at 70-110 cm that extended through the same three units and Unit 9, were dated,

as shown in Table 5.7. Most of the artifacts recovered during excavation came from these large features, but no fishing technology was identified. The artifact assemblage included 9 projectile points, 23 flake tools, 21 ground stone tools, and a small assortment of other items (Dietz and Jackson 1981).

Table 5.7. Radiocarbon dates from MNT-112 and MNT-113A through -113D, reported as intercepts (Breschini et al. 2005; Gary Breschini, personal communication 2011). *Denotes samples from loose midden. All other samples are from shell features.

Site	Provenience	Material	Date	Intercept	Period
MNT-112	Unit 5, 50cm	Abalone	340±100 BP	AD 1715	Late
MNT-112	Unit 5, 50cm	Abalone	580±100 BP	AD 1507	Late
MNT-112	Unit 5, 90-100cm*	Abalone	720±100 BP	AD 1426	Late
MNT-112	Unit 9, 130-140cm*	Abalone	4050±130 BP	2433 BC	Early
MNT-112	Monitoring*	*Haliotis*	550±70 BP	AD 1529	Late
MNT-113A	Unit 7, 59-63cm	*Haliotis*	550±100 BP	AD 1529	Late
MNT-113A	Unit 7, 59-63cm	Charcoal	260±100 BP	AD 1648	Late
MNT-113A	Unit 7, 59-63cm	*Mytilus*[1]	660±100 BP	AD 1470	Late
MNT-113B	Unit 6, 75-85cm	Charcoal	2190±120 BP	264 BC	Middle/gap
MNT-113B	Unit 6, 75-85cm	Charcoal	1970±110 BP	AD 40	Middle
MNT-113B	Unit 9, 60-100cm	*Haliotis*	2250±120 BP	159 BC	Middle
MNT-113B	Unit 9, 60-100cm	*Haliotis*	1890±110 BP	AD 264	Middle
MNT-113C	Unit 8, 82-90cm	*Haliotis*	2140±110 BP	13 BC	Middle
MNT-113C	Unit 10, 97-102cm	*Haliotis*	1780±110 BP	AD 414	Middle
MNT-113D	Unit 9, 30-40cm	*Haliotis*	710±110 BP	AD 1431	Late
MNT-113D	Unit 9, 30-40cm	*Haliotis*	630±100 BP	AD 1473	Late
MNT-113D	Unit 24, 80-110cm	*Haliotis*	3650±130 BP	1873 BC	Early
MNT-113D	Unit 25, 110-120cm	*Haliotis*	3550±120 BP	1732 BC	Early

1. Multiple specimen sample.

MNT-113A. Mammal specimens were far more common than other taxa at MNT-113A, but comprised almost entirely rodent remains. Deer were next most abundant, with 17 specimens. Fish were represented by only 31 specimens, with cabezon and rockfish the most common according to the original analysis. In Units 2 and 7, a feature with abundant shellfish remains, thermally fractured rocks and fish

bones, occurred in the 40-80 cm levels. Three radiocarbon dates for this feature were run from an abalone shell filled with charcoal and mussel, and they are listed in Table 5.7. The corrected dates span 178 years. Artifacts at MNT-113A were limited to five projectile point fragments, 19 flake tools, and a small assortment of cores, battered cobbles, etc. As at MNT-112, no fishing-related artifacts were identified (Dietz and Jackson 1981).

MNT-113B (-114). Midden deposits occurred in all units at MNT-113B, between 30 and 120 cm. Units 1 and 6 contained the only faunal remains, so Unit 6 is the only one with bone that was screened with smaller mesh. Of the fish remains, rockfish were the most abundant, followed by sardine and monkeyface prickleback. Though several features were found in these units, none included artifacts. A feature in Unit 6, at 75-85 cm, did include substantial abalone shell, thermally fractured rock, charcoal, obsidian flakes, and fish bone. One *Mytilus* shell fishhook fragment was found, in the 35-45 cm level above the Unit 6 feature. Otherwise, artifacts from the site mainly consisted of six projectile points, some flake tools and cores, and a few other items (Dietz and Jackson 1981). Both the Unit 6 feature and a feature in Unit 9 were dated (Table 5.7), showing that the site currently only dates to the Middle Period.

MNT-113C (-115). I include a brief description of MNT-113C here only because it is in the midst of the other sites along this stretch. The site appears to represent a single component Middle Period occupation, based on both the 1977 excavations (Dietz and Jackson 1981) and later testing by Morley (2010). Only units

1 and 2 were originally analyzed for shellfish and vertebrate remains. Within the mammals, after rodents, northern fur seal was by far the most common, followed by deer. All of the identifiable fish specimens came from Unit 2, which was screened only with 1/4 in mesh (Dietz and Jackson 1981). Based on my analysis of other material from the Pacific Grove sites, I determined that the lack of small mesh screens made the assemblage not useful for my particular research questions, and did not reanalyze the remains. However, among numerous other artifacts, excavations at MNT-113C produced four *Mytilus californianus* fishhook fragments, all of which are middle pieces, but one, at 32.3 mm, is long enough to make a full half circle (Dietz and Jackson 1981).

MNT-113D (-116). The largest excavation of this string of sites, MNT-113D units contained midden deposits within 70-200 cm, with loamy soil above, and yellow sandy soil or granite beneath. Unit 24 was the only unit analyzed for shellfish and vertebrates. After rodents, the next most abundant mammal taxon was sea otter, with only four specimens, and other taxa were even fewer. Fifty fish bones were identified, with rockfish most abundant, then cabezon, and the remaining species with only four or fewer specimens. Nineteen units contained features, with fish bone found in those in Unit 8, 16, and 24. The two features in Unit 16 were both pits with burned soil and fish bone in blue ash, an interesting phenomenon given that numerous burnt fish bones analyzed for this dissertation – not just from this site – were bluish-gray. In Unit 24, the feature from 50-70 cm included a *Mytilus californianus* fishhook fragment, along with a concentration of bone, shell, battered cobbles, and an abalone

disk. As shown in Table 5.7, a lower feature in Unit 24 was dated, as were features in Unit 9 and 25 (Dietz and Jackson 1981).

Perhaps as a result of the greater volume of excavated material, MNT-113D also had the most artifacts of any of these sites. Of 375 artifacts, battered cobbles, flake tools, projectile points, and *Olivella* beads were the most common. Dietz and Jackson (1981) identified one possible net weight, found in Unit 17 at 72-87 cm, and two *Mytilus* fishhook fragments, both in Unit 24, one at 60-70 cm (in the feature noted above) and one at 30-40 cm (Dietz and Jackson 1981).

In summary, Dietz and Jackson (1981) argud that the variety and types of material at MNT-112 and MNT-113A through D, suggest they were used as seasonal residential bases. Regarding subsistence, shellfish were clearly an important resource through time. They comprise the most common macro-constituent, with mussel dominating in general, but some unit levels with more abalone. Within the shellfish category, outer coast mussel (*Mytilus californianus*) abundance typically measured at 70-80% by weight, except at MNT-116, where mussel and abalone were both around 45%. Rodents are the most abundant of any mammal taxa at all of the sites. Few birds are present, except for at MNT-112 and -113, which contrasts with some other nearby coastal sites (e.g., MNT-88 and MNT-238) that have significant numbers of bird bones (Dietz and Jackson 1981). The fish species previously identified suggested a wide variety of exploitation strategies were used, but the lack of high concentrations of fish bone led Dietz and Jackson (1981:700) to argue that fishing was "incidental to other exploitative efforts."

MNT-112-113D Summary. Although the excavation techniques in these sites were not all ideal, they provide an interesting set of comparisons, since they represent three separate cultural periods in a very geographically constrained space. The Early Period occupation at MNT-113D has a less dense concentration of shellfish than later periods, and fewer artifacts and artifact types, thus leading Dietz and Jackson (1981) to argue that people were using it for shorter periods of time. They also suggested people switched from a foraging to logistical collecting settlement pattern (see Binford 1980), a topic I address further in Chapter 9.

CA-MNT-831

Right next to the MNT-112 and MNT-113A sites, MNT-831 is near Lovers Point in Pacific Grove, only a couple blocks from the coastline, and within easy access to both rocky shoreline and sandy beaches (Breschini and Haversat 2006). No clear dividing line exists between MNT-831 and MNT-112, and both sites have Early Period components. Additionally, a Late Period component at MNT-831 is not horizontally distinguishable from those at MNT-111, -112, and -113A. Archaeological Consulting performed mitigation and data recovery at MNT-831 in 2004-2005, in preparation for the Pacific Grove Senior Housing Project. MNT-831 is particularly important because it is currently the oldest identified site on the Monterey Peninsula.

The site was excavated using 10 cm levels, with sediment screened through 1/8 in mesh in the field and all screen contents returned to the lab for cleaning and sorting. Out of seven units, Units 1-2 and 5-7 are clustered together, with Unit 3 over

25 m away, and Unit 4 another 35 m beyond it. The units are all placed along a 115 m exploration trench (Breschini and Haversat 2006).

Thirty-one radiocarbon dates on MNT-831 material suggested the site had been more or less occupied since 5200 BC, though no dates fell 4770-3820 BC, or in the 1200-200 BC gap identified by Breschini and Haversat (2011). While dates from the mid-fourth millennium BC are found throughout much of the site, the earliest dates are all from Unit 4, and Breschini and Haversat (2006:76) noted that, "this pattern of clustering of occupation by time period is not uncommon." The most intensive occupation at MNT-831 occurred during the Early Period, c. 3820-3600 BC, based on 12 dates falling in just those two centuries alone (Breschini and Haversat 2006). In Table 5.8, I list the radiocarbon dates from the site, noting those units from which I have fish remains.

Excavations uncovered four burials, one with an adult and child, and stable isotope analyses indicated three individuals had diets extremely high in marine resources. The oldest burial, dated to 3304 BC, had a diet that was probably 92.5% marine, more heavily marine and higher on the trophic scale than the early Holocene/Millingstone Period burials from SCR-60/130 discussed in Chapter 3. Two burials, dating to 2861 BC and AD 82, reflected a diet of around 80% marine resources, very similar to the SCR-60/130 early Holocene values. The adult individual from the fourth burial dated much later, at AD 1750, and had consumed a substantially more terrestrial and lower trophic level diet, with a mere 10% marine foods (Breschini and Haversat 2006).

Table 5.8. Radiocarbon dates from MNT-831, reported as calibrated AD/BC intercept (Breschini and Haversat 2006). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first. *Marks proveniences from which fish remains were recovered.

Provenience	Material	Date	Period
Unit 3, 64 cm*	*Mytilus californianus*	3705 BC	Millingstone/Early
Unit 4, 20 cm*	*Mytilus californianus*	4770 BC	Millingstone/Archaic
Unit 5, 10 cm floor*	*Haliotis rufescens*	AD 696	Middle/Late
Unit 6, 0-bottom*	*Olivella* bead	2144 BC	Early
Unit 6B, 15 cm*	*Haliotis rufescens*	AD 662	Middle
Unit 7, 0-bottom*	*Mytilus* bead	1347 BC	Early
Unit 7, 75 cm*	*Mytilus californianus*	3627 BC	Millingstone/Early
Burial 1	Bone	3304 BC	Early
Burial 2	Bone	AD 82	Middle
Burial 2 backdirt	*Mytilus californianus*	2464 BC	Early
Burial 2 backdirt	*Mytilus californianus*	3306 BC	Early
Sp. 45, Burial 2, 61 cm	*Haliotis rufescens*	3727 BC	Millingstone/Early
Sp. 45, abalone layer	*Haliotis rufescens*	2402 BC	Early
Burial 3	Bone	2861 BC	Early
Burial 4a	Bone	AD 1750	Late
Trench, 0 m, 58 cm	*Haliotis rufescens*	3617 BC	Millingstone/Early
Trench, 3 m, 22 cm	*Haliotis rufescens*	AD 556	Middle
Trench, 36.5 m, 40-50 cm	*Haliotis rufescens*	3633 BC	Millingstone/Early
Trench, 56 m, 83 cm	*Haliotis rufescens*	3820 BC	Millingstone/Early
Trench, 58.9 m, 88 cm	*Haliotis rufescens*	3621 BC	Millingstone/Early
Trench, 63 m, 157 cm	*Mytilus californianus*	3705 BC	Millingstone/Early
Trench, 64.5 m, 115 cm	*Haliotis rufescens*	3702 BC	Millingstone/Early
Trench, 69.5 m, 155 cm	*Mytilus californianus*	5190 BC	Millingstone/Archaic
Trench, 69.5 m, 158 cm	*Mytilus californianus*	3771 BC	Millingstone/Early
Trench, N of Unit 4, 85 cm	*Mytilus californianus*	4805 BC	Millingstone/Archaic
Trench, N of Unit 4, 85 cm	*Mytilus californianus*	4990 BC	Millingstone/Archaic
Trench, 90 m, 130 cm	*Haliotis rufescens*	3612 BC	Millingstone/Early
Under whale rib	*Haliotis rufescens*	3604 BC	Millingstone/Early
N wall, 14 m, 78 cm	*Mytilus californianus*	3634 BC	Millingstone/Early

The faunal assemblage supports a heavily marine subsistence when analyzed using meatweight values, though rodents are, as usual, the most common by number of specimens. After rodents, "unidentified mammal" comprises the highest percentage, followed by birds, leporids, and then pinnipeds (Breschini and Haversat 2006; Porcasi 2006). Fish remains were not included in the report, as the full assemblage was sent to me for analysis.

Battered stones, faceted handstones, and pitted stones comprise the main part of the artifact collection, with limited flaked stone tools and debitage. No fishing related artifacts were identified, though Breschini and Haversat (2006) observed that one argument for the function of pitted stones, of which 121 were recovered, is that they could have been used for processing fish or shellfish. Pitted stones they submitted from another central California site produced three out of twenty-four that tested positive for residue from Salmonidae fishes, and six for shellfish residue (Breschini and Haversat 2006).

Overall, MNT-831 appears to be a residential site, though with a relatively unusual artifact assemblage compared to other sites on the Monterey Peninsula. As the oldest known site on the peninsula, MNT-831 provides an important insight into earlier occupations of the area. Both stable isotope analyses and the subsistence remains indicate people living at the locale had diets heavily dependent on marine resources.

CA-MNT-125

MNT-125 is located at the Pacific Grove Golf Course on Point Pinos, which is the tip of the Monterey Peninsula extending into the Pacific Ocean. It rests on stabilized sand dunes several hundred meters from the mostly rocky shoreline. Archaeological Consulting performed a small test excavation over two days in 2004, to determine the outer edge of the site and ensure the construction of a cart path and driveway would not impact archaeological material (Breschini and Haversat 2004).

Only one unit was excavated at MNT-125. As is typical with Archaeological Consulting work, they excavated in 10 cm arbitrary levels, and used 1/8 in dry screens in the field, with all material returned to the lab to be washed and sorted. Historic material occurred down to 60-70 cm, so the site is mixed, but most historic material was above 30 cm (Breschini and Haversat 2004). Table 5.9 displays the radiocarbon dates from the site, all of which indicate occupation AD 1440-1630.

Table 5.9. Calibrated radiocarbon intercept dates from MNT-125 (Breschini and Haversat 2004). Second *Olivella* bead date is from Breschini (personal communication 2011).

Provenience	Material	Date	Period
Unit A, 0-10cm	*Olivella* bead	AD 1630	Late
Unit A, 20-30cm	*Mytilus* shell	AD 1510	Late
Unit A, 30-40cm	*Olivella* bead	AD 1650	Late
Unit A, 40-50cm	*Mytilus* shell	AD 1440	Late
Unit A, 60-70cm	*Haliotis* shell	AD 1620	Late

Three beads, one fragment of an obsidian projectile point, and one possible pitted stone comprise all of the recovered prehistoric artifacts. Very little bone was found, and all fish bone comes from the 10-40 cm and 50-60 cm levels. None of the vertebrate bone was analyzed, but the fish bone was given to me for analysis. The shellfish appear to be mostly mussel, probably *Mytlius californianus* (Breschini and Haversat 2004).

Breschini and Haversat (2004:14) described the site as probably "a temporary campsite or small village occupied during portions of the Late Period." People were clearly exploiting both terrestrial and marine resources, including mammals, birds, fishes, and shellfish, so the site was not just a specialized activity area.

Carmel Bay Sites

Carmel Bay is only a tenth the size of Monterey Bay, on the south side of the Monterey Peninsula (Figure 5.3). Though most of the eastern edge of the bay's curve is sandy beach habitat, a rocky point extends into the bay approximately halfway between the north and south ends, where the Carmel River empties into the Bay.

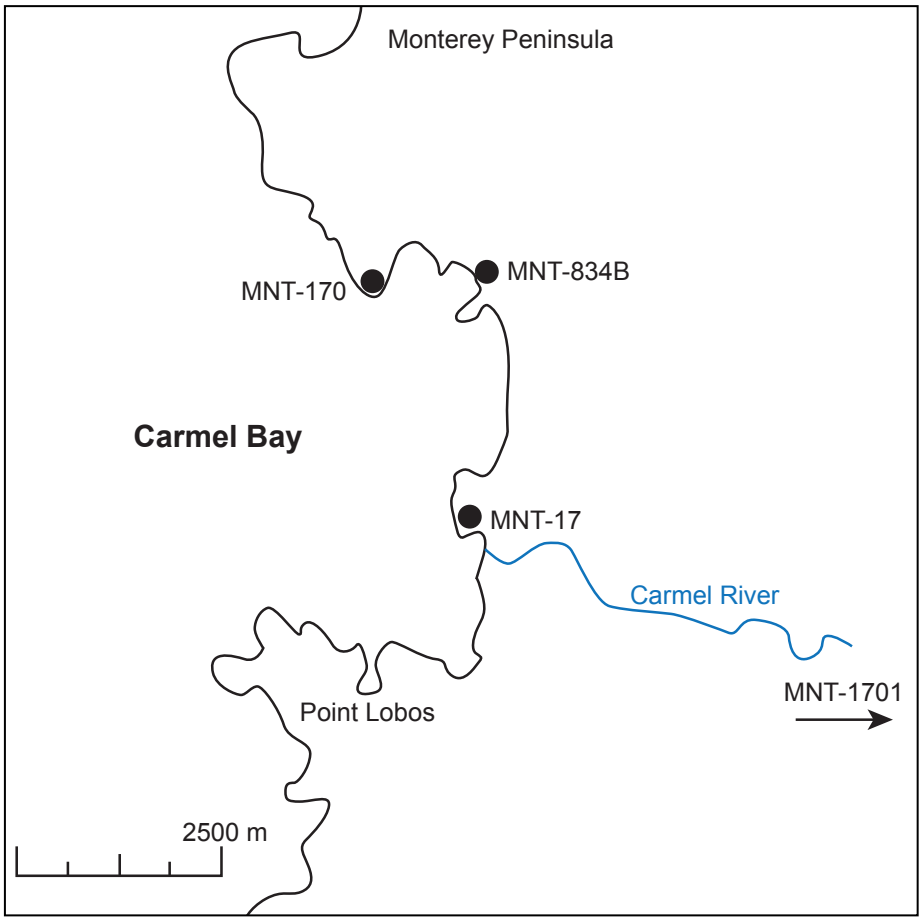


Figure 5.3. Location of sites and the Carmel River around Carmel Bay. Coastline redrawn from Google Earth satellite image.

CA-MNT-170

MNT-170 is located on Pescadero Point on the south side of the Monterey Peninsula, and has open coast on the west side and protected bay to its east. Rocky shoreline wraps around the point and sandy beach in Carmel Bay is less than 0.8 km away. Earlier excavations in 1987 worked on the southeast side of the point, where two components appeared to be horizontally stratified: a shell midden on the bluff, and an occupation slightly inland (Dietz 1991). In 1988, Archaeological Consulting performed data recovery for landscaping mitigation on the southwest side of the point (Area C), at an area facing more of the outer coast, and c. 600 m from the previous work (Gary Breschini, personal communication 2011). All of the material I analyzed was from the most recent excavation.

Archaeological Consulting excavated two 80x125 cm units, in 10 cm levels, screening with 1/8 in mesh as they usually do. No features were uncovered (Gary Breschini, personal communication 2011). According to Dietz (1991), the sediment at the site was silty/sandy. In Table 5.10, I show the radiocarbon dates from the 1988 excavations. The Early Period is dominant, c. 4050-1200 BC, but a small Late Period component is present (Gary Breschini, personal communication 2011). Since most of the span between the two later dates falls within Jones et al.'s (2007) Middle-Late Transition, I consider it MLT/Late for my analyses.

Olivella beads are the most common artifacts recovered from the 1988 excavations, followed by a small selection of bifaces, and a few utilized cobbles and pebbles (Gary Breschini, personal communication 2011). The earlier project had

produced a majority of biface fragments, as well as one *Mytilus californianus* shell fishhook fragment in the more inland deposit (Dietz 1991). Faunal analysis from the 1988 project suggested the Early Period component had much greater emphasis on marine mammals than the Late Period, but noted the small size of the Late Period sample (Langenwalter 1992).

Table 5.10 Radiocarbon dates from MNT-170, Area C (Gary Breschini, personal communication 2011). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
Monitoring, 20 cm	*Haliotis rufescens*	AD 1301	Late
Unit C, 38 cm	*Haliotis rufescens*	AD 897	Middle/Late
Unit C, 53 cm	*Haliotis rufescens*	2050 BC	Early
Unit C, 90 cm	*Haliotis rufescens*	2592 BC	Early

From the earlier excavations, Dietz (1991) identified the dense abalone shell deposit as a Late Period specialized activity area, a field camp to which people came from permanent residences in Carmel Valley. The midden that is inland from the feature, and includes much more material, is probably an Early to Middle Period seasonal residential base, since it has burials, obsidian, beads, assorted tool types, and milling equipment (Dietz 1991). Archaeological Consulting's later work also uncovered deposits dating to the Early and Late Periods, though not horizontally separated. These seem to represent a small Late Period abalone-gathering site possibly compressed above an Early Period residential site (Gary Breschini, personal communication 2011), a common pattern for the Monterey Peninsula region (Breschini and Haversat 1991b).

CA-MNT-834B

The Pebble Beach Golf Course is situated in the north end of Carmel Bay, in a fairly protected area with wide sandy beaches and some rocky promontories. MNT-834 was originally identified in 1978, and was thought to include the area from which my ichthyofaunal material came. However, Breschini and Haversat (2008:4) determined that a "substantial gap" existed between two deposits, so they designated the deposit they excavated MNT-834B. The project was mitigation for construction of two buildings, a new hole for the golf course, and the installation of a curtain drain (Breschini and Haversat 2008). Excavations from which my materials were recovered mainly took place in 1998.

Archaeological Consulting excavated units in two ways, either by 10 cm levels using 1/8 in screens, or with no levels (0-sterile) and screening with 1/4 in mesh. The latter method allowed archaeologists to excavate a larger sample, with volunteer help, than would otherwise have been possible. Unit sizes included 1x2, 1x3, 2x2, and 2x3 m. All material from the field screens was transported back to the lab and wet-screened before sorting and analysis. After these excavations, Archaeological Consulting returned in 2008 to screen soils from a trench c. 70 m long, to allow for the curtain drain placement. This was done with 1/4 in mesh (Breschini and Haversat 2008).

Historic materials throughout the site are only from the top 30 cm, suggesting little mixing with the prehistoric material below that. Excavators found fish remains in all units, and they are especially abundant by weight in Units A1, A2, B2, and B3.

Those A units are adjacent to each other, but the B units are not (Breschini and Haversat 2008).

Using Breschini and Haversat's (2011) chronology, MNT-834B is a single component, Late Period site. The Jones et al. (2007) scheme would place the site in the Middle-Late Transition and Late Period. Radiocarbon dates mainly ranged from AD 1000 to 1650, and especially AD 1200-1325 (Table 5.11). Regardless of cultural period, these dates certainly place the site's occupation within the Medieval Climatic Anomaly (Breschini and Haversat 2008). If Stine's (1994) data from the central Sierras is used, droughts were most extreme c. AD 892-1112 and AD 1209-1350 (see Chapter 2). Breschini and Haversat (2008) noted that the earliest dates from MNT-834B fall during the first span of severe drought, and that the bulk of dates fall within the second span. This is an intriguing pattern, especially given the high proportion of fish people were apparently consuming.

The initial project excavated one burial with two individuals, a woman and a 2-3 year old child, which were subsequently reburied. The curtain drain project encountered two more burials, but the drain trench was rerouted to avoid them. Shell beads and abalone pendants, numbering about 172, encompass the majority of artifacts found at the site, and were not clustered with the burials. The lithic assemblage comprises 28 flaked stone artifacts, mostly bifaces, 34 battered stones, and a small selection of other mainly groundstone artifacts.

Table 5.11. Radiocarbon dates from MNT-834B (Breschini and Haversat 2008). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
Unit A1, 20-30cm	*Olivella* bead	AD 1287	Late
Unit A1, 30cm, just above Feature 1	*Haliotis rufescens*	AD 1536	Late
Unit A1, 30cm, just above Feature 1	*Haliotis rufescens*	AD 1536	Late
Unit A1, 40cm, Feature 1	*Haliotis rufescens*	AD 1288	Late
Unit A1, 42cm, Feature 1	*Haliotis rufescens*	AD 1288	Late
Unit A1 extension, Feature 2, 60cm	*Haliotis rufescens*	AD 1202	MLT/Late
Unit A1 extension, Feature 2, 60cm	*Haliotis rufescens*	AD 1229	MLT/Late
Unit B3, 30cm, Feature 3	*Haliotis rufescens*	AD 1250	Late
Unit B3, 30cm, Feature 3	*Haliotis rufescens*	AD 1647	Late
Unit B3, 30cm, Feature 3	*Haliotis rufescens*	AD 1239	MLT/Late
Unit D1 extension, Burial	*Haliotis rufescens*	AD 1222	MLT/Late
South trench, shallow	*Mytilus californianus*	AD 1322	Late
West trench, deep	*Mytilus californianus*	AD 1006	MLT/Late
Drain trench	*Mytlius californianus* fishhook	AD 1085	MLT/Late

Notably, MNT-834B produced six shell fishhook fragments and one complete specimen; their proveniences are listed in Table 5.12. The intact fishhook is mussel shell (*Mytilus* sp.), as are all the rest except for one abalone. Breschini and Haversat (2008) directly dated one fishhook, which returned a calibrated date of AD 1085, younger than all six other fishhook dates from Monterey County. They suggest that, "this confirms the accepted belief that mussel shell fishhooks extended in time from the Middle through the Late period on the central California coast" (Breschini and Haversat 2008:41).

Most levels in the site have more mussel (*Mytilus californianus*) than abalone, which is typical of the Monterey Peninsula, where sites with lots of abalone are generally almost exclusively abalone ("abalone pavement") and are processing sites. MNT-834B appears to be a "seasonal camp or small village dedicated to exploitation

of the local marine and terrestrial environment" (Breschini and Haversat 2008:54). Freshwater was probably available from the nearby gully, and the protected shoreline would have facilitated the exploitation of coastal resources. Langenwalter II, in his analysis of the non-fish faunal assemblage, determined that, "Nearly all, or all, of the marine and terrestrial species used could have been procured within 1000 m of the site" (2008:110). Fishing was clearly an important subsistence activity, based on the numbers of fish bones recovered.

Table 5.12. Proveniences of shell fishhook and fragments found at MNT-834B, and their material (Breschini and Haversat 2008).

Provenience	Description
Unit A2, 50-60 cm	*Mytilus* fishhook fragment
Unit B1, 0-sterile	*Mytilus* fishhook fragment
Unit A3, 0-sterile	*Haliotis* fishhook fragment
Unit D1, 0-sterile	*Mytlius* fishhook fragment
Curtain drain trench	*Mytilus* fishhook (intact)
Curtain drain trench	*Mytlius* fishhook fragment
Curtain drain trench	*Mytilus* fishhook fragment

CA-MNT-17

MNT-17 is located on the large rocky point that extends into Carmel Bay on its eastern edge, just north of where the Carmel River debouches. About .75 km of rocky intertidal habitat circle the point and sandy beach continues in both directions beyond it. The southern half of this point comprises MNT-17, while the northern part has been labeled as MNT-16. Excavations at the site have occurred over numerous years, but the fish remains I analyzed mainly come from Archaeological Consulting projects in 1987, and 1996-1998, all of which were instigated to mitigate residential

construction. MNT-17 is a large site, with multiple components spread over about 50 acres (Gary Breschini, personal communication 2011).

The various projects were all excavated in 10 cm levels, and all materials left in the 1/8 in screens were removed to the lab and wet screened before analysis. Excavators designated three subsections of the site: MNT-17A on the coast, MNT-17B slightly inland, and MNT-17C occupying the southeast portion of the site, on the lagoon side of Carmel Point. Though fish bones were recovered from a few areas, the majority came from Areas 2400, 2932, and 899, all of which are in MNT-17C.

Generally, radiocarbon dates from MNT-17 appear stratigraphically congruent, with older dates lower than younger ones. This is particularly the case within individual units. Two clusters of dates seem to exist, one between the early AD 1300s and early 1600s, and one 2271-1512 BC (Table 5.13). These time spans would be placed into the Early and Late Periods, and are almost entirely horizontally discrete. Archaeological Consulting has more recently been working on another part of the site that may represent a Middle Period occupation (Gary Breschini, personal communication 2011).

MNT-17A appears to represent a Late Period coastal gathering site for abalone, and has few artifacts and faunal remains, as is typical for shellfish processing locations. In the area of MNT-17B, cultural material was sparse, but more extensive excavations produced greater numbers of artifacts, mostly battered cobbles and some ground stone artifacts (Gary Breschini, personal communication 2011).

Table 5.13. Radiocarbon dates from MNT-17, using calibrated AD/BC intercepts (Gary Breschini, personal communication 2010). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first. *Marks proveniences from which fish bone was recovered. **Multiple specimen date, not reliable.

	Provenience	Material	Date	Period
MNT-17A	AC 2870, Unit 1, 30cm*	*Haliotis rufescens*	AD 1631	Late
	AC 2870, Unit 1, 40cm*	*Haliotis rufescens*	AD 1493	Late
	AC 2870, Unit 1, 50cm*	*Haliotis rufescens*	AD 1453	Late
	AC 49, Unit 4, 38-40 cm	*Haliotis rufescens*	AD 1682	Late
	AC 49, Unit 4, 38-40 cm	*Haliotis rufescens*	AD 1807	Historic
	AC 49, Unit 4, 40-50 cm	*Haliotis rufescens*	AD 1486	Late
	AC 49, Unit 4, 45 cm	*Haliotis rufescens*	AD 1273	Late
	AC 49, Unit 4, 50-60 cm	*Haliotis rufescens*	AD 1229	MLT/Late
	AC 49, Unit 4, 60-70 cm	*Haliotis rufescens*	AD 1159	MLT/Late
	AC 49, Unit 4, 60-70 cm	Carbon rich soil	AD 370	Middle
	AC 901, Monitoring, 80 cm	*Haliotis rufescens*	AD 1691	Late
	AC 901, Monitoring, 100 cm	*Haliotis rufescens*	AD 1277	Late
	AC 901, Monitoring, 140-170 cm	Carbon rich soil	1172 BC	Early/gap
MNT-17B	AC 4005, Abalone feature, 100 cm	*Mytilus californianus*	AD 1399	Late
	AC 4005, Abalone feature, 100 cm	*Haliotis rufescens*	AD 1320	Late
	AC 593, Monitoring, 40cm*	*Haliotis rufescens*	AD 1480	Late
MNT-17C	AC 3998, Monitoring, 1 m deep	*Mytilus californianus*	345 BC	Middle/gap
	AC 899, Unit 2, 34-40cm*	*Haliotis rufescens*	AD 1314	Late
	AC 899, Unit 2, 70-80cm*	*Mytilus californianus***	1512 BC	Early
	AC 899, Unit 2, 110-120cm*	*Mytilus californianus***	1918 BC	Early
	AC 899, Unit 2, 150-160cm*	*Mytilus californianus***	2174 BC	Early
	AC 2400, Unit X, 180-190cm*	*Haliotis rufescens*	2271 BC	Early
	AC 2932, Monitoring, Augers 1-4, deep*	*Haliotis rufescens*	4355 BC	Millingstone/ Archaic

MNT-17C has some Late Period material, but mainly looks like an Early Period residential site. Material remains include at least 16 *Olivella* beads, some battered cobbles, and biface fragments. Two large side-notched points and a contracting stem point all suggest an early occupation. Two burials were uncovered during excavation, one adult male and one adult female (Gary Breschini, personal communication 2011).

Overall, at MNT-17, more mussel shell (*Mytilus californianus*) seems to occur in the lower levels, and more abalone in the later deposits. This coincides well with other research in the region and the shift from more generalized shellfish collecting to more specialized processing sites (Breschini and Haversat 1991b).

CA-MNT-1701

Located approximately 15 km inland from Carmel Bay, MNT-1701 is part of the Rancho San Carlos complex. Over 40 sites exist in the upland site complex, which was probably the location of the ethnographic village of Echilat (Breschini and Haversat 1992). From the larger upland sites, a creek system spreads out with smaller sites located along each one. MNT-1701 is along one of these creeks, less than one kilometer from the larger upland sites. While it does not technically count as a coastal site, large numbers of marine fish remains were recovered at MNT-1701, and as such it makes an interesting comparison. Archaeological Consulting excavated two 1x2 m units in 2000, using 10 cm levels and 1/8 in screens, to mitigate damage from road construction (Gary Breschini, personal communication 2011).

By Breschini and Haversat's (2011) definition, MNT-1701 is an entirely Late Period site, with over 24 radiocarbon dates ranging from AD 800 to 1450 (Table 5.14). Using Jones et al.'s (2007) chronology, these dates would span the Middle Period, Middle-Late Transition, and Late Period.

Artifacts found at the site mainly comprise mortars and pestles, with some bone awls and a few projectile points. No fishing-related artifacts were identified, and the project did not uncover any burials.

MNT-1701 represents a residential site, and was part of a much larger village complex. Over 65 radiocarbon dates represent the Rancho San Carlos complex as a whole, which date continuously from AD 800 to historic times. This area influenced Breschini and Haversat's (2011) decision to extend the Late Period back to AD 700 for the greater Monterey Peninsula area, because the sites display consistent occupation from then on (Gary Breschini, personal communication 2011). However, the majority of dates from MNT-1701 fall right within Jones et al.'s (2007) Middle-Late Transition, making this site an interesting source for understanding human subsistence during that time.

Table 5.14. Radiocarbon dates from MNT-1701, reported as intercepts, using a ΔR of 225 (Gary Breschini, personal communication 2011). For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
Unit 1, 16 cm	*Haliotis rufescens*	AD 1299	Late
Unit 1, 18 cm	*Mytilus californianus*	AD 1017	MLT/Late
Unit 1, 18 cm	*Haliotis rufescens*	AD 1184	MLT/Late
Unit 1, 20 cm	*Mytilus californianus*	AD 1415	Late
Unit 1, 40 cm	*Mytilus californianus*	AD 1035	MLT/Late
Unit 1, 40 cm	*Haliotis rufescens*	AD 1349	Late
Unit 1, 46 cm	*Mytilus californianus*	AD 1215	MLT/Late
Unit 1, 48 cm	*Mytilus californianus*	AD 1171	MLT/Late
Unit 1, 50 cm	*Haliotis rufescens*	AD 1163	MLT/Late
Unit 1, 56 cm	*Mytilus californianus*	AD 994	Middle/Late
Unit 1, 60 cm	*Mytilus californianus*	AD 915	Middle/Late
Unit 1, 60 cm	*Haliotis rufescens*	AD 1038	MLT/Late
Unit 1, 69 cm	*Haliotis rufescens*	AD 1182	MLT/Late
Unit 1, 79 cm	*Mytilus californianus*	AD 805	Middle/Late
Unit 1, 80 cm	*Haliotis rufescens*	AD 1073	MLT/Late
Unit 1, 80 cm	*Mytilus californianus*	AD 1217	MLT/Late
Unit 1, 80 cm	Charcoal	AD 1219	MLT/Late
Unit 1, 80 cm	Charcoal	AD 1220	MLT/Late
Unit 1, 80 cm	*Mytilus californianus*	AD 1242	MLT/Late
Unit 1, 80-90 cm	*Olivella* G1 bead	AD 1327	Late
Unit 1, 90 cm	*Mytilus californianus*	AD 1199	MLT/Late
Unit 2, 10-20 cm	*Olivella* G1 bead	AD 819	Middle/Late
Unit 2, 20-30 cm	*Olivella* K1 bead	AD 1308	Late

Sites Used as Comparative References

CA-SMA-18

North of Monterey Bay on the open coast, in Año Nuevo State Reserve, SMA-18 was on a stabilized sand dune surrounded by mostly sandy beach habitat, but with some rocky areas nearby. Though currently an elephant seal breeding ground, the rookery was established in the historic period, so elephant seals would not have been present during SMA-18's occupation (Hildebrandt et al. 2006).

This was a rapid-recovery salvage excavation, because elephant seal traffic during the breeding season was causing site erosion and degradation of bone and shell. The deposit was in a loose, massive sandy matrix. Over a long weekend, archaeologists from Far Western Anthropological Research Group, Albion Environmental, University of California at Santa Cruz, and several individual volunteers, excavated two one meter wide trenches, in 1x2 m segments, along the eastern and western edges of the dune. These alternated 1/8 in with 1/4 in screens for five units of 1x2 m. A third trench was then laid across the dune to join the two other trenches, and four other units were added, all screened with 1/4 in mesh. The deposit was shallow, so excavated only in two 20 cm levels. Four 20x20 cm column samples were collected in 10 cm levels and sorted through 1/16 in screens, and two flotation samples were gathered from features (Hildebrandt et al. 2006).

Radiocarbon dates and temporally diagnostic points indicate a single component, Middle Period site (Table 5.15), using the cultural chronology as published by Jones et al. (2007). If Breschini and Haversat's (2011) chronology were

used, some of the dates would fall in the Late Period. However, since SMA-18 is well north of Monterey Bay, the Jones et al. (2007) scheme may be more applicable. It is worth noting that regardless of cultural period, the site appears to have been occupied for barely 200 years.

Table 5.15. Radiocarbon dates from SMA-18, reported as "median probability" calibrated BP dates (Hildebrandt et al. 2006). It is unclear from the report if these include a marine correction factor. The *Mytilus* shell and charcoal specimens were collected from the surface. Periods divided with a slash indicate discrepancies in the cultural chronologies between Jones et al. (2007) and Breschini and Haversat (2011).

Provenience	Material	Date	Period
Surface	*Mytilus californianus*	AD 636	Middle
Surface	*Mytilus californianus*	AD 654	Middle
Surface	*Mytilus californianus*	AD 805	Middle/Late
Surface	*Mytilus californianus*	AD 757	Middle/Late
Surface	*Mytilus californianus*	AD 646	Middle
Surface	*Mytilus californianus*	AD 722	Middle/Late
Surface	Charcoal	AD 749	Middle/Late
Surface	Charcoal	AD 618	Middle
Surface	Charcoal	AD 674	Middle/Late
N4/E0, 0-20 cm	*Callorhinus ursinus*	AD 731	Middle/Late
N5/W11, 20-40 cm	*Callorhinus ursinus*	AD 578	Middle

More flaked stone artifacts were found than any other kind, but the assemblage included a diverse set of groundstone, bone, and shell items. Eighteen grooved and notched stones were probably used for fishing, eleven with slight pecking on opposite sides that would act as netsinkers, and seven with grooves all the way around that were more likely used as sinkers for hook-and-line fishing. One bipointed bone tool, a probable fish gorge, was also recovered, over 8 cm long (Hildebrandt et al. 2006).

Shellfish were mainly mussel (*Mytilus californianus*) and turban snail, with small amounts of abalone and chiton, and traces of other species. As Gifford-Gonzalez et al. (2006:29) described, the faunal remains indicate a "broad spectrum of animal resource acquisition of terrestrial and marine mammals, shorebirds, and an array of fish species." Rabbits dominate the assemblage, followed by medium-sized ruminants, and then northern fur seal. A variety of other marine mammals, carnivores, rodents, and elk were also identified. The fish remains, analyzed by Ken Gobalet, include two vertebrae most likely from a coho salmon (*Oncorhynchus kisutch*), which suggests coho are native to the area (Gifford-Gonzalez et al. 2006). Other fish species represent a selection from rocky intertidal, sandy beach, and offshore habitats. The range of sizes reflects people fishing with both nets and hook-and-line, supporting the artifact data (Hildebrandt et al. 2006).

Overall, Hildebrandt et al. (2006:16) described the artifacts recovered as, "a relatively wide range…[that] appear to represent a multi-activity residential occupation." Various birds, fishes, and northern fur seal indicate the site was at least occupied summer through winter.

CA-SCR-60/130

Finally, SCR-60 and SCR-130 were originally designated as two separate entities, but the most recent archaeological work determined they were connected and aggregated them into SCR-60/130 (Culleton et al. 2005). SCR-60/130 is on Monterey Bay, in a presently estuarine habitat near the Watsonville and Harkins Sloughs and the Pajaro River. Slightly over one kilometer west of the site, the

coastline is primarily sandy beach. However, the terrestrial habitat is drastically changed from prehistoric times, as the sea levels have risen since the earlier of the two occupations, the area is now intensively farmed, and much sedimentation has occurred over the intervening time (Culleton et al. 2005).

Pacific Legacy, Inc., performed data recovery at SCR-60/130 in 2000, to mitigate the effects of constructing a water pipeline through the area (Culleton et al. 2005). Excavations of the loamy sand deposits included multiple techniques, from hand-excavated units with arbitrary levels, screened with 1/8 in mesh, to backhoe trenching that was monitored for features. Most manual excavation centered on an area thought to be an intact deposit representing the period that Jones et al. (2007) call the Millingstone, and Breschini and Haversat (2011) call undefined, or Archaic. Test excavations and data recovery procedures encountered thirteen burials (Culleton et al. 2005).

All of the radiocarbon dates from non-burials fall into the Millingstone/Archaic Period (Table 5.16). Nine of the thirteen burials were dated, and sort into two groups, with seven occurring in the area in or near the controlled excavations, and dating to the same timeframe as the shellfish and animal bone. The other two burials are from the Early Period, c. 2500 BC, and were found in an area of the site without midden (Culleton et al. 2005).

Table 5.16. Single specimen radiocarbon dates from SCR-60/130 (Culleton et al. 2005). Dates are calibrated using CALIB 4.3, with a local reservoir correction of 225±35 RCY for the marine samples and human bone. Dates were originally reported as BP. In the Date column, "or" means two date ranges were provided in the site report, "and" means two samples were submitted for dating. For the cultural period, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

Provenience	Material	Date	Period
14 m NW of 1999 datum, 3 m W of benchmark, 0-15 cmbs	Burial 1999.1	5190-5180 or 5140-4840 BC	Millingstone/Archaic
Near Burial 1999.1	Burial 1999.2	5200-4810 BC	Millingstone/Archaic
Near Burial 1999.1	Burial 2000.1	4980-4720 and 5370-5060 BC	Millingstone/Archaic
CU-6, 13, and 16, 65-80 cmbs	Burial 2	5220-4900 and 5210-4900 or 4870-4860 BC	Millingstone/Archaic
CU-17, 68-83 cmbs	Burial 3	2660-2390 or 2380-2350 and 2560-2510 or 2500-2200 BC	Early Period
ET-8, 38 m NE of benchmark, 45-55 cmbs	Burial 4	5460-5260 and 5700-5360 BC	Millingstone/Archaic
ET-8, 65.9 m SW of benchmark, 55-65 cmbs	Burial 6	2840-2810 or 2760-2460 BC	Early Period
	Burial 8	5050-4780 BC	Millingstone/Archaic
	Burial 9A and 9B	5190-5170 or 5140-4830 and 5070-4780 BC	Millingstone/Archaic
TU1, 40-60 cmbs	*Protothaca* valve	4750-4440 BC	Millingstone/Archaic
TU1, 120-140 cmbs	*Protothaca* valve	5460-5250 BC	Millingstone/Archaic
TU5, 20-40 cmbs	*Protothaca* valve	5360-5070 BC	Millingstone/Archaic
TU5, 100-120 cmbs	*Protothaca* valve	5490-5290 BC	Millingstone/Archaic
CU-18A, 60-80 cmbd	*Protothaca* valve	5000-4710 BC	Millingstone/Archaic
CU-18A, 140-160 cmbd	*Protothaca* valve	5210-4930 BC	Millingstone/Archaic
CU-18A, 80-100 cmbd	*Clinocardium* valve	5590-5460 BC	Millingstone/Archaic
CU-18A, 140-160 cmbd	*Clinocardium* valve	5140-4900 BC	Millingstone/Archaic
CU-18A, 160-180 cmbd	*Clinocardium* valve	5130-4890 BC	Millingstone/Archaic
ET 4	*Zalophus californianus*	3780-3530 BC	Millingstone/Early
ET 7	*Cervus elaphus*	4900-4690 BC	Millingstone/Archaic

The stable isotope analyses performed on these burials to determine dietary composition, with Native American monitor concurrence, were covered in depth in

Chapter 3. Generally, they display diets high in marine resources, with somewhat more terrestrial foods included later in time (Culleton et al. 2005; Newsome et al. 2004). Based on the differences, Culleton et al. (2005:93-94) pointed out that the earlier people "may have spent more of the year based at SCR-60/130 than did the Middle Holocene group, which must have exploited other parts of the terrestrial environment than the coastal prairies near the site at least seasonally."

Subsistence remains at SCR-60/130 support the isotopic interpretations. Shellfish dominate the assemblage by weight, comprising 41,168 g compared to 3119 g of vertebrate bone, and mainly come from estuarine habitats. Ken Gobalet and Kalie Hardin analyzed the fish remains, identifying numerous cartilaginous species (sharks and rays), some freshwater taxa, several surfperches, and a small sample of mainly rocky intertidal fishes, totaling 196 specimens. The most common mammals are rodents, as is often the case, followed by elk and marine mammals. Several birds and reptiles also appear in the assemblage (Culleton et al. 2005).

Many groundstone artifacts were recovered from the site, including 11 millingslabs and 36 handstones, 22 mortars and 35 pestles. Culleton et al. (2005) say they identified nine netweights, but only seven are described in their table. Of those, four come from ET-7 and one from ET-8, with no further provenience. One was found in CU-18, at 120-140 cm below surface, and the last in SCA-4, on the surface. Though the millingslabs and handstones are typical Millingstone Period artifacts, I discussed in Chapter 3 the problems with correlation between the radiocarbon dates and groundstone artifacts. As a result, Culleton et al. (2005) did not want to

definitively assign the millingslabs and handstones to a "Millingstone Culture." However, because the dates fall into the Millingstone Period, I have incorporated the fish remains into my discussion in Chapter 8.

Generally, Culleton et al. (2005) made very few interpretations about site use for SCR-60/130. However, the burials, with Native American consent, provided important information on human subsistence during the two time periods represented at the site. The earlier group depended heavily on marine resources, and the later group apparently intensified their exploitation of terrestrial foods. Culleton et al. (2005) suggested that the proportion of terrestrial resources in the diet may reflect settlement and mobility patterns, but they did not further explain.

Summary

As is typical in the Monterey Bay area, Late Period deposits are sparser and seem to be less residential than sites from earlier periods. On the Monterey Peninsula, Late Period sites also tend to be heavy in abalone shell, with mussel (*Mytilus californianus*) appearing mainly in the more residential contexts. In all cases, however, the gathering and hunting of marine resources appears to have been an extremely important part of subsistence. While shellfish remains are particularly prevalent, significant quantities of fish, marine mammal, and waterfowl bones were also recovered from most of these sites.

Gobalet and Jones (1995) determined that, in general, Central Coast peoples exploited fishes from habitats close to the sites. To achieve an understanding of how

fishing in the Monterey Bay area changed over time, I therefore look at both estuarine and rocky/sandy shoreline sites. The sites I have described here represent a variety of time periods and habitats, thus providing both synchronic and diachronic perspectives on fishing through time (Table 5.17). In terms of site function, most sites are interpreted as representing residential bases, with a few exceptions from the Late Period, when use of the coast seems to have changed (Table 5.18).

Table 5.17. Components and nearby habitats for sites from which I include ichthyofaunal data in this dissertation. Sites are organized north to south, and grouped by area. For the temporal components, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

	Site	Temporal Components	Habitat
	SMA-18	Middle and Middle/Late	Sandy beach, open coast, some rocky shore, freshwater
Estuary	SCR-60/130	Millingstone/Archaic, Millingstone/Early, and Early	Estuary, freshwater
	MNT-228	Millingstone/Archaic and Middle	Estuary, freshwater
	MNT-229	Millingstone, Middle, and possibly Late/Protohistoric	Estuary, sandy beach, freshwater
	MNT-234	Millingstone and Middle(?)	Estuary, sandy beach
Pacific Grove	MNT-112	Early and Late	Rocky shore, sandy beach, kelp forest
	MNT-113A	Late	Rocky shore, sandy beach, kelp forest
	MNT-113B	Middle	Rocky shore, sandy beach, kelp forest
	MNT-113D	Early and Late	Rocky shore, sandy beach, kelp forest
	MNT-831	Millingstone, Early, Middle, Late	Rocky shore, sandy beach, kelp forest
	MNT-125	Late	Rocky shore, open coast, kelp forest
Carmel Bay	MNT-170	Early, some Late	Rocky shore, open coast, kelp forest
	MNT-834B	Middle-Late Transition/Late, Late, and Protohistoric	Sandy beach, protected, some rocky shore, kelp forest
	MNT-17	Millingstone/Archaic, Early, and MLT/Late	Rocky shore, sandy beach, kelp forest, freshwater
	MNT-1701	Middle/Late, Middle-Late Transition/Late, and Late	15 km inland from Carmel Bay

Table 5.18. Site functions as interpreted by the authors of the original site reports. For the temporal components, if dates fall during a span when Jones et al. (2007) and Breschini and Haversat (2011) use different names, both are listed, with Jones et al. first.

	Site	Temporal Components	Function
	SMA-18	Middle/Late	Not interpreted in site report
Estuary	SCR-60/130	Millingstone, Early	Not interpreted in site report
	MNT-228	Millingstone	Probably residential site
	MNT-228	Middle	Residential base
	MNT-229	Middle	Seasonal residential base, mobile groups
	MNT-234	Millingstone	Residential base, mobile groups
	MNT-234	Middle	Year-round residential base with specialized pelt processing
Pacific Grove	MNT-112	Early and Late	Seasonal residential base
	MNT-113A	Late	Seasonal residential base
	MNT-113B	Middle	Seasonal residential base
	MNT-113D	Early and Late	Seasonal residential base
	MNT-831	Millingstone/Early	Residential base
	MNT-125	Late	Temporary campsite or small villlage, not specialized
Carmel Bay	MNT-170	Early	Residential site
	MNT-170	Late	Abalone processing site
	MNT-834	Middle-Late Transition/Late	Seasonal camp or small village
	MNT-17	Early	Residential site
	MNT-17	Late	Abalone processing site
	MNT-1701	Middle-Late Transition/Late	Residential site part of large village complex

Screen size used in excavation, and the vertical or horizontal separation of material in multi-component sites, are two important factors in determining the reliability of assemblages. I discuss both of these topics in more detail in the next chapter, explaining why they are necessary to consider, and evaluating the quality of the assemblages I analyzed.

CHAPTER 6

Zooarchaeological Methods

In Chapter 5, I described the sites from which I analyzed fish remains for this dissertation. In any diachronic study of fishing practices, two considerations are particularly important for assessing whether these sites provide representative samples to address my research questions: specimen collection practices during excavation and discrete separation of temporal components. After a brief but necessary discussion of terminology, I address each of these in depth in the first part of this chapter. In the second part, I describe my primary data collection practices for the zooarchaeological assemblages I analyzed. In the final section of this chapter, I briefly cover the fish species I sent for proximate analyses.

What are "Small" Fishes?

Screen size, as summarized more fully in the next section, is critically important in the recovery of small fish taxa. However, in much of the archaeological research referring to acquisition of fishes in California, researchers address the issue of "small" fishes without clearly defining what they mean by the term. A reading of the literature suggests that small fishes are often considered those taxa with bones that might be caught in 1/8 in screens, but more certainly in 1/16 in screens (e.g., Gobalet 1989; Jones and Kennett 1999; Pletka 2001; Rick and Erlandson 2000; Rick and Glassow 1999). Dr. Virginia Butler (2004), a specialist in archaeological fish remains, included fishes less than 20 cm in length in a category of "very small."

Here, I define small taxa as reaching a maximum total length (TL) of less than 30 cm, including sardine and herring (Clupeidae), silversides (Atherinopsidae), Northern anchovy (*Engraulis mordax*), small surfperch (Embiotocidae), small rockfish (*Sebastes* spp.), small pricklebacks (Stichaeidae), etc. Many of these taxa are usually found at sizes much smaller than 30 cm. All but anchovy are frequently well represented in 1/8 in screens in Monterey Bay area archaeological sites. I define very small fishes as those less than 15 cm long. While vertebrae of very small fishes might not be caught in 1/8 in screens, other skeletal elements are. For example, the threespine stickleback, at 10 cm TL or smaller, is often represented by its spines, pectoral and pelvic fin elements. As I discuss below, while my divisions are mainly based on natural breaks in maximum length among Monterey Bay taxa, fishes smaller than 30 cm are also often processed differently than larger individuals (e.g., Stewart and Gifford-Gonzalez 1994; Zohar and Cooke 1997).

Collection Practices

Several experimental studies indicate that the mesh size of screen used during excavation can have a significant effect on species representation in faunal assemblages. Beyond the screen size studies that emphasize mammals (Cannon 1999; Shaffer 1992; Shaffer and Sanchez 1994), several detail the degree to which larger screen sizes problematically affect the taxonomic representation of fishes.

Early in research on the effects of screen size, Casteel (1972) showed that significant taxonomic diversity could be lost if material was screened through 1/4 in mesh, including in some cases *all* evidence of fishes. Much greater quantities of bone

are usually recovered from 1/8 in versus 1/4 in screens, and taxa identified in 1/4 in and 1/8 in mesh do not entirely overlap (Gordon 1993; Nagaoka 1994). In some cases, the use of smaller screens can completely change interpretations about peoples' use of animals, even affecting ordinal level taxonomic rankings (Cannon 1999). For example, the only substantial information on fish use from the Hohokam in the American Southwest comes from one site that used 1/8 in and 1/16 in screens. At other Hohokam sites where archaeologists used larger mesh, they hardly recovered any fish remains (James 1997).

McKechnie's (2005) research at Ts'ishaa, on the Broken Group Islands near Vancouver, found that the percent of specimens of three species in his assemblage differed drastically between remains recovered with 1/4 in versus fine-screen (1/8 in and 1/16 in) mesh: herring and anchovy rose from 1.8 to 53.3% and 1.2 to 17.8% respectively. Rockfish, on the other hand, decreased from 65.3 to 11.0%. These percentage differences argue strongly for use of smaller mesh (1/8 in or 1/16 in) to collect less biased faunal samples, an argument also supported by Zohar and Belmaker's (2005) research in Australia.

Comparisons between 1/8 in and 1/16 in screens are less common than those showing that 1/4 in screens are insufficient. Butler (1996) compared 1/8 in and 1/16 in mesh at a Stillwater Marsh site in the western Great Basin, and determined that tui chub would have been the dominant taxon in either case. However, remains from only three total species were identified in the assemblage, so Stillwater Marsh may be an unusual example. A few archaeologists working on Santa Barbara Channel sites

have compared 1/8 in and 1/16 in screening of fish bones, and concluded that 1/16 in does increase the representation of small fishes, though, again, "small" is not precisely defined (see Rick and Erlandson 2000 for citations).

Rick and Erlandson (2000) emphasized the importance of using 1/16 in screens to retrieve smaller fish, which in their study mostly included clupeids (sardine or herring) and small surfperch, but they did not provide much detail on the difference in data between their 1/16 in and 1/8 in fractions. Rick and Glassow (1999) cited Pletka's (1996) work at Santa Cruz Island, where small fish remains increased by 14% when using 1/16 in mesh instead of 1/8 in. Rick and Glassow's (1999) work at CA-SBA-53 used only 1/8 in mesh, and they suggested that, while the use of 1/16 in mesh would likely increase the numbers of small fishes, that increase is generally accompanied by a much greater proportion of unidentifiable bones. Additionally, they argued, "the relatively large number of fish bones recovered using 1/8-in. mesh, including hundreds of bones from small taxa, suggests that the data presented in this analysis are sound for determining the importance of the various fish taxa present in the deposits" (Rick and Glassow 1999:240).

At MNT-234, excavators collected bulk column samples for wet screening and flotation using 1/8 in and 1/16 in screens, in an attempt to identify which taxa and in what proportions might be lost by using only 1/8 in screens during most of the excavation. In Figure 6.1, I compare the 1/8 in and 1/16 in screen column samples to the overall excavated sample (1/8 in), using the previously analyzed data from Milliken et al. (1999). To make the graph easier to read, taxa that were represented by

fewer than 10 bones in the site, and unrepresented entirely in the column sample, were removed from the comparison. All temporal components at the site have been combined to raise the bulk sample size. The column samples produced fairly low numbers of specimens; total number of identified specimens (NISP) for fish was 265 for the 1/16 in fraction, and 16 for the 1/8 in fraction, but only 76 and 11 bones respectively were identifiable to more specific taxa than "fish." Despite the small NISP from the column samples, the results substantiate the complexity of considering various screen sizes.

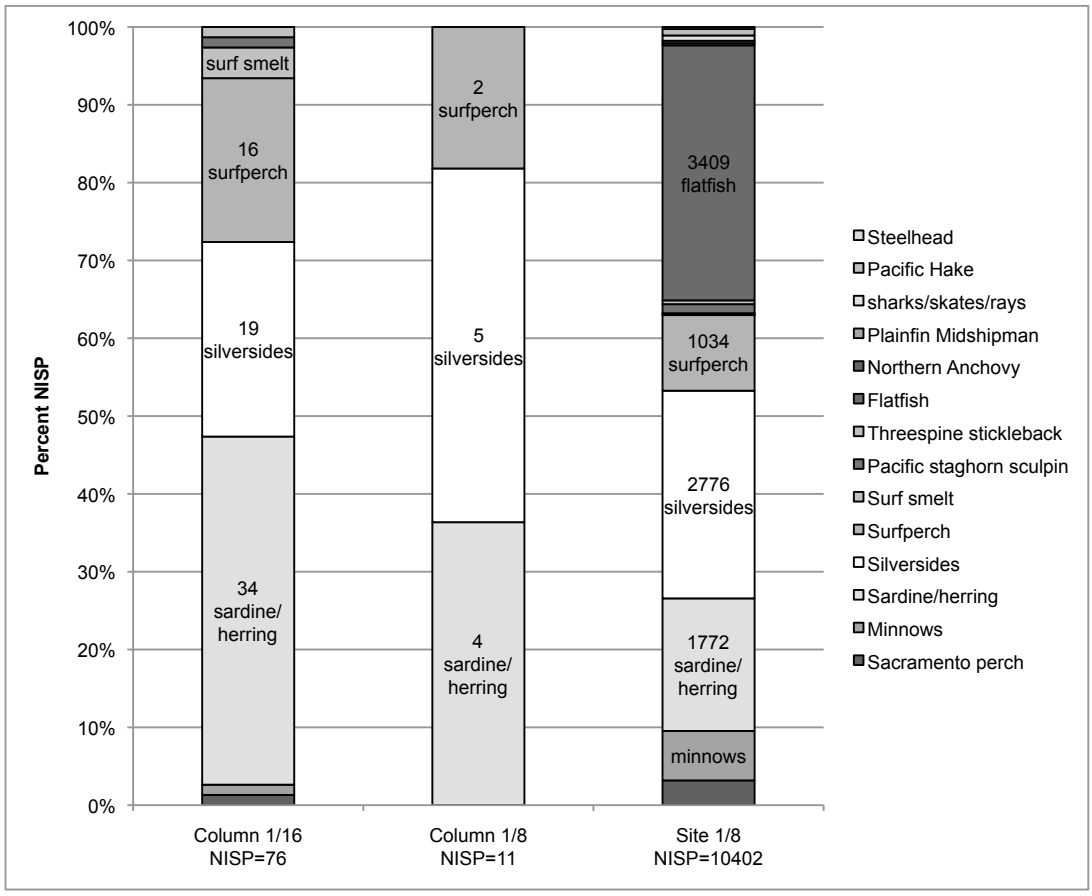


Figure 6.1. Screen size comparison of previously identified ichthyofauna from MNT-234, all temporal components combined. Does not include taxa represented by less than ten bones total in the site.

In Figure 6.1, the numbers inside the chart are the NISP for the most abundant taxa. The 1/8 in fraction of the column samples clearly is not large enough to use for comparison, and taxonomic representation does not match that of the site as a whole, which was recovered with the same screen size. Nonetheless, it captures three out of the four most abundant taxonomic categories.

The 1/16 in fraction of the column samples is also relatively small, but includes a diversity of species. For the most abundant taxa, the sardine/herring and surfperch families are relatively much more abundant than they are in the site sample, while the silversides are fairly similar. The most striking difference between the 1/16 in column and the 1/8 in site sample is the 30% of flatfish represented in the whole-site, 1/8 in sample, which are completely absent from the column sample. This might indicate that small schooling taxa such as clupeids (sardine or herring), silversides (topsmelt and jacksmelt), and surfperch, are indeed underrepresented in the site as a whole. Though clupeids and silversides both reach lengths of c. 40 cm, clupeids, topsmelt, and smaller surfperches are most commonly found at total lengths of less than 30 cm.

However, most of the MNT-234 flatfish are smaller individuals, and likely comprise a large proportion of starry flounder, which spawn in estuaries and can live in very shallow water. While starry flounder can be caught on hook-and-line, net-fishing with some form of seine in shallow estuary water would also catch them. If flatfish at MNT-234 were likely to have been net-fished, then the 1/16 in column and the 1/8 in site sample are telling essentially the same story about the *kind* of fish

people are exploiting, in terms of the required technology, organization, habitat, and so forth: over 90% of fish in the assemblage were probably caught with nets.

Overall, at MNT-234, all taxa identified in the column samples were also present in the site assemblage, and numerous taxa identified in the wider site were entirely absent in the column samples. This may be directly related to sample size, and is of little importance on its own. However, some very small taxa were captured in the wider site sample despite the use of 1/8 in screens, most notably threespine stickleback, which reaches a maximum length of 10cm. The presence of very small taxa in the 1/8 in assemblage suggests that these species can be recovered even in 1/8 in instead of 1/16 in screens, much as Rick and Glassow (1999) argued. As in their findings, over 70% of the fish specimens from 1/16 in mesh were unidentifiable to taxon, thereby complicating achievement of an acceptably sized identifiable sample.

In sum, based on experience and the authors cited above, 1/8 in screens are essential for identifying the taxa defined here as small. While those taxa may still be underrepresented without the use of 1/16 in screens, their prevalence suggests that a 1/8 in mesh size should be adequate for looking at broader patterns. Northern anchovy is the one major taxon that might be completely missing from 1/8 in samples, and I refer to that possibility in my results and discussion.

Screen-size at Project Sites

In the Monterey Bay area, CRM firms have been using 1/8 in or smaller screens for many years now, so the capture of small and very small taxa is higher than some other areas. I summarize in Table 6.1 the screen sizes used for this dissertation's

sites, based on the data described individually for each site in Chapter 5. In some cases, fish remains were only recovered from proveniences screened with 1/4 in mesh, even if the site was excavated using smaller screens as well. Taxonomic representation from sites and proveniences screened with 1/8 in mesh will be emphasized in my results and discussion.

Table 6.1. Screening methods, processing location, and excavators at project sites. The last two sites are those used just for comparison, and were not analyzed for this dissertation. AC=Archaeological Consulting, Inc., ACRS= Archaeological Consulting and Research Services, Inc., AE=Albion Environmental, CDPR=California Department of Parks and Rec, DOT=California Department of Transportation, FWARG=Far Western Anthropological Research Group, NCAG=Northern California Anthropological Group, PL=Pacific Legacy, Inc.

Site	Screen size	Processing location	Excavators
MNT-17	1/8	Lab	AC
MNT-112	1/8 and 1/4	Probably field	ACRS
MNT-113	1/8 and 1/4	Probably field	ACRS
MNT-114	1/8 and 1/4	Probably field	ACRS
MNT-115	1/8 and 1/4	Probably field	ACRS
MNT-116	1/8 and 1/4	Probably field	ACRS
MNT-125	1/8	Lab	AC
MNT-170	1/8	Lab	AC
MNT-228	1/8, 1/4 and 1/16	Field and lab	Caltrans
MNT-229	1/8 and 1/4	Field and lab	DOT, and NCAG
MNT-234	1/8 and 1/16 column	Field and lab	AC, FWARG
MNT-831	1/8	Lab	AC
MNT-834	1/8 and 1/4	Lab	AC
MNT-1701	1/8	Lab	AC
SCR-60	1/8	Lab	PL
SMA-18	1/8, 1/4, and 1/16 column	Lab	AC, AE, CDPR, FWARG

During analyses, I screened assemblages in the lab into 1/8 in and 1/4 in fractions. Therefore, sites with fish bone only recovered from 1/4 in screens can be compared to 1/4 in fractions from other sites that have both. The 1/8 in fractions in

sites of similar temporal components and habitat locations may provide some insight into what could be expected to be absent from those sites excavated with 1/4 in mesh. Those sites sampled with 1/4 in screen will thus be examined for what they may be missing, and used interpretively in the context of better-sampled sites.

Discrete Temporal Components and Radiocarbon Dating

Directly dating fish specimens is essential, particularly for samples representing times of perceived changes in species abundances. Archaeological investigations in the Monterey Bay region have traditionally relied upon crossdating from charcoal and shellfish to date strata or sites. However, bioturbation of mainland coastal and slightly inland sites provides a challenge (Bocek 1986, 1992; Erlandson 1984; Johnson 1989), as does the location of most sites on sand dunes. As a result, sites with multiple components have a substantial potential for becoming mixed over time. This problem can be addressed by focusing on sites that are either single component, or where temporal components are horizontally separated.

I described each site's components in detail in Chapter 5, and summarize these data in Table 6.2, to show how many of the sites are single component or horizontally discrete. Sites listed as horizontally discrete have components separated from one another horizontally, and therefore inter-component mixing is less likely.

Overall, given the rather substantial effects that mixing can have, assemblages from contexts where vertical mixing is more likely were considered only after single-component and spatially segregated multi-component sites were analyzed.

Table 6.2. Number of components and their spatial relationship at project sites. The last two sites are those I used just for comparison, and did not analyze. For time spans when Jones et al. (2007) and Breschini and Haversat (2011) disagree on the period, I list both connected with a slash, with Jones et al.'s definition first.

Site	Temporal Components	Component Integrity
MNT-17	Millingstone/Archaic, Early, and MLT/Late Period	Horizontally discrete
MNT-112	Early and Late Period	Horizontally discrete
MNT-113A	Late Period	Single component
MNT-113B	Middle Period	Single component
MNT-113D	Early and Late Period	Horizontally discrete
MNT-125	Late Period	Single component
MNT-170	Early, some MLT/Late Period	Some vertical, some mixed components
MNT-228	Millingstone/Archaic and Middle Period	Horizontally discrete
MNT-229	Millingstone/Archaic, Middle, and possibly Late/Protohistoric Period	Some units horizontally discrete, some possibly mixed
MNT-234	Millingstone/Archaic and Middle Period	Horizontally discrete
MNT-831	Millingstone/Archaic, Early, Middle, Late	Horizontally discrete, some possibly mixed
MNT-834	MLT, Late, and Protohistoric Period	Horizontally discrete
MNT-1701	MLT/Late Period	Single component
SCR-60/130	Millingstone/Archaic and Early Period	Horizontally discrete
SMA-18	Middle/Late Period	Single component

In addition to the issue of mixed assemblages, recent research at the Moss Landing Hill Site (CA-MNT-234) revealed that shellfish and charcoal dates do not necessarily correlate with dates from animal bone (see Chapter 5). Until recently, most radiocarbon dates from Monterey Bay area sites were on shellfish, while dates on other material were relatively rare. Dating vertebrate specimens permits a crosscheck of potential temporal mixing, as at CA-SMA-18 (Año Nuevo Point), where dates on fur seal and *Mytilus* shells were in agreement, after the marine reservoir correction was applied (Hildebrandt et al. 2006).

The radiocarbon dates on CA-MNT-234 vertebrate material have made it clear that fish remains from each site, especially those from sandy matrices, need to be dated directly. In an ideal world, this project would have dated several fish bones from throughout the stratigraphic column at each site, to assure their chronology agreed with the dates from shellfish. However, budget limitations made such an undertaking impossible, and instead two fish bones were chosen to date from most sites.

Appendix 3 lists the samples submitted for radiocarbon dating, with taxon and element details. Because of the reservoir effect described in Chapter 3, I chose specimens from only marine fish species to date, since the marine correction factor is known, unlike those for Elkhorn Slough or the freshwater sources along the coast. Anneke Janzen performed the collagen extraction under my oversight at Dr. Paul Koch's isotope analysis lab in Earth and Planetary Sciences at the University of California, Santa Cruz. Laboratory procedures were modified from Brown et al. (1988), Stafford et al. (1988), and Tuross et al. (1988), and I can provide a detailed description upon request. The collagen was then sent to Lawrence Livermore National Laboratory's Center for Accelerator Mass Spectrometry for dating.

Primary Zooarchaeological Data Collection

All assemblages analyzed for this project came from previously excavated sites, and were sorted for fish bones before I received them. After analysis, I returned materials to their respective curation facilities, as presented in Table 6.3.

Table 6.3. Curation locations for the assemblages analyzed for this dissertation.

Site	Curation Facility
MNT-17	Monterey County Archaeological Archives, Salinas, CA
MNT-112	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-113	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-114	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-115	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-116	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-125	Monterey County Archaeological Archives, Salinas, CA
MNT-170	Monterey County Archaeological Archives, Salinas, CA
MNT-228	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-229	Monterey Bay Archaeological Archives, University of California, Santa Cruz
MNT-234	Moss Landing Marine Laboratories, Moss Landing, CA
MNT-831	Monterey County Archaeological Archives, Salinas, CA
MNT-834	Monterey County Archaeological Archives, Salinas, CA
MNT-1701	Monterey County Archaeological Archives, Salinas, CA

For each sample, stray mammal bones and shellfish fragments were removed and set aside for curatorial staff, and then the remaining fish specimens were sorted into categories of identifiable and indeterminate elements. I follow Grayson (1984) in defining a specimen as a whole or a fragment of archaeological bone or tooth, and element as a particular bone in a skeleton. Names for elements were based on Cailliet et al.'s (1996) *Fishes: A Field and Laboratory Manual on their Structure, Identification, and Natural History*, D.Y. Cannon's (1987) *Marine Fish Osteology: A Manual for Archaeologists*, and Rojo's (1991) *Dictionary of Evolutionary Fish Osteology*. For each specimen, I recorded values for a number of analytical categories, which are listed in Table 6.4 and described in detail next.

From sites screened with 1/8 in or larger mesh, bone fragments that passed through the 1/8 in screen were removed from analysis. This seemed the best way to deal with the tiny bone fragments that occur in the bottom of provenience bags due to

the friable nature of fish bones. Counts of indeterminate elements, when based only on pieces larger than 1/8 in, are thus mainly restricted to specimens collected during excavation.

Table 6.4. Data fields used during analysis and recording of fish remains.

Variable	Content Type/Range
Screen size	1/16, 1/8, 1/4 inch
Taxon	-
Element	See text
Side	Left, right, axial, indeterminate, NA
Landmark	Yes, no, indeterminate
Portion	Complete, fragment, indeterminate, NA
Size	See Table 6.5
Bone color	Munsell color codes, see Table 6.6
Burning	None, carbonized, calcined
Pitting	None, light, medium, heavy
Rounding	None, light, medium, heavy
Deformation	None, light, medium, heavy
Measurements	Mainly for surfperch, see Table 6.7

Taxonomic Identification

After the initial sort, identifiable specimens were divided into element and side of the body, then classified to the most specific taxonomic level possible, using numerous comparative skeletons on loan from the California Academy of Sciences Department of Ichthyology, a few from Dr. Virginia Butler (Portland State University), and my own personal collection built specifically for this dissertation research. For some elements, no discernable osteological difference exists among representatives of a genus or family, and I thus adopted a more conservative approach and assigned them to higher taxonomic levels than species. Some specimens resembled a particular species but, due to either comparative collection limitations or

specimen condition, could only be tentatively identified. Though marked as such (e.g., "cf. *Phanerodon furcatus*) in the database that will be available, I have treated them as definitive identifications for the analyses in this dissertation. Any specimens that were clearly fish and bone, rather than cartilage, but could not be assigned a more specific taxon, were referred to Actinopterygii (ray-finned fishes).

A few taxonomic categories merit more explanation here. First, salmonid elements are extremely difficult to identify to species. On the California Coast, only members of the genus *Oncorhynchus* are present, and their remains are rare in Monterey Bay area assemblages. For all salmonid specimens I analyzed, I only identified them as *Oncorhynchus* sp. Specimens listed as either coho salmon (*Oncorhynchus kisutch*) or steelhead/rainbow trout (*Oncorhynchus mykiss*) were identified by Ken Gobalet in previous analyses of the assemblage.

Second, leopard shark (*Triakis semifasciata*) vertebrae are also not easily distinguishable from other species in the same family (Gobalet et al. 2004). Based on modern species use of Elkhorn Slough, I argue that triakid vertebrae in my assemblages are most likely from leopard sharks. However, I identified one tooth from a soupfin shark (*Galeorhinus galeus*) based on Eschmeyer et al.'s (1983) drawings of shark teeth and confirmed by Ken Gobalet using comparative specimens, so the triakid remains are not entirely leopard shark.

Finally, my identification of batrachoid specimens as plainfin midshipman (*Porichthys notatus*) and not specklefin midshipman is based on their current range restriction to south of Point Conception (Eschmeyer et al. 1983).

Element Identification

Based on Virginia Butler's advice, I assigned one landmark for each element, normally the most robust part and often an articular surface. For example, the landmark on the maxilla is the articular surface on the dorsal side of the anterior end; the quadrate's landmark is the condylar surface on the ventral end. For each vertebra, I required the presence of greater than 50% of the centrum to assign a landmark. I then noted for each archaeological specimen whether the landmark was present.

A landmark system is commonly applied in ichthyozooarchaeological research (e.g., Butler 1990; Kopperl 2003; West 2009), and its purpose is to help in the later calculations of minimum numbers of individuals, or other derived quantification methods. If only specimens with landmarks present are used for calculations, this removes the possibility of counting the same element twice. Several elements and less identifiable categories, such as branchials, suborbitals, scales, and indeterminate ray/spine/ribs, were considered either too ambiguous in form for assignment of landmarks, or were not identified to taxon, thus rendering landmarks less important.

Fragmentation

To examine fragmentation, I employed a very simple method of classifying specimens: each was marked as a fragment (FR), complete (CO), or not applicable (NA). "Complete" specimens included all those more than 75% complete, except for vertebrae, which needed to be over 50% complete, as in the landmark category. I used NA when determining the degree of completeness was difficult or impossible; e.g.,

for branchiostegal rays, fin rays, indeterminate ray/spine/ribs, branchials, scales, and indeterminate elements.

Size

Each specimen was assigned a size category, as shown in Table 6.5, referring to the maximum total length that the identified species is known to reach. As such, it is a very broad classification. I created the categories using a list of all Pacific Coast fishes, and based the divisions mostly on where natural breaks in maximum total length seemed to occur. Small taxa and small individuals of medium taxa are also of a size more likely to be caught with nets or in tide pools, rather than with hook and line.

Table 6.5. Definitions of size categories used during analysis.

Size	Total length	Example taxa
Very small	<15 cm	Threespine stickleback
Small	15-29 cm	Northern anchovy, some rockfishes, some surfperches, and some pricklebacks
Medium	30-80 cm	Sardine, herring, some rockfishes, some surfperches, monkeyface prickleback
Large	81-169 cm	Some salmon, Pacific hake, cabezon, lingcod, jackmackerel, starry flounder
Very large	170-305 cm	Bat ray, salmon shark, sturgeon
Extremely large	>400 cm	Some sharks, swordfish

Fishes offer inherent complications for dividing into size categories, since, unlike mammals and birds, they all start as small fry, and then grow indeterminately. Additionally, some taxa I identified to the family or genus level include species that might fall into various size categories. Surfperches (Embiotocidae), and rockfishes (genus *Sebastes*), are two common taxa that reflect this problem. As a result, I

designated one individual of c. 30 cm total length from each of those taxa to represent the boundary between size classes. Specimens larger than elements from those individuals are considered medium sized, and the rest are small. I similarly used a 26 cm *Lavinia exilicauda* to estimate size for minnows and suckers (Cypriniformes). For most family and genus level identifications, whether or not the vertebrae fall through a 1/4 in screen is a close enough estimate of size.

Color

To explore both handling practices and taphonomy, I recorded bone color using a Munsell soil color chart (Munsell 1992). Most colors came from the 10 YR page, with some from 7.5 YR and 2.5 Y (Table 6.6). Burnt fish bones also occasionally take on a noticeably blue hue, and I assigned gley chart colors in those instances. Most archaeological fish bones are one color overall, but for some mottled specimens, I recorded the dominant color. Specimens of the same element and taxon that differed substantially in color received their own bags and catalog numbers.

Table 6.6. Munsell codes and color equivalents used during analysis.

Munsell codes	Munsell color
N3/	Very dark gray (gley chart)
N4/	Dark gray (gley chart)
N5/-N/6	Gray (gley chart)
N7/	Light gray (gley chart)
5B 4/1	Dark bluish gray (gley chart)
5B 5/1-6/1	Bluish gray (gley chart)
5B 7/1	Light bluish gray (gley chart)
2.5Y 8/2-8/4, 7/3-7/4	Pale yellow
7.5YR 4/6-5/8	Strong brown
7.5YR 6/3-6/4	Light brown
7.5YR 7/2-6/2	Pinkish gray

(continued on next page)

Table 6.6. (continued)

Munsell codes	Munsell color
7.5YR 8/3-8/4, 7/3-7/4	Pink
7.5YR 8/6, 7/6-6/8, 6/6-6/8	Reddish yellow
10YR 2/2	Very dark brown
10YR 3/1	Very dark gray
10YR 3/2	Very dark grayish brown
10YR 3/3	Dark brown
10YR 4/1	Dark gray
10YR 4/2	Dark grayish brown
10YR 4/4-3/6	Dark yellowish brown
10YR 5/1-6/1	Gray
10YR 5/2	Grayish brown
10YR 5/3-4/3	Brown
10YR 6/2	Light brownish gray
10YR 6/3	Pale brown
10YR 6/6-6/8	Brownish yellow
10YR 7/1-7/2	Light gray
10YR 8/1	White
10YR 8/2-8/4, 7/3-7/4	Very pale brown
10YR 8/6-8/8, 7/6-6/8	Yellow
10YR5/4-5/6	Yellowish brown
10YR6/4	Light yellowish brown

Modifications

To characterize how different types of fish were processed, thermal alteration to bones was noted. Since fish bones are rarely partially burned, specimens were noted as unburned, carbonized, or calcined. On the rare occasion when a specimen was only partially thermally altered, I recorded it as calcined if any portion was identifiable as such, or carbonized if obviously burned but not calcined. This allowed me to monitor the greatest degree of thermal exposure undergone by the specimen.

Cutmarks, carnivore marks, rodent gnawing, and root etching, are common modifications to mammal and bird bones with which I have experience working, and I recorded them on fish elements when found. However, in the Monterey Bay fish

assemblages, most of these modifications were non-existent, and root etching was minimal.

The possible presence of carnivore digestive acid was evaluated using criteria described by Butler and Schroeder (1998), who included pitting, rounding, and deformation as potential indicators of acid. I checked for these indicators only on unburned specimens identifiable to element, but excluding fin spines, rays, pterygiophores, branchials, scales, or suborbitals, because these elements are difficult to taxonomically identify beyond the level of Actinopterygii (ray-finned fishes).

Butler and Schroeder (1998:959) define *pitting* as, "the presence of pits or small cavities on relatively flat surfaces of bone." I checked for pitting on the flat surfaces of most specimens. For vertebrae, I only recorded pitting on the face of the centrum. *Rounding*, according to Butler and Schroeder (1998:960), "refers to the condition of broken edges or worn down original surfaces of specimens," often along the edge of vertebral centra, "in the form of one or more scallops or crenulations." I paid particular attention to vertebral centra edges when recording rounding. Another potential result of carnivore acid is *deformation*, most frequently of vertebrae (Butler and Schroeder 1998). I recorded deformation for any specimens that exhibited it, which ultimately comprised mainly vertebrae, as Butler and Schroeder (1998) noted.

In addition to carnivore acid, excavation and screening damage can also cause pits and erosion of bone specimens. Therefore, I considered the color of the modification when determining whether it was caused in the past or in modern times. If the modification exposed inner bone structure of a noticeably different color than

the outer surface, I assumed this signaled an effect of excavation or screening, and did not record it as acid.

Size Estimates

Research on several fish species has shown that nearly all bone element measurements significantly correlate with body length (e.g., Hansel *et al*. 1988; Owen and Merrick 1994; Zohar *et al*. 1997). Changes in average element size have been viewed as a reflection of body size in investigations of resource depression, especially exploitation depression (e.g., Broughton 1997). Most fishes are probably difficult to overharvest with pre-industrial fishing technology, since they either lay high numbers of eggs (into the millions) or give birth to multiple young, many species migrate long distances, and larvae and juveniles can disperse well outside of their natal zone. However, some viviparous (live-bearing) species with smaller brood sizes may be more susceptible to resource depression, whether exploitation, behavioral, or microhabitat depression. I therefore focused my measurements, listed in Table 6.7, on a set of surfperch elements, since species from this family are viviparous and have much smaller brood sizes than most other fish species common in coastal California archaeological assemblages. Although surfperch elements are usually identifiable only to genus or family level, a shift to smaller elements should reflect people taking smaller fishes, whether smaller individuals of the same species, or smaller species (Butler 2001). This may indicate some form of exploitation depression (Butler 2001), especially if the larger and smaller individuals were all probably caught with the same form of fishing technology.

Table 6.7. Measurements taken on surfperch (Embiotocidae) specimens.

Element	Measurement Description
Vomer	Widest part of triangle
Vomer	Width of ventral ridge, just posterior of triangle
Basioccipital	Centrum width
Parasphenoid	Width just posterior to the lateral wings
Parasphenoid	Width of the wide ventral, posteriormost projection
Premaxilla	Dorsoventral length of anteriormost projection (without teeth)
Premaxilla	Total length of toothplate (straight length between ends, not curved)
Dentary	Dorsoventral length of symphysis
Dentary	Symphysis to lateral fork between dorsal and ventral limbs
Angular	Articular surface to posteriormost point of main limb
Angular	Dorsoventral length of posterior edge, without retroarticular. From dorsal edge of angular, to ventral edge of articular surface
Quadrate	Width of condyles
Quadrate	Condyles to dorsal edge that connects with the metapterygoid
Lower pharyngeal	Anteroposterior measurement of toothplate along the central line, not including the untoothed pointy tip
Otolith	Maximum length
Otolith	Maximum width

Curation and Documentation

After analysis, I bagged each specimen with others only if all had the same values for every data category (e.g. left quadrate, fragment, *Sebastes* sp.). Each bag was assigned a catalog number, which allowed correlation of the identified specimen(s) with the database entry. I used FileMaker Pro® Version 10.0 to create a relational database for each site's material.

Quantification

Zooarchaeological counting methods possess inherent problems, and because zooarchaeologists usually deal with fragmentary samples of a larger, probably skeletally selected population, a perfect method of quantification is unlikely to exist. Numbers of identified specimens, or NISP, is the simplest method of quantification,

being the count of each individual fragment (Grayson 1984). NISP is the observed number of actual specimens, and unaffected by how the assemblage is aggregated. However, when archaeologists use NISP statistically, they assume each specimen is independent, meaning that no specimens came from the same individual. Because NISP counts each fragment separately, this assumption might frequently be false (Grayson 1984; Reitz and Wing 1999).

Fragmentation can also substantially and differentially affect taxonomic abundances when counting with NISP. This is less problematic for fish remains, however, because of the way fish bones break; specimens frequently either have a landmark or are unidentifiable. Additionally, if specimens without landmarks are removed from consideration, the ones left each only represent one element. The relationship of specimens with landmarks to those without also provides a measurement of the degree of fragmentation in an assemblage.

That various vertebrate taxa have varying numbers of bones also influences taxonomic abundances. Fishes have evolved over 500 million years, and more derived taxa typically (but not always) have fewer vertebrae, vertebral accessory bones, bones in the skull, and bones in the tail (Helfman et al. 1997). For instance, salmonids, a more ancestral family of fish, have on average 60 vertebrae each (Butler 1990), whereas *Sebastes* sp., a more derived genus, average 26 vertebrae (Chen 1986). Moreover, individuals within the same species can have differing numbers of bones. Sardine (published as *Sardinops caerulea*, now considered *Sardinops sagax*)

along the Pacific Coast of North America, for example, range from 49 to 54 in the number of vertebrae an individual has (Clark 1936).

Some derived quantification methods, by contrast, can account for specimen interdependence and sometimes for fragmentation but in turn are affected by aggregation effects. Minimum numbers of individuals, or MNI, is a commonly used derived value that quantifies the fewest number of individual animals required to create an assemblage. It corrects for differing numbers of skeletal elements among taxa, and for differential fragmentation when calculated to do so.

The problem of aggregation effects arises only in samples that are subdivided by strata or some other subsampling methods, such as cooking features. It stems from the necessity of choosing the most abundant element in each subsample with which to estimate MNI. The most abundant element can vary from one subsample to another, depending on how the assemblage is divided, and therefore the total site MNI can also change (Grayson 1984). Since MNI values can fluctuate according to assemblage subdivision or aggregation, taxonomic abundance ratios can also change, which Grayson (1984) argued makes them inappropriate for use in statistical analyses. Most of the sites I analyze in this dissertation are single-component and excavated without division into natural strata, so specimens from all arbitrary levels usually are treated as a single sample. Thus, the risk of aggregation effects in the use of MNI is less relevant. However, MNI values can also be tightly predicted from NISP in most cases (Grayson 1984), and as a result, I quantify my assemblages using NISP.

Early in the history of zooarchaeology, researchers used bone weights or numbers to calculate meat weights, but the relationship is not a linear one, making the validity of the method questionable (Grayson 1979; Ringrose 1993). Meat weight calculations are based on an "average" individual that does not take into account variations in animal body size (Grayson 1979), which is known to differ widely geographically and to change over time (Reitz and Wing 1999). Meat weights calculated from bone numbers are also based on MNI, and are subject to the same aggregation problems as MNI in stratified or otherwise subdivided samples (Grayson 1979). Bone weight is an inappropriate measure, because it can be altered by taphonomic processes such as mineralization or leaching, or even vary within a living animal population based on factors such as age, where bones of very old and very young animals are normally less dense (see Lyman 1994; Reitz and Wing 1999; and citations therein). Because of these critiques, I use counting methods and not bone weight to quantify my assemblages.

Meat weight calculations can also be affected by butchery and differential transport of body parts. With fishes, most of the meat is on the trunk, which means butchery, if it occurs, is mainly restricted to removing the head. With salmon, the heads may be retained, but processed differently from the body, because the heads are particularly fatty (Butler 1993). On larger fish, the fins may also be removed and the trunk cut into pieces for cooking (Stewart and Gifford-Gonzalez 1994; Zohar and Cooke 1997). Small fishes are often left whole; e.g., the Dassanetch and Turkana in Kenya did not process fishes less than 30 cm in length (Stewart and Gifford-Gonzalez

1994); fishes shorter than 32 cm standard length in Parita Bay, Panama, were only gutted (Zohar and Cooke 1997); and in California, the Tolowa simply laid out smelt to dry whole on the beach (Gould 1975; Halperin 1980). Butchery should therefore have little effect on meat weight estimates. Most of the species in my assemblages are small, and would easily have been caught near the sites sampled, and therefore they were probably processed minimally, if at all, before transport to a residential base.

The proportion of cranial to post-cranial remains can help identify whether processing occurred. High frequencies of cranial remains with few post-cranial elements would suggest they the bones were recovered from a processing site, from which the trunks were then removed (Butler 1993; Hoffman et al. 2000). High proportions of post-cranial bones are one indicator of a culturally deposited assemblage, whether due to butchery and transport, or differential culinary processing of fish body parts (Butler 1993; Hoffman et al. 2000; Zohar et al. 2001). This assumes fishbone preservation was good, which must be determined based on other criteria.

Because of the simple processing that may have occurred with fishes, and the small size of those species in Monterey Bay area assemblages, the assumption that one MNI equals one whole fish is more reasonable than it is for mammals, or even larger fishes caught at a distance from their final destinations, which could be subject to more butchery (e.g., Hoffman et al. 2000). However, the problem remains of estimating the individual fish's size, and the concept of an "average weight" of an individual is not applicable to organisms with indeterminate growth (Reitz and Wing 1999:226-227). Due to these concerns, I do not calculate meat weights.

Biomass estimates are sometimes made based on skeleton weight, because the relationship between skeleton and body weight scales with size in all animals (Reitz and Wing 1999:70-71). Allometric regressions formulated for specific taxa could help accuracy in this, because some variation exists. However, biomass estimates still do not address the problem of taphonomic processes that can affect bone weight, and this makes comparing results from different site assemblages difficult. Calculating biomass within one site may be less problematic, assuming that all specimens have undergone the same degree of diagenesis.

Statistical Analysis

When comparing taxonomic content of assemblages, I used a Fisher's Exact statistical test in several cases to assess whether two assemblages were independent. While Pearson's chi-squared tests are more commonly used in archaeological research, they typically require larger sample sizes, and few entries with cells of $n<5$ (Freund 2001). Because my assemblages sometimes had small sample sizes or varied widely in their taxonomic content, leading to low or zero counts in several cells, a Fisher's Exact test was more appropriate. I ran the analyses in R, an open source programming language, which uses Monte Carlo simulation on the Fisher's Exact test for larger tables. With larger sample sizes, or pooled data, I switched to chi-squared analyses, or used both to double-check results. The chi-squared test produces an X^2 statistic, degrees of freedom (df), and a p value, where if $p<0.05$, I interpret the samples as being independent, that is, unlikely to have been drawn from a similar

parent population. A Fisher's Exact test only produces a *p* value, but I use the same 0.05 threshold.

Proximate Analysis

The USDA National Nutrient Database provides nutritional information for only a small subset of the North Pacific fish taxa found in Monterey Bay archaeological sites (http://www.nal.usda.gov/fnic/foodcomp/search/). An extensive literature search produced proximate composition (fat, protein, ash, and moisture content) for some additional species, mainly from fisheries research (e.g., Sidwell et al. 1974; Stansby 1976). However, many archaeologically prominent taxa are not commonly consumed today, and the literature lacks information on their nutritional yields.

Because I wanted to include such data in my analyses, I sent several flesh samples from such species to Covance Laboratories in Wisconsin. The samples all derived from wild individuals caught along the California coast, as it is understood that captive fishes have different diets and often very different proportions of lipids than do wild conspecifics. These are listed in Table 6.8, including the person or event from which I acquired the fishes, and the specific locations they were caught if known.

Table 6.8. Samples sent to Covance Laboratories for proximate analysis.

Species	Common name	Provenience
Scorpaenichthys marmoratus	Cabezon	From Jim Russell. Caught at Bean Hollow, near Pescadero, 7/16/10.
Scorpaenichthys marmoratus	Cabezon	From Jim Russell. Caught at Bean Hollow, near Pescadero, 7/16/10.
Scorpaenichthys marmoratus	Cabezon	Monterey Bay, MLML ichthyology class.
Atherinopsis californiensis	Jacksmelt	From Jim Russell. Caught in Monterey Bay, 2010.
Atherinopsis californiensis	Jacksmelt	From Jim Russell. Caught in Monterey Bay, 2009.
Atherinopsis californiensis	Jacksmelt	From Jim Russell. Caught in Monterey Bay, 2009.
Cebidichthys violaceus	Monkeyface prickleback	From Kirk Lombard, caught in San Francisco Bay, February 2011.
Cebidichthys violaceus	Monkeyface prickleback	From Kirk Lombard, caught in San Francisco Bay, February 2011.
Xiphister mucosus	Rock prickleback	From Dustin McKenzie. Caught on coast north of Santa Cruz, February 2011. Combined fillets of two individuals.
Xiphister mucosus	Rock prickleback	From Dustin McKenzie. Caught on coast north of Santa Cruz, February 2011. Combined two whole, gutted fish.
Amphistichus argenteus	Barred surfperch	Santa Cruz Surfperch Derby 3-20-10.
Amphistichus koelzi	Calico surfperch	Santa Cruz Surfperch Derby 3-20-10.
Amphistichus koelzi	Calico surfperch	Santa Cruz Surfperch Derby 3-20-10.
Embiotoca jacksoni	Black surfperch	Santa Cruz Surfperch Derby 3-20-10.
Embiotoca jacksoni	Black surfperch	Santa Cruz Surfperch Derby 3-20-10.
Embiotoca lateralis	Striped surfperch	Santa Cruz Surfperch Derby 3-20-10.
Embiotoca lateralis	Striped surfperch	Santa Cruz Surfperch Derby 3-20-10.
Embiotoca lateralis	Striped surfperch	Santa Cruz Surfperch Derby 3-20-10.
Hyperprosopon argenteum	Walleye surfperch	Central Coast of California.
Paralichthys californicus	California halibut	From Jim Russell. Caught at Bean Hollow, near Pescadero, 7/16/10.

Summary

The sites analyzed for this dissertation provide a good sampling of cultural periods in the Monterey Bay area, but also vary in stratigraphic integrity and recovery methods quality. Based on these, I have ranked samples into two groups. The first includes sites with little evidence of mixing, in which the direct dates on shell or

charcoal and fish bone display concordance, and which were excavated using 1/8 in screens. Fortunately, at all of the sites where my samples for dating produced results, they agreed with the shellfish and charcoal dates. Therefore, the second group includes sites with small sample sizes, or where excavation only used 1/4 in mesh in areas where bone was recovered. These latter sites are either excluded or treated with circumspection in my discussion and interpretations in Chapters 8 and 9. In the next chapter, I present a dynamic state variable model as a new approach for making predictions about the zooarchaeological record.

CHAPTER 7

A State-Dependent Foraging Model

In Chapter 5, I discussed how dynamic state variable modeling (DSVM) addresses some of the problems of rate-maximization models in behavioral ecology. DSVM permits the exploration of what factors are important to a forager's decisions, what it costs the forager not to reach optimum fitness, and how the forager's state can affect which choices are optimal (Mangel and Ludwig 1992). Because I wished to explore the differential value and costs of obtaining fishes in general and specific taxa in varied habitats with different risks, I decided to develop a DSVM for this dissertation, instead of using a traditional rate maximization model.

I chose to explore a patch choice model because I am particularly interested in why prehistoric coastal peoples might exploit different resources from very different patches, such as fishes from a local estuary, or deer from a terrestrial patch. Oftentimes, archaeologists discount the importance of fishes, despite studying groups that live in areas with access to incredibly rich marine and estuarine resources. Even when fishes are acknowledged as an abundant resource, they are often considered a second-choice prey item, probably because they are generally smaller than commonly exploited terrestrial animals like deer. However, fishing may be a more dependable method of acquiring resources than hunting, even if the individual packages of meat are smaller, and it is also potentially a safer activity, or one that can be done by many members of a group, including, for example, children.

"Patches" in this model can be thought of as equivalent to exploiting a particular prey type – species that have similar behavior and can be caught with the same technology in a specific habitat. Broughton (2002), for example, divides patches into terrestrial mammals, estuarine fishes, and waterfowl, and then ranks resources separately within each "patch."

Developing a dynamic state variable model to explore foraging behavior requires two main parts. I use a backward iteration, or stochastic dynamic programming (SDP) equation, to calculate the optimal decision to make at any given state and time. Afterward, I use a forward simulation to display the results of a forager making optimal decisions through time, while her state changes as a result of the decisions she makes. The backward iteration uses probabilities (e.g., probability of predation, probability of catching prey, etc.) in the creation of a decision matrix, and the forward simulation applies those probabilities to a forager's decisions to determine the outcome. The model is formed so that the forager's goal is to optimize her fitness (requiring her survival), not maximize her energetic rate of return.

I programmed the model in R, a free software environment available at http://www.r-project.org/. The equations for the model are explained below, and the code can be found in Appendix 4. I created the model relying heavily on Clark and Mangel (2000) and Mangel and Clark (1988).

My results show that energetic rate of return – what I call the mean benefit of exploiting a patch – is predicted to be a less important factor in subsistence decisions than several other variables, especially the probability of successfully exploiting the

resource under consideration. Note that this is not the same as the rate of encounter, because it is a measurement of how often a forager actually *acquires* the resource she is seeking, rather than how often she finds it. The cost of resource exploitation and the possibility of injury or death also have a large effect on predictions of patch choice. Foragers are predicted to most often exploit safer, less costly resources, even if those foods provide a lower benefit. Furthermore, the forager's physiological condition is predicted to affect her decisions, so that the optimal patch to exploit can change even without a shift in environmental conditions. In this chapter, I describe the model's construction, the general results, and my interpretation of the implications of those results. I provide the more specific results of my sensitivity analysis in Appendix 5.

Parameters

I define two main regions in the model, A and B, which represent the coast and inland, respectively. Region A comprises three patches. Patch 1 is a resting patch, where a forager does not attempt to acquire resources, but also has zero probability of mortality, based on the assumption that hunting prey is more dangerous than resting. This could be considered equivalent to a home base. Patches 2 and 3 are resource patches, which are defined using several parameters as listed below. The forager can move to any of the patches at each point in time, or can choose to abandon the region entirely and move to Region B (inland), at which point the model stops.

I define the parameters for the model, forager, and each patch and region in Table 7.1. I consider the forager's state to be her energy reserves. Patch parameters include the cost of pursuing prey, the probability of injury or death while foraging, the probability of finding prey, and the benefit of catching prey in each patch. The cost and benefit of each patch are used to adjust the forager's state value. In this model, these probabilities may differ among patches, but do not change based on the forager's state. The forager's state, however, does vary, which subsequently affects her patch choices and risks assumed.

Table 7.1. Parameters in the state dependent model

Symbol	Description
t	Current time step in the model
T	Number of time steps in model
x	State value (energy reserves)
$x_{\max}$	Maximum state value of forager
x_c	State value at or below which forager dies
x_o	Parameter used to make fitness non-linear
i	Labels for patches
i^*	Optimal patch to exploit
l	Forager's location (whether in Region A or B)
α_i	Cost of pursuing prey in each patch
β_i	Probability of mortality in each patch
λ_i	Probability of finding prey in each patch
$\overline{y}_i$	Mean benefit of catching prey in each patch
α_b	Perceived cost of searching for food in Region B
β_b	Perceived probability of mortality in Region B
λ_b	Perceived probability of finding food in Region B
$\overline{y}_b$	Perceived benefit from prey in Region B
t_m	Time spent moving to Region B
$\alpha_m(t_m)$	Cost of moving to Region B

I also include physiological constraints, by defining an upper limit to the state, above which the forager receives no further benefit from her food, and a lower limit, below which she dies. These limits allow the forager to make different decisions based on the level of her state, because as energetic reserves decrease, and starving becomes more likely, acquiring food becomes more imperative.

Patch Characteristics

At each time increment in the model, after the forager decides which patch to exploit, she may either catch prey, with probability λ_i, or not catch prey, with probability $1-\lambda_i$. Regardless of whether the forager acquires prey, the attempt costs her part of her energy reserves, *x*. I assume that pursuing and capturing prey entails a risk to the forager, and therefore I assign each patch a mortality risk, β_i.

The forager only increases the value of her state if she successfully exploits a patch. The mean benefit ($\overline{y}_i$) of exploiting a patch, however, is a function of the probability of acquiring prey, λ_i, and the benefit when it is caught, y_i. Note that the actual benefit of catching prey will be higher than the mean benefit, because sometimes the forager does not succeed in acquisition.

I let Y_i denote the increment in energy reserves from a single visit to patch i; it is y_i with probability λ_i, and 0 with probability $1-\lambda_i$, so that

$$E\{Y_i\} = y_i \bullet \lambda_i + 0 \bullet (1-\lambda_i) = \lambda_i y_i = \overline{y}_i \tag{7.1}$$

where I have specified y_i.

A prey item with a lower probability of being caught would then provide a greater state gain (increase in energetic reserves) when caught, much like a deer might compare to a fish. Using this calculation rather than simply y_i and λ_i permits holding the mean benefit of foraging in a patch constant, while changing the variance (*Var*) of the benefit. This is because

$$Var\left\{Y_i \middle| y_i\right\} = E\left(Y_i^2\right) - \overline{y}_i^2$$

and

$$E\left\{Y_i^2\right\} = y_i^2 \bullet \lambda_i + 0 \bullet \left(1 - \lambda_i\right) = y_i^2 \lambda_i = \left(\frac{\overline{y}_i}{\lambda_i}\right)^2 \lambda_i = \frac{\overline{y}_i}{\lambda_i}$$

so that

$$Var\left\{Y_i \middle| y_i\right\} = \frac{\overline{y}_i^2}{\lambda_i} - \overline{y}_i^2 = \left(\overline{y}_i^2\right)\left[\frac{1}{\lambda_i} - 1\right]. \tag{7.2}$$

As a result, when the probability of finding prey (λ_i) is changed, the variance changes as well, while the mean benefit remains the same (Figure 7.1).

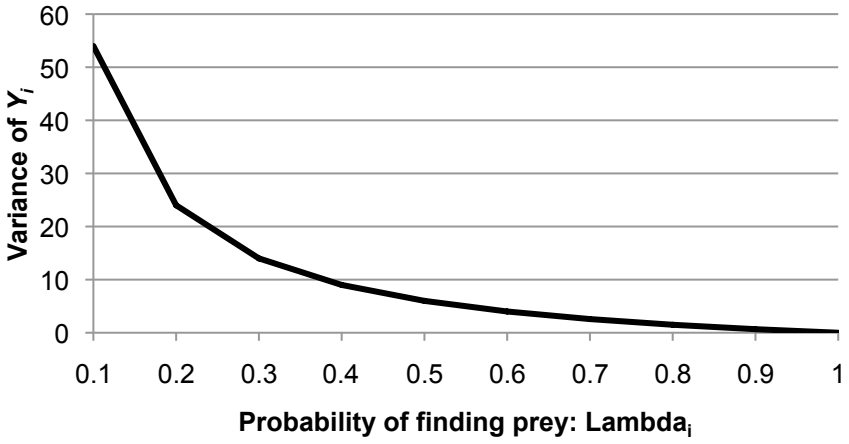


Figure 7.1. Relationship between $Var\left\{Y_i \middle| y_i\right\}$ and λ_i, using $\overline{y}_i = 6$. If the forager is guaranteed to find prey, no variance exists, and the benefit is the same as the mean benefit.

Dynamic Programming Equation

The dynamic programming part of this model calculates the optimal decision at any given time and state, by starting at the final time step. The terminal fitness represents the forager's expected future fitness at the last time step *T*, given that the forager's state is $X(T) = x$ (Clark and Mangel 2000; Mangel and Clark 1988). The fitness values from the end condition are then filled into the final column of a fitness matrix for each value of *x*. The end condition is the same for each region *l*, which means the forager's state is related to her fitness in the same way in both regions at the end of the model. However, the remaining fitness values and optimal decisions will vary, and are therefore calculated separately.

In the simplest case, fitness could be defined as 1, if the individual is alive with reserves above a critical value x_c ($x > x_c$) at the last time step, and otherwise 0 (Mangel and Clark 1988). In many contexts, however, fitness is affected by more than just whether or not an organism is alive, so I use a terminal fitness function to relate final state values with future fitness (Mangel and Clark 1988). For this model, I define a non-linear relationship between state and fitness, given that the forager is in region *l*, using $x_o = 0.5x_{\max}$, and a parameter $\gamma = 4$, so that the terminal fitness function is:

$$F\left[x,T\middle|l\right] = \frac{\left(x - x_c\right)^{\gamma}}{\left(x - x_c\right)^{\gamma} + \left(x_o - x_c\right)^{\gamma}} \tag{7.3}$$

with the understanding that $F\left[x,T\middle|l\right] = 0$ if $x \le x_c$.

This fitness function has two main implications: First, if the forager starves, she dies, and does not accrue any fitness; and second, fitness saturates at high levels of the forager's state. Biologically, for an organism close to starvation, any increase in state value would have a significant effect on its fitness. For an organism with nearly as many resources as it can possibly have, each increase in state is less significant, because it already has a high fitness.

Acquiring more food is likely to have a convex-concave utility function, *because* added food increments have a higher value when resources are low (Winterhalder et al. 1999). A forager is predicted to be more likely to take risks when on the convex part of the curve (lower state and fitness values), and more risk-averse when on the concave part (Mangel and Clark 1988). As a result, I chose $\gamma = 4$, because it provides a convex-concave curve, while not being so steep that it approaches being a step function (Figure 7.2).

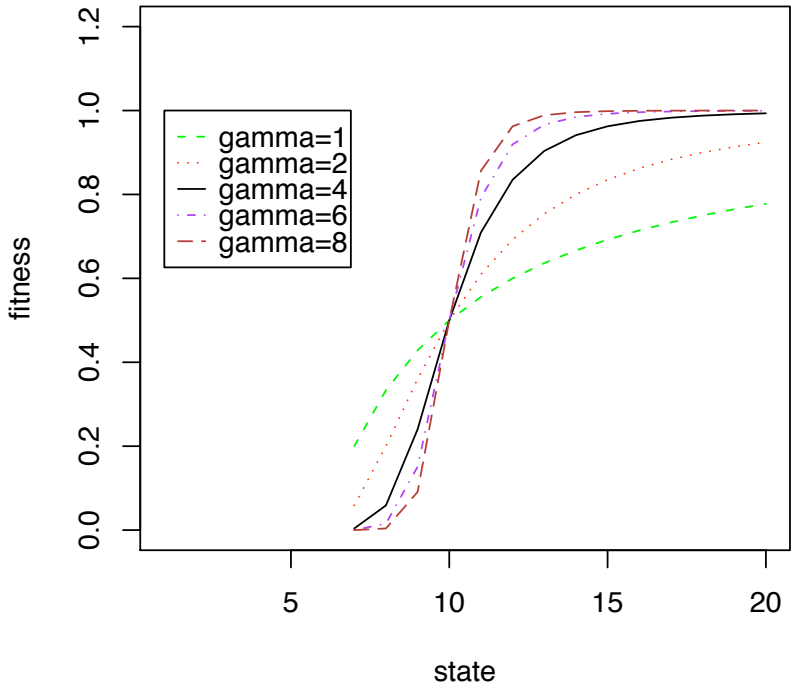


Figure 7.2. Terminal fitness curves using Equation 5.3, with $x_o = 0.5x_{\max}$, $x_c = 6$, and varying values of γ (gamma). The solid line is $\gamma = 4$, which is the value I ultimately chose.

Backward Iteration

Given the parameters of each patch, the forager at each time step can choose which patch will give her the best combination of survival likelihood *and* expected fitness at the final time period *T*, when fitness is calculated (Mangel and Clark 1988):

$$F\left[x,t|l\right] = \max_i V_i\left(x,t|l\right) \tag{7.4}$$

where $V_i\left(x,t|l\right)$ represents the value of choosing each patch at time *t*, given that $X\left(t\right) = x$, and that the forager is in region *l*.

In modeling, I assume that the forager has full knowledge of the relationship between state and fitness, understands the characteristics of each patch, and also knows when the model will be ending (i.e., when her fitness will be calculated). At each time step, therefore, the forager follows the stages in Figure 7.3.

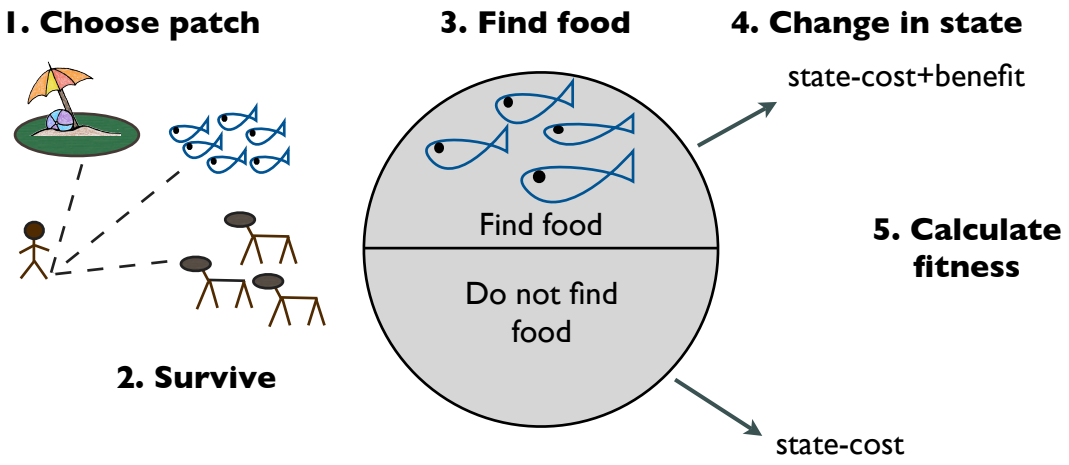


Figure 7.3. Forager's steps during each time *t*.

When the forager makes her decision about which patch to exploit, she bases it on her expected fitness at the beginning of the next time step, $t+1$, which is determined from her state value at the end of the current time step *t*. So, if she finds food, which she does with probability λ_i, her fitness would be

$$F\left[x-\alpha_i+y_i, t+1 \middle| l\right], \tag{7.5}$$

and if she does not find food, fitness would be

$$F\left[x-\alpha_i, t+1 \middle| l\right]. \tag{7.6}$$

Regardless of whether the forager finds food, she has to survive the patch she chooses to exploit $(1-\beta_i)$. The basic value of each patch at time *t*, given that $X(t)=x$, is therefore:

$$V_i(x,t|l)=(1-\beta_i)\left\{\lambda_i F\left[x+y_i-\alpha_i,t+1|l\right]+(1-\lambda_i)F\left[x-\alpha_i,t+1|l\right]\right\}. \quad (7.7)$$

At *T-1*, since the forager only has to determine which patch provides the best chance for maximum fitness in one more time step, the calculation is relatively simple for each state *x*, and is performed for all values of *x*. The fitness at *T* is then calculated using the end condition. Moving backward from time *T*-2 to $t=1$, fitness at each time step has been defined by the previous loop of the model.

Equation 7.7 is extremely important for understanding how a forager makes a decision when this model runs. Therefore, to illustrate this in a more realistic manner, I provide a numeric example of how to determine the value, *V*, of choosing Patch 2 at state $x=15$ and time $t=19$, given that the forager is in Region A. I set the probability of mortality as $\beta_2=.001$, the probability of finding prey as $\lambda_2=0.8$, the cost of foraging in Patch 2 as $\alpha_2=2$, and the benefit of acquiring prey as $y_2=5$. With these parameters, Equation 7.7 becomes:

$$V_2(15,19|A)=(1-.001)\left\{0.8F\left[15+5-2,20|A\right]+(1-0.8)F\left[15-2,20|A\right]\right\} \quad (7.8)$$

This numeric example produces two possible values of *x* at the next time step: 18 if the forager finds food, and 13 if the forager does not. If the model only has 20 time

steps, then $t+1=T$. Using Equation 7.3, and $x_o = 10$, the associated fitness values would be:

$$F\left[18,20|A\right] = \frac{(18-6)^4}{(18-6)^4 + (10-6)^4} = .988 \tag{7.9}$$

and

$$F\left[13,20|A\right] = \frac{(13-6)^4}{(13-6)^4 + (10-6)^4} = .904 \tag{7.10}$$

Substituting these numbers into Equation 7.8 produces:

$$V_2\left(15,19|A\right) = \left(.999\right)\left(0.8 \times .988 + 0.2 \times .904\right) = .97\,. \tag{7.11}$$

Given that the forager is in Region A, her expected fitness value at $t = 20$ of going to Patch 2 at time $t = 19$, with $x = 15$, is thus approximately 0.97. After the same calculations are performed for the other patches, the optimal patch to choose to exploit at that particular state and time is the patch with the highest expected value, which I call *i**. If two patches end up with the same value, I have written the model so that the forager chooses the lower numbered patch (e.g., Patch 2 over Patch 3).

The actual calculation I use in this model is slightly more complicated, because constraints need to prevent the state from being higher than the maximum value ($x > x_{\max}$) or lower than the minimum value (in this case $x < x_c$). I therefore add maximum and minimum functions into the equation (Mangel and Clark 1988), where $\min\left(A,B\right) = A$ if $A < B$ and B otherwise, and $\max\left(A,B\right)$ is defined in an analogous manner.

$$V_i(x,t|l) = (1-\beta_i)\begin{Bmatrix} \lambda_i F\left[\min(x+y_i-\alpha_i, x_{\max}), t+1|l\right] \\ +(1-\lambda_i)F\left[\max(x-\alpha_i, x_c), t+1|l\right] \end{Bmatrix} \quad (7.12)$$

Linear Interpolation

The described method of calculating the benefit of catching prey can result in benefit values (and therefore state values) that are continuous. However, fitness can only be calculated using discrete state values, so I use linear interpolation to determine fitness from non-integer values of x (Clark and Mangel 2000; Mangel and Clark 1988). First, I calculate the following two values:

$$x' = \min(x-\alpha_i+y_i, x_{\max}) \quad (7.13)$$

$$x'' = \max(x-\alpha_i, x_c) \quad (7.14)$$

The *min* and *max* functions work the same way as in Equation 7.12, to prevent x from going outside of its defined values. Put in Equation 7.12, x' is used to calculate fitness in a patch if the forager is successful, and x'' if foraging is unsuccessful. Both of these values can be non-integers. The following description of interpolation applies to both x' and x'', but I use x' as an example.

I define the nearest integers to x' as x_l for the nearest lower integer, and x_u (or x_l+1) for the nearest higher integer. Subtracting x_l from x' produces the difference between the two, or q_x (Figure 7.4). Fitness is calculated at each of the nearest integer values, and then weighted in importance based on how close each integer was to the original value of x', the state value after the forager acquired prey.

$$F(x') = (x'_l)(1-q_x) + F(x'_l+1)(q_x) \quad (7.15)$$

Although the computer can only store integer values, interpolation permits the calculation of fitness while treating x as a continuous variable.

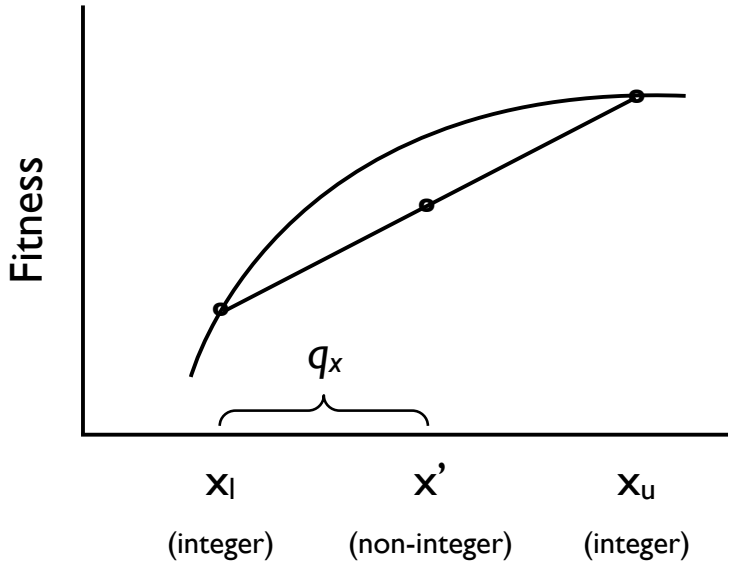


Figure 7.4. Graphic representation of linear interpolation: the curved line represents the fitness function, and the straight line is the interpolation, so that fitness can be calculated between integers.

The same calculations are performed for x'', to calculate fitness for the forager if food is not acquired. The value equation now includes constraints and interpolation, so it becomes:

$$V_i(x,t|l) = (1-\beta_i)\begin{Bmatrix} \lambda_i\left[F(x'_l)(1-q_x) + F(x'_u)(q_x), t+1|l\right] \\ +(1-\lambda_i)\left[F(x''_l)(1-q_x) + F(x''_u)(q_x), t+1|l\right] \end{Bmatrix} \quad (7.16)$$

Abandonment

In addition to choosing a particular patch in this model, I include the fitness value of abandoning Region A entirely and migrating to Region B, while incorporating the energetic and temporal costs. The forager perceives Region B to

have a certain set of patch parameters, and knows how much time and energy it will take to migrate. Given those considerations, if she thinks moving to Region B provides a higher fitness value than exploiting a local patch, she is predicted to abandon Region A.

The perceived fitness value of Region B is calculated first because it is a DPE in itself, and is referred to later in the Region A DPE. I treat Region B as one patch, with one set of parameters, and since the forager does not live in Region B, the parameters represent her perceptions of the conditions. The end condition and fitness equation are the same in Region B as they are for Region A. Region B also uses interpolation, but here I show the basic fitness equation, to emphasize that the parameter values used are specific to Region B.

$$F\left[x,t\middle|B\right]=\left(1-\beta_i\right)\begin{Bmatrix}\lambda_b F\left[\min\left(x-\alpha_b+\bar{y}_b,x_{\max}\right),t+1\middle|B\right]\\+\left(1-\lambda_b\right)F\left[\max\left(x-\alpha_b,x_c\right),t+1\middle|B\right]\end{Bmatrix} \tag{7.17}$$

As with Region A, Equation 7.17 is calculated for all $X(t)=x$ at each time step, so that I can determine the forager's fitness based on any state value she has when she reaches Region B.

Decision Making

The heart of a dynamic programming model is the backward iteration, represented by the stochastic dynamic programming equation (Clark and Mangel 2000). For Region A, after I determine the optimal decision at each state value for time *T-1*, I move the model backward again to *T-2* and perform the same sequence of

calculations. At each time step, I cycle the model through all values of $x > x_c$, and at each state *x*, I calculate the value of going to each patch *i*. I repeat these loops until $t = 1$. The easiest calculation of expected fitness given the forager's state is at the last time step, because no foraging decision needs to be made. Therefore, this backward iteration allows me to determine the optimal decision at each *previous* time step, because I know what the expected fitness is for each possible decision at the *next* time step.

The optimal foraging patch $i^*(x,t|A)$ is the patch with the highest expected fitness value at time *t*, given that the forager is in Region A, and that $X(t) = x$. I treat abandonment as leaving for a different "patch" entirely, so that mathematically, the forager is still choosing the highest value among patches. If the perceived fitness of exploiting Region B is higher than that of staying in any of the Region A patches, the forager is predicted to migrate. I incorporate into this part of the formula the time to move, t_m, and the cost of moving, α_m. I set $\alpha_m = t_m$ so that longer migrations are more expensive. Additionally, I add constraints so that the forager cannot abandon Region A if the cost of moving would reduce her state below x_c, or if the time to move would take the model beyond *T*. Equation 7.18 represents the dynamic programming equation for an environment with three patches in Region A, and the option to abandon to Region B:

$$F[x,t|A] = \max\begin{Bmatrix} V_1(x,t|A), V_2(x,t|A), V_3(x,t|A), \\ F[\max(x-\alpha_m, x_c), \min(t+t_m, T)|B] \end{Bmatrix} \quad (7.18)$$

This part of the model only determines the decision the forager makes *given that she is in Region A*. Once she has decided to migrate to Region B, she has no further choices to make.

Because a DSVM incorporates both state *and* time, when those values vary, so does which patch the forager is predicted to choose to optimize her fitness. Depending on the time and the forager's energetic reserves, Patch 2 may be a worse choice than Patch 3, a better choice, or equal. An example of this can be seen in Figure 7.5, in which I graph the fitness values of each resource patch at one time step. The resulting chart also shows the convex-concave shape of the predicted fitness curve.

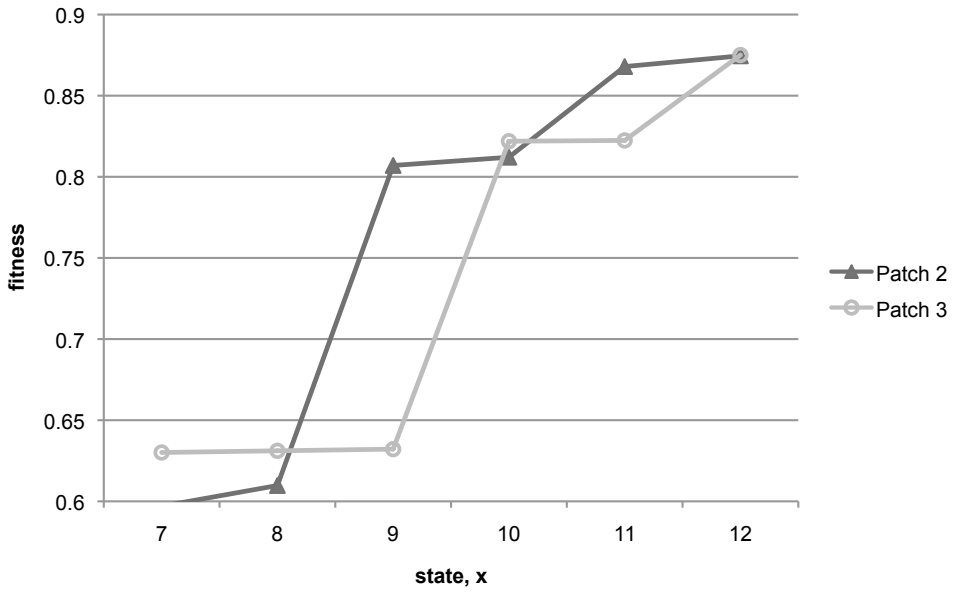


Figure 7.5. Fitness associated with a subset of state values at time $t = 1$. Patch parameters ($\alpha_i, \beta_i, \lambda_i, y_i$) and the decision matrix for this figure can be found in Appendix 5, Table and Figure 5.

Forward Simulation

After the backwards iteration has calculated the optimal patch decision $i^*(x,t|A)$, I run the model forward through time to explore the interaction of environment, stochasticity in survival and finding food, and state. The forager begins in Region A and I assign a starting state value. In general, I begin the forager at a state value halfway between $x_{\max}$ and x_c, but as part of the sensitivity analysis explored higher and lower state values. I use *W* to denote the state variable in the forward simulation, to keep the stored values separate from the backward iteration. I ran the simulation multiple times to determine average results, and a *k* variable keeps track of which simulation loop the model is in.

The forward simulation allows me to use a Monte Carlo process to perform computer experiments in the environment described by the patch parameters (Clark and Mangel 2000; Mangel and Clark 1988). A forager is introduced to the environment, and the model cycles through time steps to determine what happens to her, assuming she makes optimal decisions at each step. I started the model at $t = 1$, and the forager chooses the optimal patch *i** to exploit, given that $W(t) = w$, based on the decision matrix produced during the backward iteration. I used a random number generator to pick a value between 0 and 1, and if the number falls within the probability of acquiring prey in that patch, the forager is successful and acquires a gain in state value. For example, if the probability of acquiring prey is 0.8, the forager

is successful if the random number is less than or equal to 0.8. Thus, if she is successful at finding food, her new state is

$$W(t+1,k) = \min\left[W(t,k) + y_{i*} - \alpha_{i*}, x_{\max}\right] \tag{7.19}$$

and if she does not find food, the new state is

$$W(t+1,k) = W(t,k) - \alpha_{i*}\ , \tag{7.20}$$

with the understanding that if the right hand side of Equation 7.20 falls below the critical level, the forager is dead and her state is set to the critical level. When choosing *i**, the forager can also choose to abandon Region A, at which point I record the time and state at abandonment, and end the simulation loop.

The forager still cannot acquire more than a certain amount of resources, but the model needs to determine if the forager dies from starvation, so the state value must be allowed to go below x_c. If the forager remains in Region A, the next *t* loop first determines if the forager is still alive, and only continues with the patch choice decision if $w(t) > x_c$. Otherwise, the model moves on to the next simulation *k*, and records that the forager died during that run.

Results of Model Exploration

To provide a visual context for this analysis, I describe the format I chose for the model's backward iteration output. The important decision matrices and the details of how I explored the effects of parameter changes are available in Appendix 5, and are an important resource for anyone who wants to understand the relationship

between parameter values and model results in more depth. In this section, I analyze the results and their implications. I explain what the model predicts for the forager's optimal patch choices, based on the backward iteration and decision matrix, and the outcomes of those decisions as they result from the forward simulation. In general, the model predicts resources with a high rate of energetic return are only exploited regularly in extremely rich environments, and otherwise are only turned to when the forager is low on reserves. In most cases, predictably acquired resources are more commonly included in the forager's diet. Remember that a patch in this model is equivalent to a forager exploiting a particular prey type.

Description of Output

To plot the results of the SDP model, I display the optimal decision matrix for Region A as a grid, with time on the x-axis and state values on the y-axis. Time in the model is an arbitrary unit, but could be thought of as days, weeks, months, etc. I set $x_{\max} = 20$, and run the model for $T = 50$. I call this last time step the end of the season, but it represents the point at which a forager's fitness is calculated. To focus on how a forager's decisions might vary without a change in patch conditions, I keep patch values consistent through time in each run of the model. I explore the effects of different patch type combinations by running the model multiple times with varying parameters.

The decision matrix displays the optimal patch choice marked by number for each value of *x* and *t*. For example, if the forager's state value is 19, and the current time is 49, the number displayed in that cell represents the patch the forager is

predicted to optimally exploit. The zeros in the decision matrix represent a combination of state and time where the forager cannot make a decision because she is either dead or has reached the end of the model. I set $x_c = 6$, so the forager starves if $x \leq 6$. I give an example of a decision matrix in Figure 7.6.

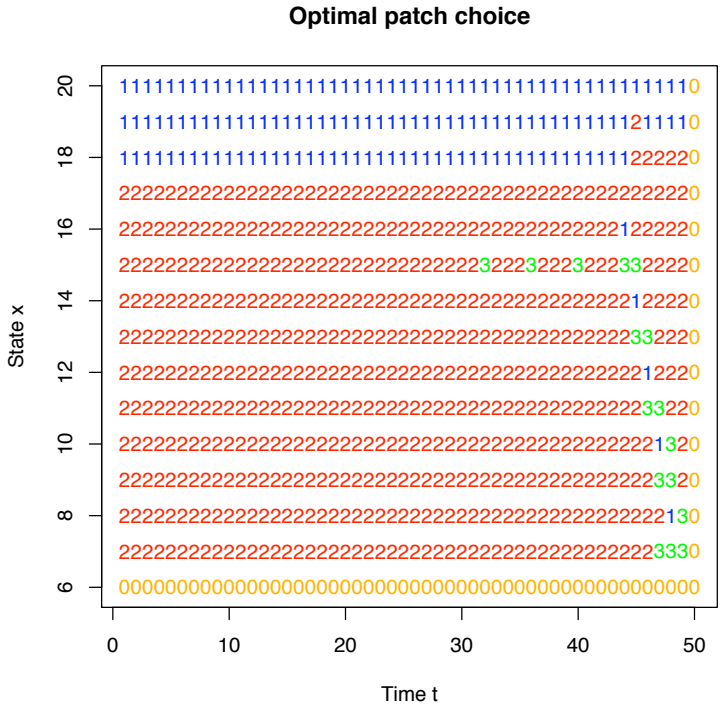


Figure 7.6. An optimal decision matrix of patch choice produced by the backward iteration of the dynamic programming equation for Region A. The 0's represent combinations of state and time where the forager cannot make a decision, because she is dead or has reached the last time step. The other three patches are represented by numbers 1-3, with Patch 1 as the rest patch, and Patches 2 and 3 resource patches.

In Figure 7.6, at $x = 19$ and $t = 49$, the forager is predicted to stay in Patch 1. As described earlier, Patch 1 is a resting patch: acquiring food is impossible, and staying in Patch 1 costs $x = 1$, but the mortality rate is also zero. I focus on Patch 2 and 3 in my discussion of results, as food can be acquired in both patches, but it is

important to note that staying in Patch 1 is frequently the optimal decision, especially when a forager's state is high. This is one of the results of putting physiological restraints on the forager – she has no reason to forage when her energy reserves are high, because she cannot absorb any more food. Staying in the rest patch and not chancing the possibility of mortality therefore makes more sense. Although food storage practices can affect day-to-day foraging decisions, this exercise begins with a simpler model to explore fundamental influences on forager patch choice, to which other factors, such as foraging for food storage, can be subsequently added.

Results

Several important implications result from the model. In Table 7.2, I summarize the results of my sensitivity analysis of the backward iteration, showing how changes in certain parameters affected the decision matrix. The sensitivity analysis is described more thoroughly in Appendix 5. In Table 7.3, I interpret those results to illustrate the behavioral implications, emphasizing the difference between the predictions of a rate maximization model and my DSVM. I describe the behavioral effects in more detail after the table. It is important to remember here that each patch is equivalent to exploiting a particular prey type, i.e., fishing, hunting for deer, etc.

Table 7.2. Summary of sensitivity analysis, showing which parameter changes have the most important implications. Figure numbers refer to Appendix 5.

Change to model parameter	Effect of change on decision matrix	Figure
$\uparrow \overline{y}_3$, mean benefit	Mostly unimportant if λ_i is higher in Patch 2	1
$\uparrow \lambda_3$, probability of finding prey	Patch 3 more likely to be exploited	2
$\uparrow \lambda_2, \lambda_3$, probability of finding prey in both patches	Patch 3 becomes more desirable at middle levels of state, as $\overline{y}_i$ increases in importance	3
$\uparrow \alpha_3$, cost of foraging	Patch 3 less desirable again	4
$\lambda_2 = \lambda_3$, $\alpha_2 < \alpha_3$, $\overline{y}_2 < \overline{y}_3$	Patch 3 more desirable at low levels of state	5
$\alpha_2 = \alpha_3$, $\overline{y}_2 < \overline{y}_3$, $\beta_2 < \beta_3$	Patch 3 only optimal occasionally at middle levels of state and as $t \to T$	None
$\lambda_2 > \lambda_3$, $\alpha_2 < \alpha_3$, $\overline{y}_2 < \overline{y}_3$, $\beta_2 < \beta_3$	Patch 3 only optimal at low level of state, as $t \to T$, and if $\overline{y}_2$ is very small	6
$\uparrow \lambda_b$ very high, $\overline{y}_a > \overline{y}_b$	Abandon as $t \to T$	7
$\downarrow \lambda_a$	Abandon as $x \to x_c$ and as $t \to T$	8
$\uparrow \alpha_m(t_m)$, cost of abandoning	Abandon at higher levels of state	None

Table 7.3. Comparison of rate maximizing and state dependent model predictions based on the backward iteration and resulting decision matrix of my patch choice model.

Topic	Prediction: Rate Maximizing	Prediction: State Dependent
Patch choice	All or nothing	Multiple patches
Rate of return	Maximize	Only important when patches are similar and easy to exploit
Predictability of prey acquisition	Unimportant, except as affects rate of return	Very important, when patches are more difficult to exploit
Prey size	Larger prey are better	If large prey are less predictable, more costly to exploit, and more dangerous, only exploited when forager is close to starvation
Abandonment	Silent	Abandon when reserves start to get low, but before too low to migrate, *and* when Region B has high predictability of prey acquisition
End of season	No effect	Risk-taking more likely when approaching the last opportunity to gain fitness

Patch Choice. My state dependent patch choice model indicates that in most contexts, a forager is predicted to exploit multiple patches even without any change in the environment. Changes in the forager's energy reserves can lead her to make very different decisions, typically choosing riskier ones with higher payoff when her reserves are low. Because she never experiences the average condition of a patch, but is instead only sometimes successful, her energy reserves change in a stochastic fashion. The forager makes patch choice decisions based in part on knowing that a foraging trip might not be successful, and what implication this has for her reserves. Thus, I predict that archaeological evidence of exploitation of multiple patch types will be found, *regardless of changes in environmental conditions*.

Rate of Return. The actual rate of energetic return only appears to be an important decision-making variable when most of the resource patches' conditions are the same, *and* when the probability of finding prey is above a certain threshold. I show in Figure 7.7 how the forager is only expected to consider the mean benefit of acquiring prey (i.e., the rate of return) in making decisions when the probability of successful patch exploitation is high.

When the forager has a very high probability of acquiring resources, she is predicted to exploit the *patch with a higher average rate of return* when she is well fed, but she is predicted to use *the patch with the highest probability of success* when she has lower energetic reserves. However, note that, when conditions are highly predictable and above that threshold ($\lambda_3 > 0.7$ in Figure 7.7), the forager only rarely has reserves so low as to justify exploiting the most predictable patch with the lower

rate of return. Furthermore, while she is predicted to exploit the patch with a higher rate of return more often than the predictable patch, she still does not need to make many trips, because she can be successful fairly easily.

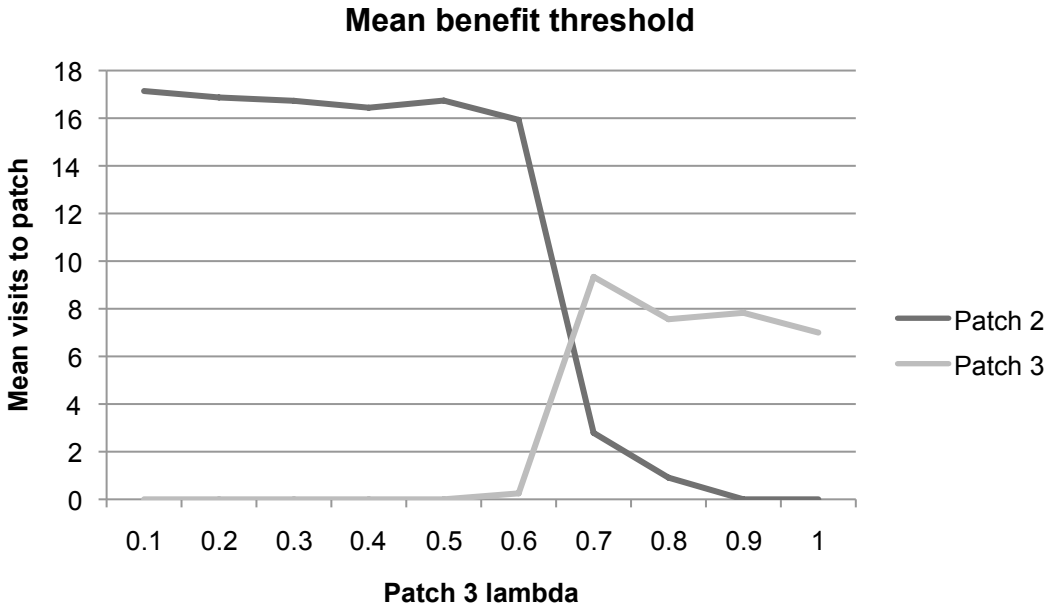


Figure 7.7. Mean visits to resource patches out of 100 simulation runs for each value of λ_3. I held the mean benefits of the patches constant at $\overline{y}_2 = 4$ and $\overline{y}_3 = 9$. All other parameters are the same for both patches, except I set $\lambda_2 = 0.8$. I then increased λ_3 by increments of 0.1. Because the mean benefit does not vary, and other parameters are equal, this graph shows how mean benefit is only important above a certain threshold when the probability of finding prey is high.

Predictability of Prey Acquisition. When patch conditions are less predictable, the probability of catching prey becomes an important factor. All other parameters being equal, a forager is predicted to exploit a patch with a higher probability of finding prey, but a much lower rate of return, to the near-exclusion of a less

predictable patch with larger prey items. Resources from the patch with a lower probability of catching prey would therefore be rare archaeologically, because the forager is only predicted to exploit it occasionally.

Prey Size. If a patch with a high benefit is also slightly riskier and costlier to exploit, and has a less predictable outcome, the forager is predicted to only exploit it when she is close to starvation. With the parameters provided in Table 7.4, despite the high probabilities of finding prey in both resource patches, the slightly higher mortality rate and higher cost of foraging influence the optimal decision enough that the forager is predicted to only try for Patch 3's higher return when close to starvation or at the end of the season (the final time step). Based on 100 simulation runs, the forager visited Patch 2 successfully a mean of 19.81 times out of 50 time steps, and Patch 3 only 0.04 times.

Table 7.4. Parameters for determining the influence of mortality rate and cost of foraging on patch choice. Both the benefit and mean benefit of Patch 3 are much greater than Patch 2.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.8	0.7
$\overline{y}_i$ [mean benefit]	3	9
$\overline{y}_i$ / λ_i [benefit]	3.75	12.8
β_i [mortality rate]	.004	.006
α_i [cost of foraging]	2	3

Based on the ethnographic studies covered in Chapter 4, hunting appears to be a more dangerous activity than most other kinds of resource acquisition. I thus predict shellfish and nearshore fishes to be commonly exploited resources, because they are

fairly low in risk, require relatively little energy to acquire, and are generally more predictable. On the other hand, hunting deer and larger ungulates or fishing in open water for large pelagic species might occur when a forager's energetic reserves are lower. I discuss this further in the summary below.

Abandonment. A forager can only abandon her home region if she has enough reserves to get her through the migration to another region. If she is about to starve, she is predicted to stay where she is and try to acquire resources from nearby patches, because she cannot afford to move. Additionally, her perception of the probability of catching prey in the other region is extremely important. If the forager thinks her probability of acquiring resources is much higher in the second region, she is predicted to always abandon her home region, though waiting until her reserves start to get low, or the end of the season approaches.

If conditions are very good in both of the resource patches in Region A, but the probability of finding prey is even better in Region B, and $\overline{y}_2 < \overline{y}_b < \overline{y}_3$, the forager is predicted to abandon Region A near the end of the season, when her reserves are high enough she does not need the higher benefit of Patch 3 (see Figure 7 in Appendix 5 for the parameter values and resulting decision matrix). In such a context, although few combinations of state and time exist where her optimal choice is to abandon, she is nonetheless predicted to abandon Region A approximately 95% of the time, based on 100 simulations. I show the most common combinations of time and state at abandonment in Figure 7.8.

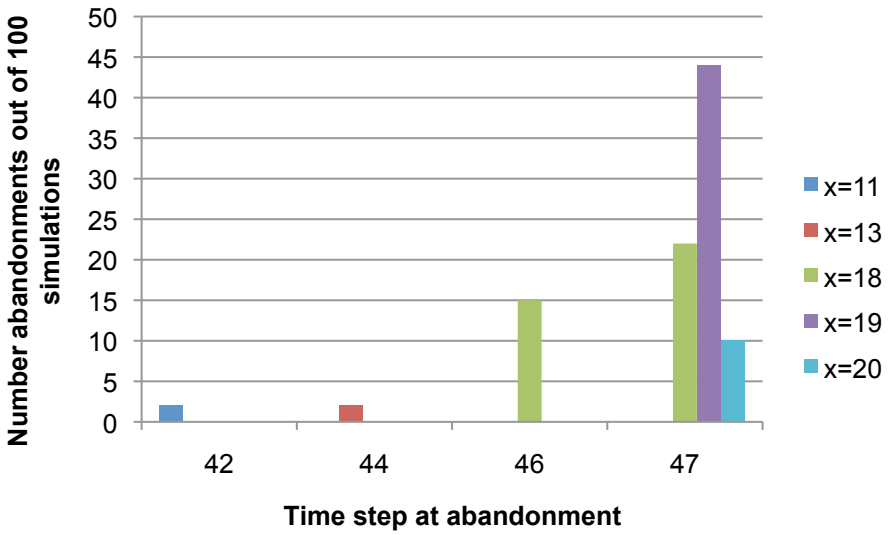


Figure 7.8. Time and state at abandonment when conditions are good in both resource patches and in Region B. The most common times to abandon are when $x \to x_{\max}$ and $t \to T$.

By contrast, when resources are more difficult to acquire in Region A, the forager is predicted to abandon when her reserves get low, in addition to when the end of the season approaches (see Figure 8 in Appendix 5). Still, the most common combinations of time and state at abandonment are those toward the end of the season and higher state values (Figure 7.9), though both slightly lower than in Figure 7.8.

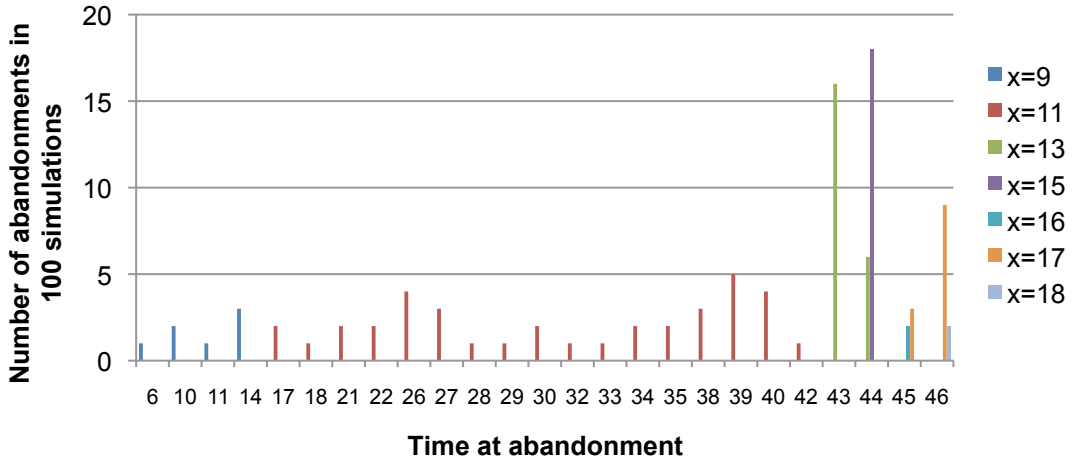


Figure 7.9. Time and state at abandonment when conditions are more difficult in Region A.

Overall, abandonment is predicted to occur when a forager can estimate the conditions of the area to which she wants to migrate, believes those conditions are much better than those where she currently lives, and, while she might wait until her reserves are low, she is predicted to move before her physiological condition becomes extremely poor.

End of Season. In the model, fitness is assessed at the last time step. I assume the forager has knowledge of when her fitness will be calculated. When she approaches the point when she will have no further opportunity to accrue fitness, her decisions may change. If her fitness is low, she is predicted to be more likely to take risks for the potential of a higher fitness increase.

Summary of DSVM Results

Dynamic State Variable Modeling is a powerful tool for exploring the influence of multiple factors on a forager's decisions about resource exploitation. Through sensitivity analysis of a simple patch choice DSVM, I have shown how the mean benefit of exploiting a patch (i.e., the "rate of return") is most important when resources are overall very easily acquired, and most of the patch parameters are the same. However, the *probability of successfully acquiring prey* has a larger effect on the forager's decisions under most conditions. While the probability of success cannot be directly measured archaeologically, it must be either estimated – even in relative terms – or varying values used to create hypotheses.

For example, one can assume that nearshore fishes and deer took the same amount of energy to exploit, and were equally safe activities. A deer would provide considerable meat if captured, and nearshore fishing would produce enough meat to survive on, but perhaps half that of deer. If nearshore fishes had a high probability of successful exploitation, and deer only slightly less, my DSVM indicates that a forager is predicted mostly to visit the deer patch, and be successful enough that her reserves would rarely decrease to the point where fishing would be the optimal choice. In such an instance, deer remains would be abundant in archaeological sites (with transport effects taken into consideration), and fishes would be minimally represented.

However, resource patches also often have differing degrees of mortality risk and costs associated with exploitation. Even a small difference in these two parameters causes the mean benefit to lose importance in my DSVM. When I

assigned a slightly higher mortality risk and energetic cost to the deer patch, the forager was predicted to attempt deer hunting only when her energetic reserves were low, which occurred rarely given the high success rate of fishing. Furthermore, as many studies have stressed, larger body sizes are often not correlated with higher return rates because larger prey are more mobile, and therefore more difficult to catch even after they are encountered (Bird et al. 2009). While I kept mean benefit somewhat higher for larger prey in this model, higher pursuit costs would make deer hunting even less frequently an optimal decision.

Therefore, in a generally rich environment, the DSVM predicts resources with a *higher probability of successful exploitation, lower mortality risk, and lower energetic cost to be exploited more frequently*, even if they have a significantly lower benefit and mean benefit than other resource options. At the same time, the DSVM results indicate that a forager is still occasionally predicted to exploit the resources with a high rate of return when her reserves get low. Archaeologically, the first kind of resource would be much more common than the latter, though both would be present.

Characterizing Monterey Bay Area Resources

Through a DSVM, I have shown how each of the included variables can affect foraging decisions, but the model uses abstract characterizations of resources to explore which variables were most important. To explore the model's implications for zooarchaeological assemblages in the Monterey Bay area, it is necessary to describe

the region's resources in the same terms. In the remainder of this section, I describe ethnographic research that addresses the particular variables included in the model, and use those data to classify Monterey Bay area resources. Though exact values for the relevant variables are rare in ethnographic research, qualitative and relative values do exist in some studies across the world.

Risk of Mortality or Injury

As detailed in Chapter 4, foraging for resources of any kind can be dangerous (Bennett et al. 1973; Blurton Jones and Marlowe 2002; Hill 1988; Hill and Hawkes 1983; Hill et al. 2007). With regards to fishing, Acheson (1981) argued that it is generally less dangerous in the intertidal zone than in open water. I have based my evaluations of mortality or injury risk on the assumptions that capturing large-bodied prey will generally be more dangerous than catching small-bodied prey, and that fishing becomes less safe as people move farther offshore.

Benefits and Costs of Exploitation

I assigned relative benefits of catching prey based mainly on body size, but with increased benefits for taxa that would probably be mass captured. Similarly, the cost of acquiring small species is generally lower, especially for fishes caught from shore. Mobile, terrestrial prey items require more effort to search, catch, and handle, and the cost often increases with body size. For marine mammals in rookeries, I have categorized the average cost as low, though the species, sex, and age of an individual prey could significantly affect the difficulty of exploitation.

Probability of Success

The probability of successfully exploiting a prey item is one of the most influential variables in the model. Bliege Bird's (2007) focal studies of Meriam foragers in Melanesia assessed time allocation to various fishing activities, success rates per standardized two-hour periods, their rates of return, etc., and provide some of the only data of this sort. Sardine netting had a success rate of 0.94 per observation period, fishing with small hooks on the beach a success rate of 0.755, and fishing with large hooks in nearshore waters a mere 0.489 success rate (Bliege Bird 2007). Chapman (1987) noted that reef fishing was more dependable than men's hunting in Oceania. In Micronesia, the Ifaluk fished most frequently by trolling in the open water for yellowfin tuna. Out of 58 days in which they trolled, they successfully caught yellowfin tuna on 51 days, though their per capita rates of return ranged from 0.236 to 9.035 kg/hour, averaging 1.68 kg/hr (Sosis 2002).

With regard to success rates in acquiring large terrestrial prey, such hunting seems to be predictably successful only in very specific conditions, such as persistence hunting by the !Xo and /Gwi from Botswana, which had an 80-100% chance of success (Liebenberg 2006). However, this was only attempted occasionally because it depended upon the temperature being high enough to contribute to prey exhaustion. By contrast, the !Xo and /Gwi had a 60% success rate when hunting with dogs, 45% with club and spear, and 5% with bow-and-arrow (Liebenberg 2006). The hunting success rate of the Agta in the Philippines was 41% or less, depending on who was hunting and how (Biesele and Barclay 2001). Hawkes et al. (1991)

calculated that a Tanzanian Hadza hunter had a 97% chance of *failure* on any given day of hunting, and the highest success rate was only 12%. For the Siona-Secoya of Ecuador, a hunter had the highest probability (49.7%) of catching a wooly monkey in a day of hunting, about a 30% chance of killing a peccary, and a much lower probability of acquiring anything else.

Hunting large game also typically requires more effort and time than catching small animals (Szuter 1991). The Martu of Australia had high success rates for hunting cats and sand monitors and much lower success at hunting substantially larger kangaroos and bustards (Bird et al. 2009). The Aché experienced a high success rate while hunting in groups, but they also mainly hunted game smaller than 10 kg. The !Kung, by comparison, tended to hunt for larger game more individually and were less frequently successful (Hill and Hawkes 1983).

To summarize, the ethnographic literature suggests that larger, mobile prey types are more difficult to catch than smaller prey. Although hunting commonly has a relatively low success rate, small animal exploitation can reach a success rate of over 90%. Fishing productive areas with nets also resulted in extremely high success rates, with hook-and-line fishing being somewhat less successful.

Characterizations of Resources

Based on these ethnographic studies, I assigned relative qualitative values to common taxa found in Central Coastal California archaeological sites, for the variables I used in the DSVM (Table 7.5).

Table 7.5. Characteristics of commonly exploited resources found in California coastal archaeological sites.

Patch type	Probability of success	Mortality or injury risk	Cost of search, pursuit, handling	Benefit
Tidepool fish	High	Very low	Low	Low-medium
Estuary fishing (nets)	High	Very low	Low	Medium
Rocky shore hook-and-line	Medium	Low	Low	Medium
Nearshore (from boats)	Medium	Medium	Medium	Medium
Offshore	Medium-low	High	High	Medium
Intertidal shellfish	Very high	Very low	Low	Low
Birds	Medium	Low	Medium	Medium
Rabbits	Medium-high	Low	Medium	Medium
Deer	Low	Medium	Medium-high	High
Pinnipeds in rookeries	High	Medium	Low	Very high
Pinnipeds in water	Low	High	High	Very high

Given the importance of probability of success, and that some resources can be mass collected, I predict tidepool and estuarine fishes, shellfish, and pinnipeds in rookeries (especially young pups) would be frequently exploited, despite the small size of individuals in the first three categories.

The next most commonly exploited resources would include rocky shoreline fishes, birds, rabbits and other small animals that might have a slightly lower probability of success and higher injury risk or cost. Deer, offshore fishes, and pinnipeds in water are all large bodied, with very high yields and potentially high rates of return, but they are also mobile and more dangerous to exploit. Adult pinnipeds in rookeries might also fall into this category, as it can be dangerous to approach both males and females close enough to dispatch them. Therefore, despite

the larger size of deer, pinnipeds, etc., my state-dependent model indicates a forager is predicted to frequently opt for other prey species.

However, it is important to remember that the forager's state changes stochastically, and depending on her energetic reserves, different resources are predicted to be her optimal choice for exploitation. I assume with the characterization of resources above that the probability of catching large mobile prey is below the threshold when mean benefit becomes important. I believe this is a reasonable assumption because hunting mobile prey is often associated with low success rates in the ethnographic literature. Moreover, the higher mortality risk and cost of exploitation reduce the frequency with which the forager is predicted to hunt those prey types. Nonetheless, when the forager's reserves decrease, she is predicted to be more willing to risk failure for the possibility of acquiring a high benefit. As a result, without any change in environmental circumstances, those large mobile prey types are still predicted to be occasionally exploited. Archaeologically, then, a variety of prey types would be present in an assemblage, with an emphasis on those that can be exploited with a high probability of success, have a lower cost, and are safe.

Summary

Mathematical models provide a way to simplify systems and explore how parts of those systems interact. As Mangel and Clark (1988) stated, a model that is as complicated as the system it represents will be just as difficult to understand. For this dissertation, I chose to create a model that focuses on foraging success, costs and

benefits, and risk of mortality, because most of these variables are commonly used in foraging models, but have not all been included together. By incorporating all of them simultaneously, and adding in the forager's changing physiological state, I have shown how a DSVM's predictions can diverge considerably from those of traditional rate-maximization models. Although many other factors, such as division of labor or storage of surplus, could influence the model's predictions, the same is true of most optimal foraging models. While the current exercise did not include these, I emphasize that the present DSVM offers a means of exploring the effects of some significant variables on foraging decisions, and that I chose this particular set of variables for comparisons of DSVM and rate-maximization predictions. While other variables can be included later, they are beyond the scope of this dissertation.

In the next chapter, I present the results of my zooarchaeological research, describing the taxonomic distributions present at each site, and how those distributions change over time. Then, in Chapter 9, I analyze how the DSVM's predictions explain the archaeofaunal evidence, and discuss the implications for Monterey Bay area culture history.

CHAPTER 8

Zooarchaeological Evidence for Patch Exploitation

I analyzed 18,168 fish specimens from 13 sites for this project and Table 8.1 shows their distribution among the sites. In this chapter, I first summarize the fragmentation and burning modifications at the different sites to argue for why I consider them comparable. I then present taxonomic results from each site, moving north to south as I originally described the sites in Chapter 5.

Table 8.1. Numbers of identified fish specimens for the 13 sites analyzed for this dissertation. Sites are ordered geographically.

Site	NISP
MNT-228	266
MNT-229	1452
MNT-234	601
MNT-112	216
MNT-113A	76
MNT-113B	264
MNT-113D	126
MNT-831	2305
MNT-125	25
MNT-170	535
MNT-834B	1617
MNT-17	2940
MNT-1701	7748
Total NISP	**18171**

After presenting individual site summaries, I compare sites by habitat and period, to elucidate the changes over space and time. As will be seen, taxonomic distributions of fishes vary significantly both by site locations and by cultural periods,

and are relevant to understanding which specific habitats people were exploiting, what kinds of technology they might have used, and whether they were targeting species with higher lipid content. At the end of this chapter, I describe how the results of the proximate analysis relate to the changes in patch type exploitation. In Chapter 9, I examine how these zooarchaeological data relate to the predictions of a dynamic state variable model, and inform our understanding of the region's culture history and human subsistence adaptations.

Because my dissertation modeling focuses on patch choice, I confine my detailed presentation here to the archaeofaunal data that relate to this question: site location, taxa represented, and proximate composition. I provide the specific taxonomic data for each site within its summary, but group taxa into larger categories based on habitat and fishing technology for the section where I compare material among sites. Further data on modifications are found in Appendix 6.

I identified 58 taxa during my analyses, including some identifications at the level of order, family, and genus. In Table 8.2, I list the Linnaean names, common names, and habitat descriptions for the various taxonomic categories. As with all of the tables in this chapter, taxa are listed in evolutionary order, with more ancestral taxa first and more derived fishes last.

Table 8.2. Scientific names, common names, and habitat descriptions for taxa identified for this dissertation.

Linnaean name	Common name	Habitat
Chondrichthyes	Sharks and rays	Multiple possibilities
Chondrichthyes (shark)	Sharks	Multiple possibilities
Galeorhinus galeus	Soupfin shark	Offshore, coastal, bays, muddy shallows, to 1350 ft
Triakis semifasciata	Leopard shark	Coastal, inshore, sandy and rock-strewn flat bottom near rocky reefs, to 300ft
Chondrichthyes (ray)	Rays	Multiple possibilities
Myliobatis californica	Bat ray	Bays, sloughs, kelp beds, sandy/rocky bottoms, intertidal to 150 ft
Acipenseridae	Sturgeon	Most likely freshwater (white) or brackish (green)
Actinopterygii	Ray-finned fishes	Multiple possibilities
Clupeiformes	Sardine/herring/anchovy	Pelagic
Engraulis mordax	Northern anchovy	Pelagic, nearshore, surf zone, sometimes estuaries
Clupeidae	Sardine and herring	Pelagic
Clupea pallasi	Pacific herring	Offshore, or estuaries, harbors
Sardinops sagax	Pacific sardine	Pelagic, nearshore
Cypriniformes	Minnows and suckers	Freshwater, several habitats
Cyprinidae	Minnows	Freshwater, several habitats
Gila crassicauda	Thicktail chub	Slow backwaters, marshes
Lavinia exilicauda	California roach	Sloughs, streams, and reservoirs
Orthodon microlepidotus	Sacramento blackfish	Shallow lakes, sluggish pools
Catostomus occidentalis	Sacramento sucker	Lakes, streams, pools
Oncorhynchus sp.	Salmon and trout	Ocean and coastal streams
Oncorhynchus kisutch	Coho salmon	Ocean and coastal streams
Oncorhynchus mykiss	Rainbow trout/steelhead	Ocean and coastal streams
Merluccius productus	Pacific hake	Usually near bottom of moderate depths to 3000 ft. Can be found in large schools.
Porichthys notatus	Plainfin midshipman	Bays on mud or sand bottom, intertidal
Atherinopsidae	Silversides	Bays, rocky areas, kelp beds, sloughs
Gasterosteus aculeatus	Threespine stickleback	Fresh and saltwater, near shore to 90 ft

(continued on next page)

Table 8.2. (continued)

Linnaean name	Common name	Habitat
Scorpaeniformes	Mail-cheeked fishes	Multiple possibilities
Sebastes sp.	Rockfish	Several habitats, but can easily be caught nearshore in rocky habitats, kelp beds
Hexagrammidae	Greenlings	Mostly rocky areas, shallow or intertidal
Hexagrammos sp.	Kelp or rock greenling	Rocky areas (both species), kelp beds (H. decagrammus)
Ophiodon elongatus	Lingcod	Rocky inshore, young inshore on sandy/muddy bay bottoms
Cottidae	Sculpin	Several habitats, but many found in intertidal
Leptocottus armatus	Staghorn sculpin	Nearshore, bays, estuaries, sand bottom to 300 ft
Scorpaenichthys marmoratus	Cabezon	Intertidal to 250 ft (rocky, estuaries, etc.)
Atractoscion nobilis	White seabass	Rocky bottom, reefs and kelp beds
Archoplites interruptus	Sacramento perch	Sloughs, pools, lakes
Carangidae	Scad, yellowtail, jackmackerel	Pelagic, yellowtail and young jackmackerel can be found in kelp beds
Trachurus symmetricus	Jackmackerel	Pelagic and offshore, young near kelp and piers
Embiotocidae	Surfperches	Rocky areas, sandy beaches, kelp beds, bays, estuaries, etc.
Amphistichus sp.	Barred, calico, or redtail surfperch	Surf along sandy beaches, barred also near rocks and pilings, redtail also sometimes bays and backwaters
Embiotoca sp.	Black or striped surfperch	Rocky, kelp, bays and piers or sandy surf
Embiotoca jacksoni	Black surfperch	Rocky near kelp, sometimes bays and piers, intertidal to 150 ft
Embiotoca lateralis	Striped surfperch	Rocky coast, kelp, sandy surf near rocks, to 70 ft
Hypsurus caryi	Rainbow surfperch	Rocky shore, kelp, to 130 ft (not in surf)
Phanerodon sp.	Sharpnose or white surfperch	Inshore or offshore
Phanerodon furcatus	White surfperch	Piers, bays, quiet water, sandy areas, offshore near rocks, to 140 ft
Rhacochilus sp.	Rubberlip or pile surfperch	Rocky, kelp, pilings, to 150 ft
Rhacochilus toxotes	Rubberlip surfperch	Rocky, kelp, jetties and pilings, to 150 ft
Rhacochilus vacca	Pile surfperch (Pile perch)	Rocky, kelp, pilings, structures, inshore to 150 ft
Stichaeidae	Pricklebacks	Mostly intertidal rocky shore
Gibbonsia sp.	Kelpfish	Rocky, algae or seaweed, tidepools, kelp, exposed coast, to 70 ft

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Table 8.2. (continued)

Linnaean name	Common name	Habitat
Sphyraena argentea	Pacific barracuda	Near shore, near surface, to 60 ft, young enter bays
Scombridae	Tuna, mackerel, albacore	Pelagic, inshore and offshore
Scomber japonicus	Pacific/Chub mackerel	Pelagic, inshore
Pleuronectiformes	Flatfishes	Sand and mud bottom, intertidal, bays, sloughs, deep water, etc.
Platichthys stellatus	Starry flounder	Nearshore, estuaries, to 900 ft

Throughout this chapter, I use scientific names in the summary tables for each site, to be very clear which taxa I identified. For the graphs in which I show proportions of different taxa, I group many taxa together into common name categories. The most frequent examples are sharks and rays, minnows and suckers, sardine and herring, and various surfperches. Each of these includes species that were either likely caught in the same way, taken in the same environment, or are difficult to identify to species. The category Actinopterygii, or ray-finned fishes, refers to specimens that are identifiable as being bony fish parts, but could not be distinguished to a finer taxonomic level.

Assemblage Comparability

Radiocarbon Dating Results

Due to a combination of small sample sizes and poor backgrounds, many of the samples I submitted for dating produced results that could not be usefully interpreted (Tom Guilderson, personal communication 2011). This may have been from the collagen extraction we performed at UCSC, poor preservation, or having small samples to start with. The samples that did generate useful information correlated well with previous shellfish and charcoal dates, suggesting a high degree of confidence in the cultural periods to which sites are assigned (Table 8.3).

Seven sites were multi-component, and even with directly radiocarbon dating fish bone, these were more complicated to deal with than anticipated, based on my initial understandings of site stratigraphy. Fish bones were not always available from

the units that were in the best horizontally separated components, and in some sites with vertical separation, determining where the boundary between components occurred was difficult. For these sites, I briefly describe how I divided the assemblage in relation to the fish remains. Single component sites are of course much more straightforward, and six assemblages of 13 fall in this category. Many of them have relatively short occupations, under a few hundred years.

Table 8.3. Original date ranges for each site and the intercept date for my fish samples, as calculated for me by Gary Breschini. I have noted which samples could not be usefully interpreted. Sites are in geographical order. Full detail on samples, sample numbers, and date ranges can be found in Appendix 3.

Site	Original Site Dates	Fish Dates
MNT-228	5553-5314 BC, AD 249-623	AD 802
MNT-229	6400-4670 BC, 210 BC-AD 710	AD 381
MNT-234 (Area C)	6060-5025 BC	5594 BC
MNT-234 (Primary Midden)	5110 BC-AD 1710	35 BC-AD 98
MNT-112	AD 938-1715	AD 938, AD 1491
MNT-113A	AD 1470-1529	AD 1491
MNT-113B	264 BC-AD 264	No useful results
MNT-113C	13 BC-AD 414	No useful results
MNT-113D	1873-1732 BC, AD 1431-1473	No useful results
MNT-831	5190-4770 BC, 3820-3604 BC, AD 82-662	AD 531, AD 695
MNT-125	AD 1440-1663	AD 1663
MNT-170	2592-2050 BC, AD 897-1301	2029 BC
MNT-834B	AD 1006-1647	AD 1260
MNT-17	4355 BC, 1512-2271 BC, AD 1277-1631	No useful results
MNT-1701	AD 805-1415	No useful results

Fragmentation

To assess the fragmentation of each assemblage, I compared the proportion of complete specimens to identifiable fragments and specimens for which I did not collect portion data. The last category mainly comprises unidentifiable elements that

appear to be fish bone. Overall, complete specimens comprised 46-86% of the assemblages, with most above 60% (Figure 8.1). Using linear regression (Figure 8.2), I show that as would be expected, the proportion of complete specimens was somewhat negatively related to the percentage of unidentifiable (Actinopterygii) specimens, indicating that a more fragmented collection is less identifiable. In contrast, the abundance of rockfish, which comprise much of the onshore single capture patch type, does not correlate with the proportion of complete specimens, and neither does the abundance of surfperches (Figure 8.2).

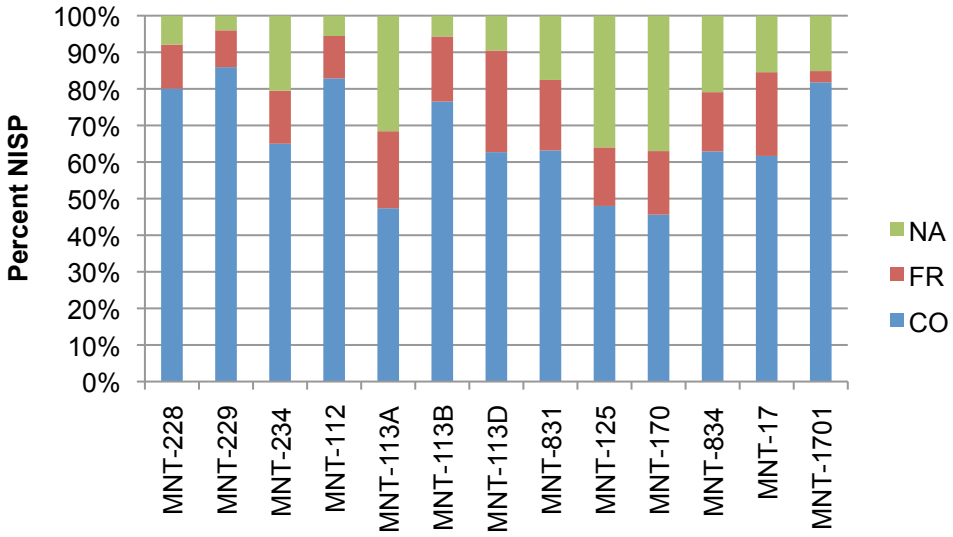


Figure 8.1. Fragmentation of assemblages, with sites in order geographically north to south. CO=specimen >75% complete, FR=specimen <75% complete, NA=elements for which I did not collect fragmentation data (e.g., fin rays and unidentifiable elements).

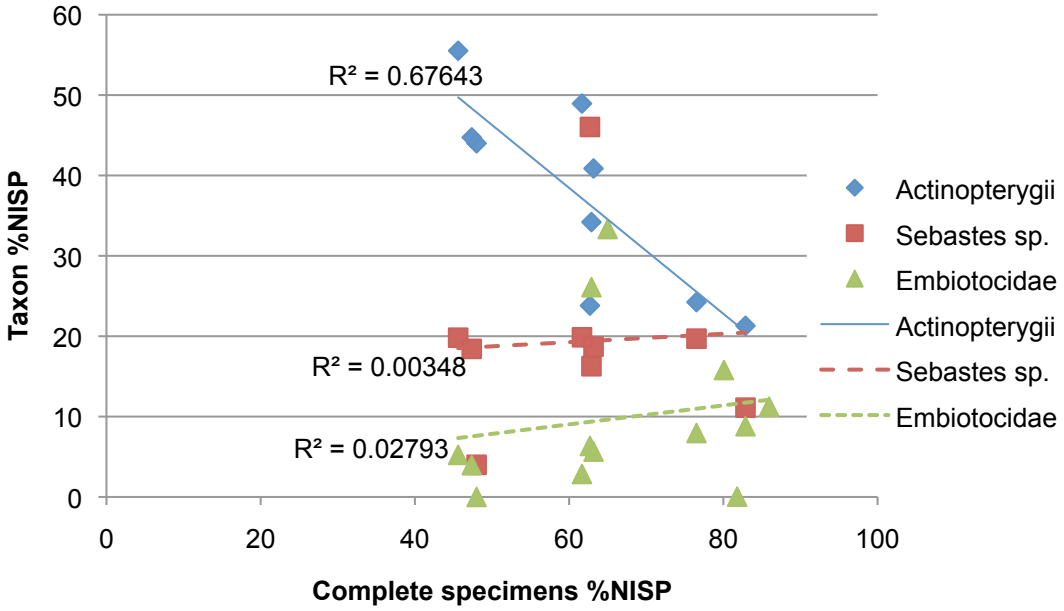


Figure 8.2. Relationship between the fragmentation of each assemblage and the proportion of Actinopterygii (unidentifiable taxon) and *Sebastes* sp. (rockfish, onshore single capture patch). Only sites from the rocky/sandy shoreline patch are included.

However, the proportion of specimens identified as clupeids does vary significantly with assemblage fragmentation (Figure 8.3), suggesting that sites with higher fragmentation rates may underestimate the abundance of estuary/boat mass captured species. For the trends I identify later in this chapter, differential preservation of clupeid remains mostly has the effect of increasing their overall representation. I describe the more specific potential effects in the section comparing sites to each other.

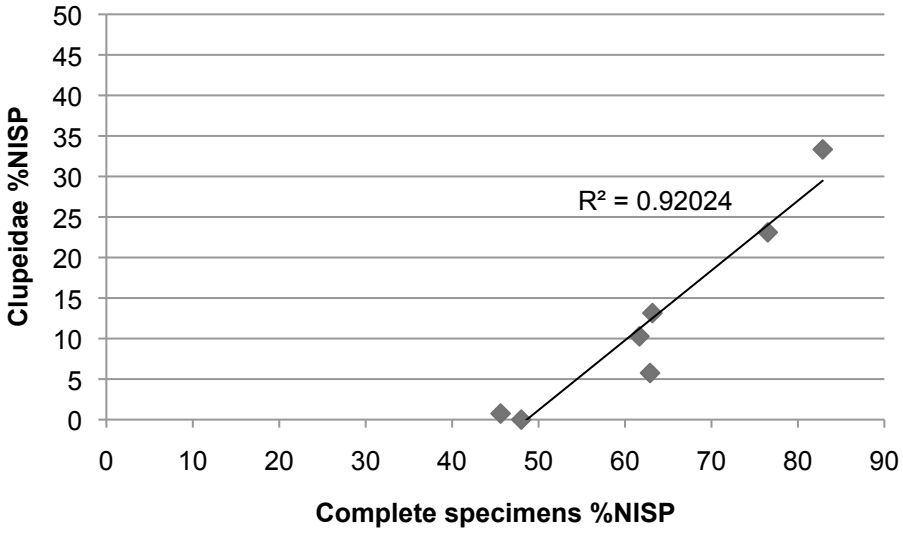


Figure 8.3. Relationship between assemblage fragmentation and proportion of Clupeidae (estuary/boat mass capture). Only sites from the rocky/sandy shoreline patch are included, and to minimize the effects of screen size on these small taxa, MNT-113A and -113D are excluded.

Thermal Modification

Most assemblages, divided into periods, had 5-12% of the specimens either carbonized or calcined (Table 8.4). Calcined specimens reflect exposure to higher temperatures than bone that has just been carbonized (Lyman 1994; Shipman et al. 1984). MNT-831 had higher values of overall percent burned in the Millingstone and especially the Middle Period, in both cases due to a greater abundance of calcined specimens. MNT-113B, which is almost adjacent to MNT-831, also has a high proportion of burned specimens, similarly driven by high percentages of calcined remains. Therefore, at both of these sites, people appear to have heated more bones and to higher temperatures than at other sites.

Table 8.4. Burn modifications by time period and site. Specimens of unknown period are not included.

Period	Site	Calcined NISP	Carbonized NISP	Unburned NISP	Total NISP	Percent Burned
Millingstone	MNT-228	0	1	20	21	5
Millingstone	MNT-17	4	19	366	389	6
Millingstone	MNT-229	6	5	105	116	9
Millingstone	MNT-234	1	19	581	601	3
Millingstone/ Early	MNT-831	42	20	284	346	18
Early	MNT-113D	0	3	48	51	6
Early	MNT-17	62	100	1511	1673	10
Early	MNT-170	25	23	428	476	10
Middle	MNT-113B	29	19	216	264	18
Middle	MNT-228	1	2	242	245	1
Middle	MNT-229	61	90	1150	1301	12
Middle	MNT-831	51	14	131	196	33
MLT/Late	MNT-112	4	10	202	216	6
MLT/Late	MNT-170	1	1	41	43	5
MLT/Late	MNT-1701	20	363	7365	7748	5
MLT/Late	MNT-834	85	116	1416	1617	12
Late	MNT-113A	0	1	75	76	1
Late	MNT-125	1	1	23	25	8
Late	MNT-17	14	13	242	269	10

Summary of Assemblage Comparability

Based on these criteria, I argue that the assemblages are comparable, with some constraints. The dates on fish specimens correlate well with those on shellfish and charcoal, thereby suggesting that the earlier interpretations of periods of occupation are reliable. The MNT-234 Primary Midden is the one exception, and while the mammal remains have dependably dated to the Middle Period, I discuss in the MNT-234 section below why that might not be true for the fish remains.

Fragmentation rates appear to affect clupeid remains more than any other common taxa identified for this dissertation. In many cases, this means clupeid

abundance is probably underestimated, and I take into consideration the degree of fragmentation when interpreting my results. The presence of carbonized and calcined specimens at these sites is an indicator of the cultural origin of the fish remains and for the most part varies between 5% and 12% of the assemblages. MNT-113B and MNT-831 both have high percentages of carbonized or calcined remains, but their taxonomic distributions fit well with trends between the Early and MLT Periods. The greater thermal modification might be due simply to the excavation of more features at these sites. It is difficult to tell with MNT-831, but at MNT-113B, a majority of fish specimens came from a feature that included charcoal and thermally fractured rock.

Results from Estuary Sites

MNT-228

The Millingstone Period deposit at MNT-228 is apparently constrained to one area of the site (Area B), while Middle Period dates came from several places in the rest of the site (Area A). Units 1 and 2 both dated to the Millingstone Period, and the component is probably present in Unit 17, which is between the dated units. I identified material from Units 1 and 17, but when comparing this sample to that cited in the original site report (Jones et al. 1996), it became apparent that the materials deposited in the Monterey Bay Archaeological Archives did not comprise the entire assemblage originally analyzed. This is also true with the mammalian assemblage (Diane Gifford-Gonzalez, personal communication 2011).

I did not use the data from the Area B summary (Jones et al. 1996), because it was unclear from the site report if Unit 15, which dated to the Middle instead of Millingstone Period, was included. Unit 17, however, was listed separately. Therefore, in Table 8.5, I have copied the site report data for Unit 17 (converted to Linnaean taxonomy), and compared it to my data. The original analysis listed three times the number of specimens I recovered, and several more species. Of the two taxa listed only from my analysis, Actinopterygii are simply unidentifiable fish remains, and were not tallied in the site report, and my identification of *Catostomus occidentalis* may simply be a more specific identification of the Cypriniformes specimen in the site report. I did not include Unit 2, because it was screened with 1/4 in mesh.

Table 8.5. Taxonomic representation by numbers of identified specimens in Millingstone Period deposits at CA-MNT-228, comparing Jones et al. (1996) data with that collected for this project.

Taxon	This project Unit 1	This project Unit 17	Site report Unit 17	Total Unit 1 and Unit 17 (report)
Triakis semifasciata	2	0	0	**2**
Myliobatis californica	1	2	9	**10**
Actinopterygii	1	4	0	**1**
Clupeidae	0	3	3	**3**
Cypriniformes	0	0	1	**1**
Cyprinidae	0	0	3	**3**
Catostomus occidentalis	0	1	0	**0**
Porichthys notatus	0	0	1	**1**
Atherinopsidae	0	1	5	**5**
Gasterosteus aculeatus	0	0	3	**3**
Cottidae	0	0	1	**1**
Archoplites interruptus	0	0	7	**7**
Embiotocidae	2	3	6	**8**
Rhacochilus vacca	0	1	8	**8**
Total NISP	**6**	**15**	**47**	**53**

Jones et al. (1996) also reported a column sample from Unit 1 screened with 1/16 in mesh, but did not separate the results of this sample from the rest of the Unit 1 excavation, screened with 1/8 in mesh. As a result, I have combined the site report's data on Unit 17 with my data from Unit 1 for representing the Millingstone component at MNT-228, using 1/8 in mesh, resulting in a total of 53 specimens (Table 8.5). The column sample produced 12 total specimens, ten of which were small taxa (sardine/herring, silversides, stickleback, sculpin), one pile perch, and one flatfish.

Area A units all dated to the Middle Period, which makes it possible to use Jones et al.'s (1996) original summary data (note that in the original report's Table 4.10, the column titles for Area A and Area B are reversed). I analyzed a small sample from Area A, including Unit 9 and two levels from Unit 10, to get more information on modifications, element distributions, and fragmentation. In Table 8.6, I compare site report data to my sample, grouped into broader taxonomic categories when possible. Overall, taxonomic distributions are fairly similar between the two, with four of the least common taxa from the original summary not captured in my data. The greatest discrepancy occurs between the sardine/herring and silversides: I identified similar percentages of each, whereas I calculate from Jones et al.'s (1996) data that they identified 16% sardine/herring and 36% silversides. This may partly be a result of my sample not being representative, but may also be due to inter-analyst variation (Gobalet 2001). Regardless, these fishes are all small schooling taxa that would have been caught with nets. If the sardine/herring category represents Pacific

herring, they and the silversides would both have been available in the estuary. However, based on my overall research results presented here, the sardine/herring category is more likely to represent sardines than herring.

Table 8.6. Taxonomic representation by numbers of identified specimens in Middle Period deposits at CA-MNT-228, comparing Jones et al. (1996) data with that collected for this project.

Taxon	Report	This project
Sharks and rays	45	4
Ray-finned fishes	0	31
Sturgeon	8	0
Northern anchovy	256	14
Sardine and herring	634	51
Minnows and suckers	149	9
Salmon and trout	17	3
Plainfin midshipman	62	4
Silversides	1451	60
Threespine stickleback	429	18
Rockfish	2	0
Staghorn sculpin	110	0
Other sculpin	5	1
White seabass	1	1
Sacramento perch	119	5
Surfperches	731	38
Pricklebacks	0	1
Kelpfish	4	0
Gobies	6	0
Flatfish	42	5
Total NISP	**4071**	**245**

In Figure 8.4, I present a comparison of the MNT-228 datasets for Millingstone versus Middle Periods, combining that from the Jones et al. (1996) report and my own analysis. A chi square analysis on the taxonomic categories as

grouped in Figure 8.1 is highly significant ($X^2 = 225.7824$, df = 12, $p < 2.2e\text{-}16$). Surfperches, sharks/rays, and Sacramento perch dominate the assemblage in the Millingstone Period, while small schooling fishes are more abundant in the Middle Period. Bat ray comprises most of the shark/ray category in both periods. All of the most abundant taxa can be caught in freshwater or estuarine environments. However, if the sardine/herrings are sardines, they would require boat trips into the bay beyond the kelp beds.

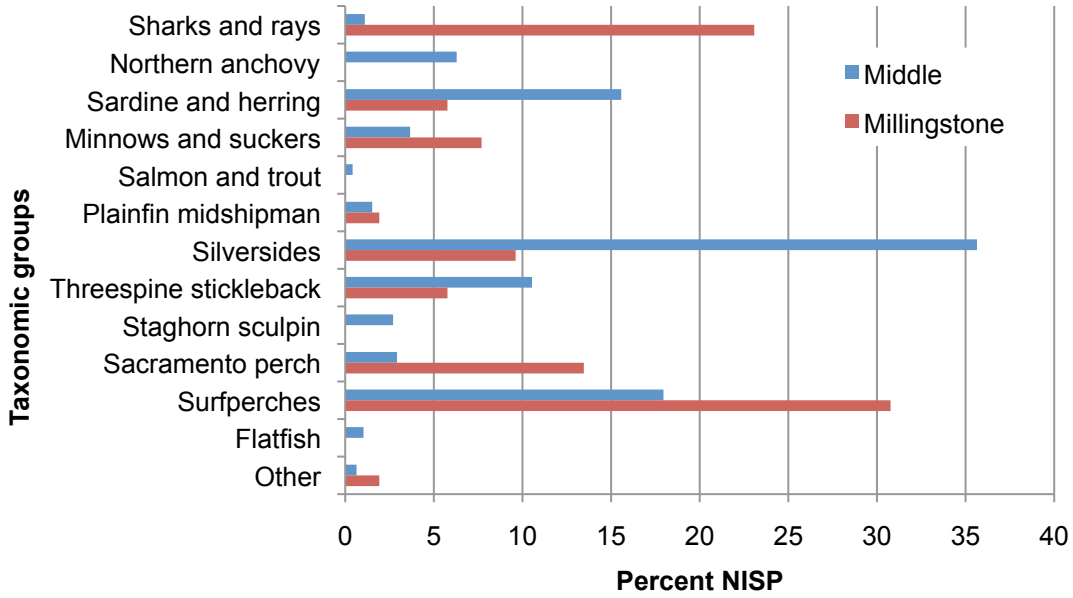


Figure 8.4. Percent NISP of taxonomic groups at CA-MNT-228, comparing the Millingstone and Middle Period components. "Other" includes remaining species with NISP<10 in both components.

Among the less common taxa, three specimens are kelpfish that come from rocky intertidal habitats, and two are rockfish that are usually rocky shoreline or kelp forest species. One white seabass (*Atractoscion nobilis*) vertebra stood out in this

assemblage, as it came from a very large individual that was probably caught from a boat, unless the fish somehow stranded. The vertebra is approximately 3 cm in diameter and over 4 cm long, whereas almost all of the other remains in the site are smaller than 1/4 in mesh (only seven out of the 245 specimens I sampled were caught in a 1/4 in mesh). It also has heavy carnivore gnawing around the edges. A piece of the vertebra was submitted for radiocarbon dating and falls in the Middle Period, so it is not intrusive from a later time.

MNT-229

MNT-229 has a Millingstone/Archaic occupation dating to 6400-4670 BC, while the Middle Period is represented by material dating to 210 BC-AD 710. Archaeological work at the site was divided into Northern, Middle, and Southern Excavation Areas. In addition, Unit 4 was placed off to the west near the shore. Based on the original excavations by Dietz et al. (1988), both the Southern Excavation Area and Unit 4 yielded exclusively Middle Period dates down to 120 cm and 160 cm respectively. I assigned all material from these units to the Middle Period. In the Northern and Middle Excavation Areas dates were almost entirely Middle Period at 0-100 cm and Millingstone/Archaic below 100 cm. Three of these dates were stratigraphically incongruent, but the majority support this division.

Data derived from the small sample I took of rapid recovery units and shovel test units were not significantly different from the control unit data (Fisher's Exact $p>0.05$). I thus combined the various unit types together in my analyses. The Middle Period sample from MNT-229 is much larger than the Millingstone assemblage and

this may account for the higher number of identified taxa from the Middle Period (Table 8.7).

Table 8.7. Taxonomic representation by numbers of identified specimens in Middle and Millingstone Period Deposits at CA-MNT-229.

Taxon	Millingstone	Middle	Unknown
Chondrichthyes	1	0	0
Chondrichthyes (shark)	9	5	0
Triakis semifasciata	7	7	0
Myliobatis californica	3	6	0
Acipenseridae	0	1	0
Actinopterygii	21	162	9
Clupeidae	2	67	13
Clupea pallasi	0	1	0
Sardinops sagax	0	1	0
Cypriniformes	2	86	0
Cyprinidae	29	468	7
Gila crassicauda	1	1	0
Lavinia exilicauda	2	4	1
Orthodon microlepidotus	0	15	0
Catostomus occidentalis	7	87	0
Oncorhynchus sp.	0	12	0
Oncorhynchus kisutch	0	1	0
Oncorhynchus mykiss	0	1	0
Merluccius productus	1	5	1
Porichthys notatus	0	7	0
Atherinopsidae	0	25	1
Gasterosteus aculeatus	0	1	0
Sebastes sp.	0	1	0
Cottidae	0	2	0
Leptocottus armatus	0	1	0
Archoplites interruptus	10	163	0
Embiotocidae	21	139	3
Amphistichus sp.	0	1	0
Rhacochilus vacca	0	1	0
Stichaeidae	0	2	0
Gibbonsia sp.	0	1	0
Scombridae	0	1	0
Pleuronectiformes	0	24	0
Platichthys stellatus	0	2	0
Total NISP	**116**	**1301**	**35**

However, when I combined taxa into larger categories, freshwater species – minnows, suckers, and Sacramento perch – clearly dominate both assemblages (Figure 8.5). All remaining species can be caught in an estuary, aside from a few specimens included in the "Other" category. The sardine/herring, silversides, and surfperches can all be caught with nets.

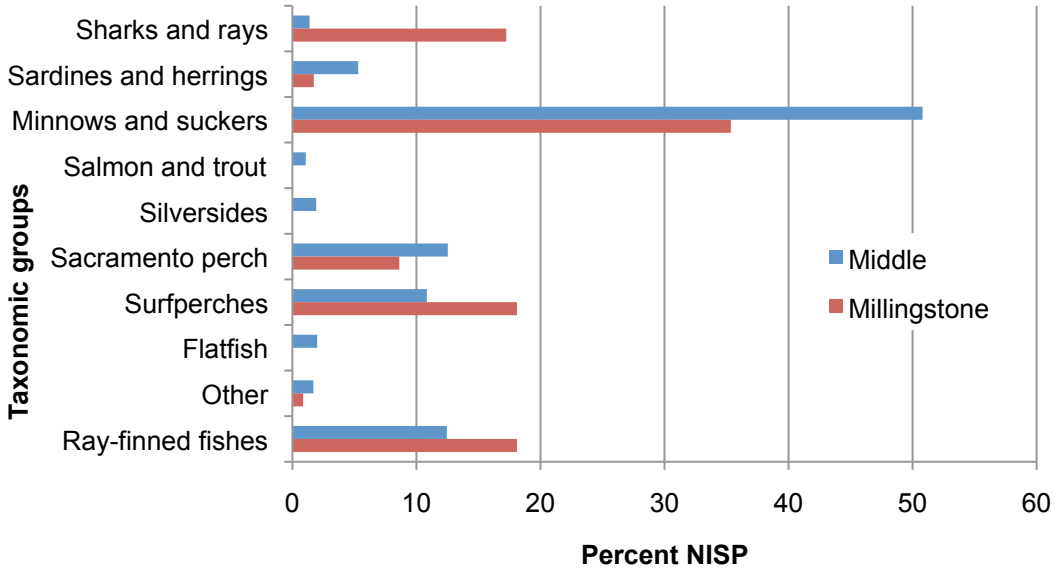


Figure 8.5. Percent NISP of taxonomic groups at MNT-229 by cultural period. "Other" includes remaining species with NISP<10.

The Millingstone and Middle Period assemblages at MNT-229 are significantly different (X^2=122.8646, df=9, p<2.2e-16 for the combined categories shown in Figure 8.5), with sharks and rays providing the largest difference between observed and expected values.

MNT-234

Radiocarbon dates at MNT-234 are problematic. As discussed in Chapter 5, original shellfish and charcoal dates from the Primary Midden showed a long sequence of occupation. Subsequent mammal and fish remains all dated to the Middle Period. While one might argue that the vertebrates were used during a short period of time, it is unclear why the other materials would date to a much longer span. Furthermore, I chose a selection of Pacific hake vertebrae to date for the fish, because they were the only obviously marine species apparent in the assemblage, making it possible to calculate the correct marine reservoir correction. However, northern fur seals are the most abundant mammal taxa in the assemblage and Pacific hake currently comprise about 18% of northern fur seal diet off the California coast (Antonelis and Perez 1984). While I did not find evidence of digestive acid on the vertebrae, I am concerned these could be a non-cultural addition to the midden. I am therefore not confident that the fish remains in the Primary Midden date only to the Middle Period. On the other hand, the *Amphistichus* fish specimen I dated from the horizontally discrete Millingstone deposit in Area C was congruent with the other dates from that unit. I have thus included the material from Area C.

MNT-234 is located at the mouth of the slough and is starkly different from MNT-229 in its lack of freshwater species from the Millingstone component (Table 8.8). However, sharks/rays and surfperches comprise high proportions of the assemblage, similar to MNT-229 (Figure 8.6). While I did not include Primary Midden material here, it is worth noting that only 16 total shark or ray specimens

were identified in the entire non-Millingstone assemblage, despite a sample size of nearly 21,000 (Milliken et al. 1999). Cartilaginous fishes are thus present in barely trace amounts in the larger MNT-234 assemblage, but comprise 12% of the Millingstone component identified here. MNT-234 also has high proportions of sardine/herrings and silversides, small schooling fishes that can be caught with nets. One *Atractoscion nobilis* specimen was also identified at MNT-234, like at MNT-228, though this specimen is from an earlier cultural period.

Table 8.8. Taxonomic representation by numbers of identified specimens in Millingstone Period Deposits at CA-MNT-234.

Taxon	**NISP**
Acipenseridae	1
Chondrichthyes	23
Chondrichthyes (ray)	3
Chondrichthyes (shark)	1
Triakis semifasciata	10
Galeorhinus galeus	1
Myliobatis californica	33
Actinopterygii	152
Engraulis mordax	1
Clupeidae	89
Sardinops sagax	8
Porichthys notatus	1
Atherinopsidae	30
Hexagrammos sp.	1
Ophiodon elongatus	1
Leptocottus armatus	3
Atractoscion nobilis	1
Embiotocidae	200
Amphistichus sp.	1
Phanerodon sp.	2
Phanerodon furcatus	2
Rhacochilus vacca	33
Stichaeidae	1
Pleuronectiformes	3
Total NISP	**601**

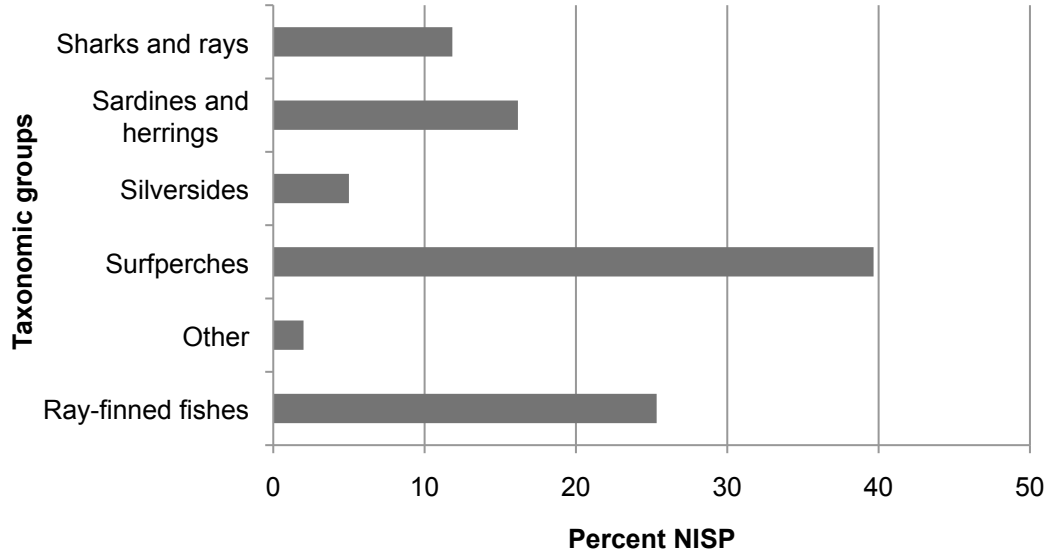


Figure 8.6. Percent NISP of taxonomic groups at MNT-234, for the Millingstone Period. "Other" includes remaining species with NISP<10.

Results from Pacific Grove Sites (Rocky Shore, Sandy Beach, and Kelp Forest)

MNT-112 and MNT-113A

These adjacent sites are essentially single component, dating to the Late Period based on Breschini and Haversat's (2011) chronology. However, Jones et al. (2007) would assign the date on fish bone from MNT-112 to the very end of the Middle Period. I have labeled it here as MLT/Late, since most of the extended occupation falls within the MLT.

The MNT-112 assemblage is larger than MNT-113 and in Table 8.9 I show the data from Unit 8, which was screened with 1/8 in mesh. When *Sardinops sagax* is combined with the more general Clupeidae category, sardine/herrings comprise almost 40% of the assemblage (Figure 8.7). By contrast, the MNT-113A collection

has no sardine/herrings or silversides, but this may be due to sampling, since the assemblage is small and was mostly recovered with 1/4 in mesh.

Table 8.9. Taxonomic representation by numbers of identified specimens in MLT/Late Period deposits at CA-MNT-112 and Late Period deposits at MNT-113A.

Taxon	MNT-112	MNT-113A
Actinopterygii	46	34
Clupeidae	72	0
Sardinops sagax	12	0
Porichthys notatus	7	0
Atherinopsidae	11	0
Sebastes sp.	24	14
Hexagrammos sp.	5	0
Ophiodon elongatus	2	0
Scorpaenichthys marmoratus	12	15
Embiotocidae	19	3
Embiotoca sp.	0	3
Embiotoca jacksoni	0	1
Sphyraena argentea	2	0
Stichaeidae	4	5
Pleuronectiformes	0	1
Total NISP	**216**	**76**

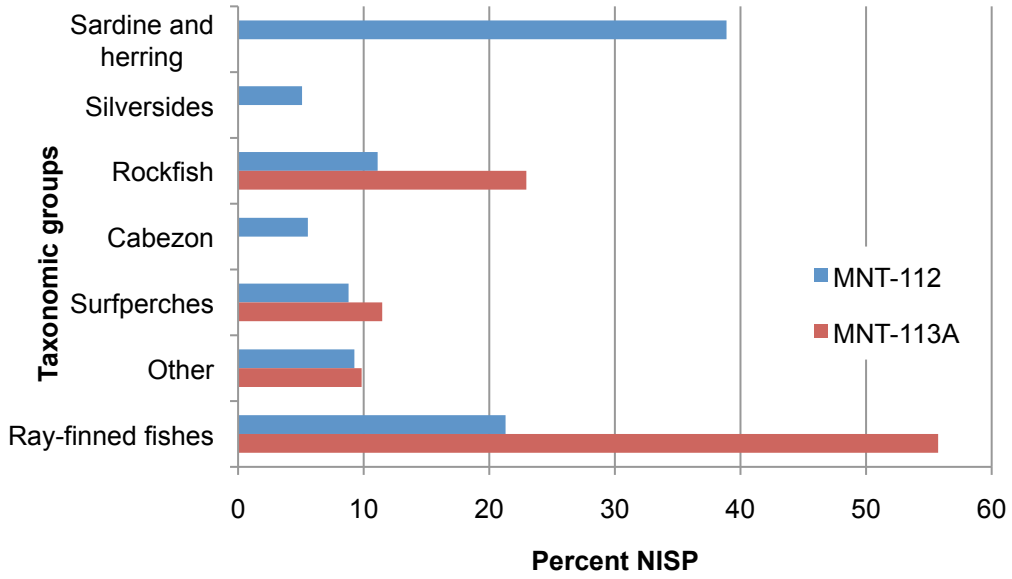


Figure 8.7. Percent NISP of taxonomic groups at MNT-112 compared to MNT-113A. "Other" includes remaining species with NISP<10 at both sites.

MNT-113B

MNT-113B is a single component, Middle Period site. All of the fish remains came from Unit 6, which was also the only unit screened with 1/8 in mesh. Similar to the Late Period MNT-112, sardine/herring dominate this assemblage, followed by rockfish (Table 8.10, Figure 8.8). Overall, the identified remains are mainly small schooling fish, which were probably netted, and intertidal species that could be caught from on shore.

Table 8.10. Taxonomic representation by numbers of identified specimens in the Middle Period Deposit at CA-MNT-113B.

Taxon	**NISP**
Actinopterygii	64
Chondrichthyes	1
Clupeidae	61
Sardinops sagax	7
Atherinopsidae	18
Sebastes sp.	52
Hexagrammos sp.	6
Ophiodon elongatus	1
Scorpaenichthys marmoratus	15
Embiotocidae	21
Rhacochilus vacca	1
Stichaeidae	16
Platichthys stellatus	1
Total NISP	**264**

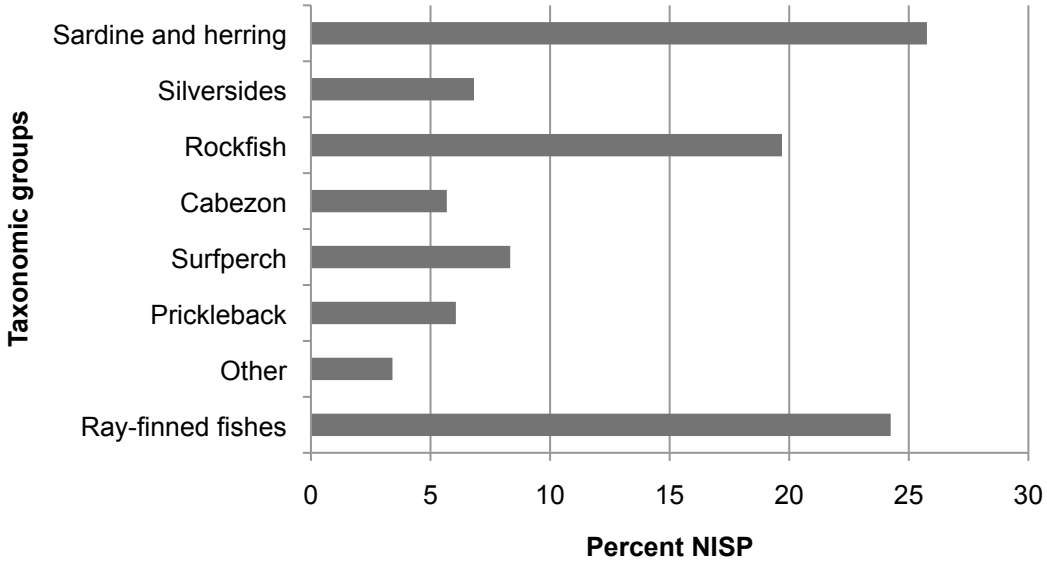


Figure 8.8. Percent NISP of taxonomic groups at MNT-113B. "Other" includes remaining species with NISP<10.

MNT-113D

MNT-113D has an Early Period component in Units 24 and 25, and a Late Period component in Unit 9. However, the two Unit 9 dates are also from significantly shallower levels (30-40 cm) than the dates from the other units (80-120 cm), so it is unclear whether components at the site are horizontally or vertically discrete. All of the small assemblage of fish remains came from Unit 24 and, unfortunately, neither of the specimens I submitted for dating had useful results.

When taken as a whole, the taxa identified at this site can all be caught from shore except for *Merluccius productus* (Table 8.11). However, this site was screened with 1/4 in mesh, so even if small schooling fishes such as sardine/herring were present at the site they would not have been recovered.

Table 8.11. Taxonomic representation by numbers of identified specimens in the entire deposit at CA-MNT-113D.

Taxon	Total NISP	80-120 cm only
Actinopterygii	30	16
Merluccius productus	1	1
Scorpaeniformes	1	0
Sebastes sp.	58	20
Ophiodon elongatus	4	2
Scorpaenichthys marmoratus	18	7
Embiotocidae	8	5
Embiotoca sp.	1	0
Stichaeidae	5	0
Total NISP	**126**	**51**

Because both of the Early Period dates were in the 80-120 cm levels, I separated out 0-80 cm (n=57) from 80-120 cm (n=51), but they were not significantly different (Fisher's Exact p=0.2114). However, despite the small sample size, the aggregated 120-160 cm level sample (n=18) differed significantly from the higher two (p<0.0001). Cabezon and pricklebacks comprised a much higher proportion of the lowest levels than the other levels (Figure 8.9). Furthermore, when total NISP is plotted by level for Unit 24, an area of low abundance of total fish specimens exists at 110-130 cm (Figure 8.10).

While I do not want to make too much of this distinction given the small sample sizes, it is possible Unit 24 at MNT-113D represents two or even three occupations. Further radiocarbon dating would help elucidate whether this is true. In the meantime, I will only consider the 80-120 cm levels, which are dated in that unit and an adjacent one to the Early Period.

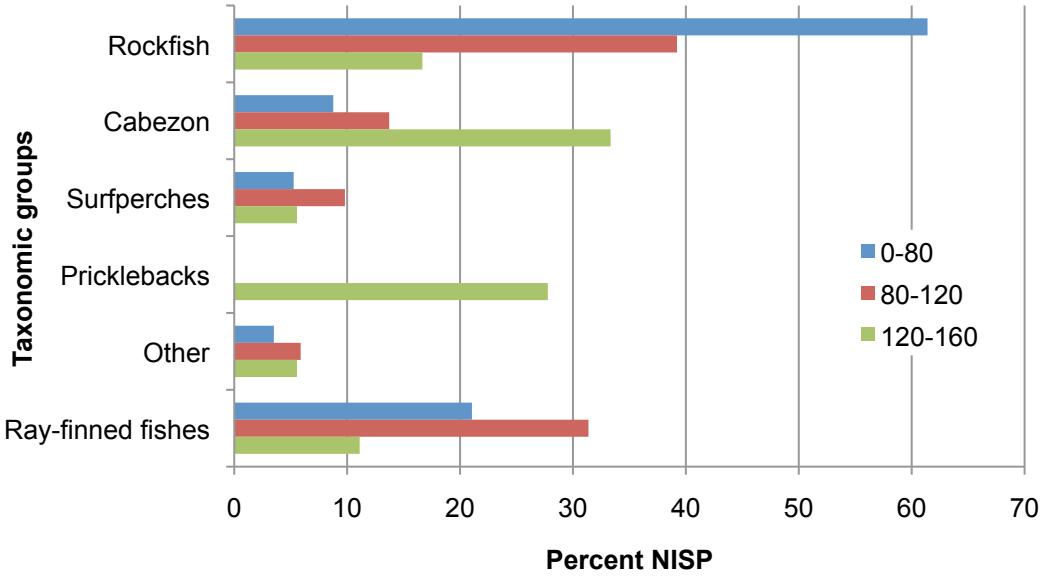


Figure 8.9. Percent NISP of taxonomic groups at MNT-113D. "Other" includes remaining species with NISP<5.

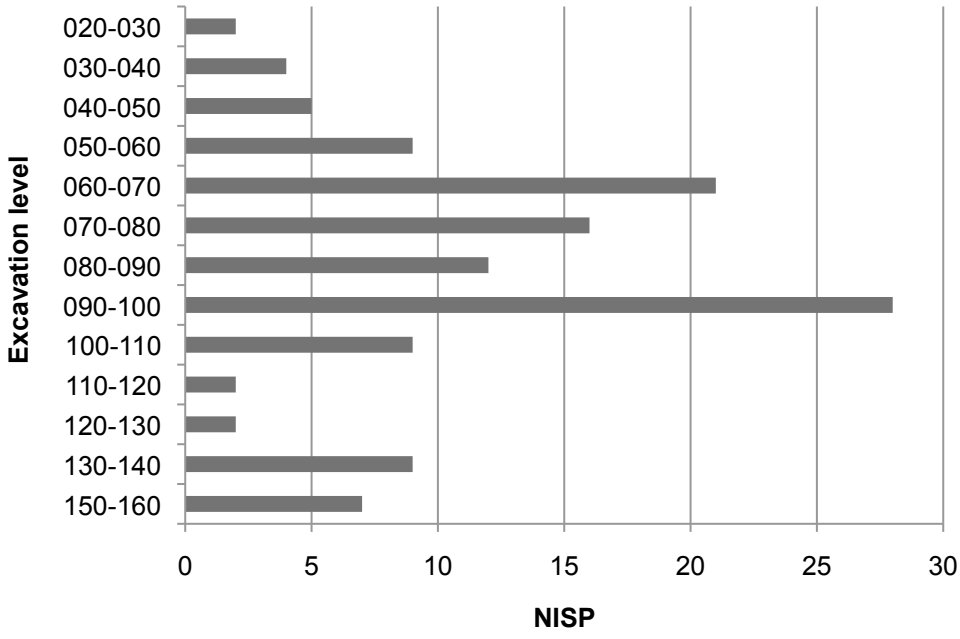


Figure 8.10. Total fish NISP by excavation level at MNT-113D. The sediment matrix at this site was described as loamy soil above the midden, and sandy soil or granite below (Dietz and Jackson 1981).

MNT-831

MNT-831 appears to have been occupied during all cultural periods, but the dating of the site is complicated. Furthermore, several units were excavated from surface to sterile soil without using arbitrary levels. As a result, several radiocarbon dates from the site do not have a vertical provenience, though they were still submitted to help determine the nature of the site (Breschini and Haversat 2006).

Of the dates with vertical proveniences, every specimen dating to the Middle or Late Period came from 25 cm or above and Late Period dates only occurred in areas without fish remains. All dated specimens with depth proveniences below 30 cm dated to the Millingstone/Early or Millingstone/Archaic. All four Millingstone/Archaic dates came from around Unit 4. However, a fish specimen from that unit returned a Middle Period date that was recovered stratigraphically below a Millingstone/Archaic specimen, which may indicate some mixing.

Twenty out of twenty-nine dates from the site represent the Early Period, as defined by Breschini and Haversat (2005, 2006, 2011), and many of these are from a brief 200-year span. Breschini and Haversat (2006) therefore argued that the most intensive occupation must have occurred at that time. I decided to consider those fish specimens above 30 cm as assignable to the Middle Period, and referred those below that depth to the Millingstone/Early Period. However, I also examined the fish remains by 10 cm strata, to determine if significant differences existed in the stratigraphic column.

Fish remains came from both excavation contexts – units excavated in 10 cm levels and those excavated 0-bottom – with the majority coming from units without arbitrary levels (Table 8.12). Taxa are mostly rocky shoreline species, of the sort caught with hook and line or in tide pools, and small schooling species that can be caught with nets. The barracuda (*Sphyraena argentea*) and Pacific mackerel (*Scomber japonicus*) both require boats, as might the clupeids if they represent sardines and not herring.

Table 8.12. Taxonomic representation by numbers of identified specimens in Millingstone/Early Period (marked in table as just Early), Middle Period, and unknown deposits at CA-MNT-831.

	Units with Levels		Units without Levels		
Taxon	**Early**	**Middle**	**6**	**6B**	**7**
Actinopterygii	134	87	82	71	568
Clupeiformes	0	0	0	0	1
Clupeidae	35	12	36	17	203
Sardinops sagax	3	0	2	2	5
Atherinopsidae	8	3	4	3	35
Scorpaeniformes	0	0	0	1	3
Sebastes sp.	78	35	39	34	245
Hexagrammos sp.	11	5	14	0	39
Ophiodon elongatus	3	3	1	0	9
Cottidae	0	1	0	1	2
Scorpaenichthys marmoratus	30	12	26	16	117
Embiotocidae	21	15	21	11	62
Rhacochilus vacca	2	1	0	0	5
Sphyraena argentea	1	0	0	0	0
Scomber japonicus	0	1	0	0	0
Stichaeidae	20	21	9	11	68
Total NISP	**346**	**196**	**234**	**167**	**1362**

The proportions of different taxonomic categories are fairly similar among the two components I have defined, as well as the units excavated without levels (Figure 8.11). A chi-square test of Middle Period and the Millingstone/Early levels indicated

the difference between these two samples was not significant ($X^2 = 11.9104$, df = 8, $p = 0.1552$). I excluded Actinopterygii from these tests, because its value is more a reflection of the level of fragmentation, and hence the identifiability, of the assemblage than a separate taxonomic category.

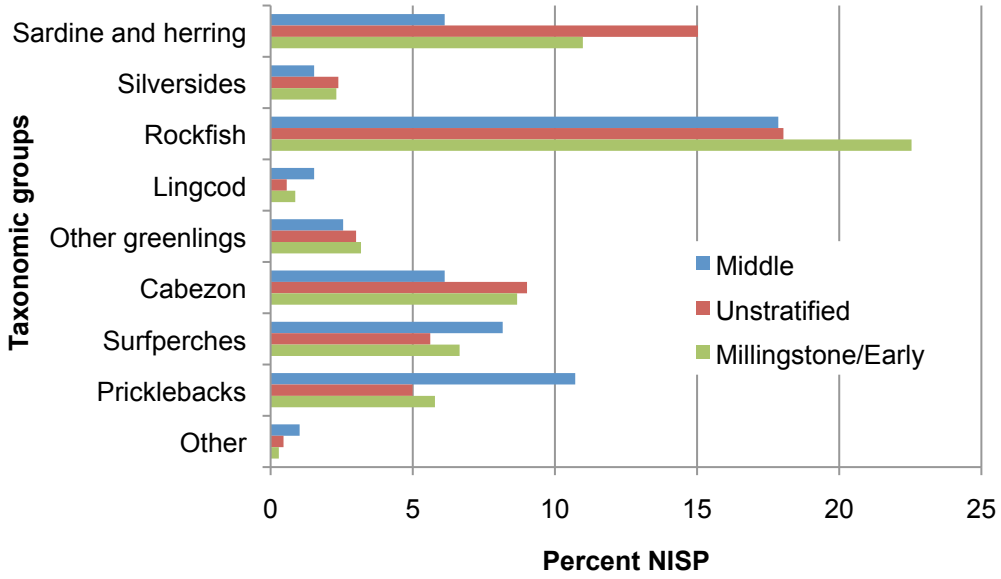


Figure 8.11. Percent NISP of taxonomic groups at MNT-831. "Other" includes remaining species with NISP<10 in all three provenience categories. Ray-finned fishes comprise 39-44% of each category's assemblage, but I have removed them from this graph to make the proportions of other species more visible. Percentages on this graph only add up to 100% when ray-finned fishes are included.

The units without levels are not significantly different from the Millingstone/Early component, but they are distinct from the Middle Period levels ($X^2 = 29.2211$, df = 8, $p = 0.00029$). Most significant are the higher proportions of sardine/herring and lower proportions of pricklebacks in the units with levels. The similarity in identified fish taxa between the units without levels and the

Millingstone/Early proveniences probably reflects the much more substantial Early Period component at the site.

MNT-125

A single component Late Period site, MNT-125 excavations produced only 25 total fish specimens, of which only 14 were identifiable to family or species (Table 8.13). All of the taxa are rocky shoreline intertidal species easily caught in tide pools or from shore.

Table 8.13. Taxonomic representation by numbers of identified specimens in the entire deposit at CA-MNT-125.

Taxon	NISP
Actinopterygii	11
Sebastes sp.	1
Cottidae	1
Scorpaenichthys marmoratus	6
Stichaeidae	6
Total NISP	**25**

Results from Carmel Bay Sites (Rocky Shore, Sandy Beach, and Kelp Forest)

MNT-170

Excavators at MNT-170 identified Early and Late Period components, though Jones et al. (2007) would place one date at 38 cm in the Middle Period, and much of the occupation span within the Middle-Late Transition. Based on the radiocarbon dates, I have considered one 10 cm arbitrary level of unknown temporal origin, as it is between the other dated components. I assigned above 40 cm to the MLT/Late Period and below 50 cm to the Early Period, based on dates at 53 and 90 cm.

Overall, the Early Period component is substantially larger than that of the Late Period, though the former also has a high proportion – 58% – of unidentifiable fish remains (Table 8.14). Rockfish dominate the Early Period assemblage, while the MLT/Late Period has a more even distribution of rockfish, cabezon, surfperches, and pricklebacks (Figure 8.12).

Table 8.14. Taxonomic representation by numbers of identified specimens in Early and MLT/Late Period deposits at CA-MNT-170.

	Cultural Period		
Taxon	**Early**	**Unknown**	**MLT/Late**
Chondrichthyes	1	0	0
Actinopterygii	277	6	14
Clupeidae	4	0	0
Sardinops sagax	0	0	1
Oncorhynchus sp.	2	0	0
Atherinopsidae	0	0	1
Sebastes sp.	98	1	7
Hexagrammidae	0	0	1
Hexagrammos sp.	18	1	1
Ophiodon elongatus	2	0	1
Cottidae	1	0	0
Scorpaenichthys marmoratus	21	5	6
Embiotocidae	20	2	6
Hypsurus caryi	1	0	0
Rhacochilus vacca	5	0	0
Stichaeidae	26	1	5
Total NISP	**476**	**16**	**43**

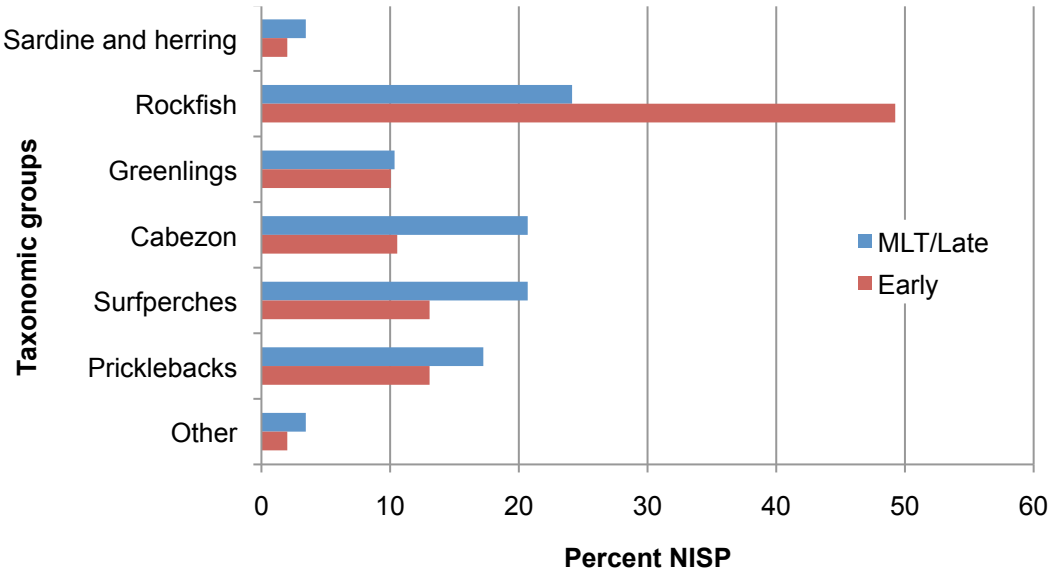


Figure 8.12. Percent NISP of taxonomic groups at MNT-170. "Other" includes remaining species with NISP<5 in both periods. The high proportion of ray-finned fishes in the Early Period made it difficult to see other taxa, so I removed them from consideration for this figure.

When Actinopterygii are removed from consideration, the taxonomic distributions are significantly different, despite the small sample size for the MLT/Late Period (Fisher's Exact $p = 0.00901$, for the taxon list in Table 8.14). However, this is driven by three taxa, all of which only have one identified specimen. Two are only important due to the specificity of taxonomic identification in each period; when *Sardinops sagax* is included in Clupeidae, and *Hexagrammos* sp. within Hexagrammidae, results are no longer significant (Fisher's exact $p = 0.08174$). The remaining important taxon is Atherinopsidae, and removing it from the previous calculation results in $p = 0.1932$. All of the identified taxa are easily caught from a

rocky shoreline, and small schooling species comprise a very small percentage of both components.

MNT-834B

Much of MNT-834B dates to the span Jones et al. (2007) call the Middle-Late Transition and Breschini and Haversat (2011) call the Late Period. Several shellfish pieces also date to the Late Period by both chronologies. For my comparisons among sites, I include MNT-834B within an MLT/Late category.

Samples analyzed from MNT-834B come from deposits screened with both 1/8 in and 1/4 in mesh, with a higher proportion from 1/4 in proveniences. As expected, most of the small schooling fishes are from Unit A1, which was screened with 1/8 in mesh (Table 8.15). However, only one taxon, Cottidae, was identified in A1 and not in other units. The 1/4 in units therefore appear to have captured the various taxa exploited, even if they severely underestimate the importance of small schooling fishes.

Fisher's Exact tests on A1 compared to the other non-feature units support this interpretation. I included *Sardinops sagax* in Clupeidae, and the assorted surfperch species into Embiotocidae, because those specimens identified to the family level probably included the same species. I also removed specimens attributed to the general category of Actinopterygii from consideration, because the specimens unidentifiable to a more specific taxon were a much lower percentage in unit A1 compared to the other units (25% vs. 34-39%). Under those conditions, the results of Fisher's Exact tests comparing units A1 to A2, and A1 to A West 1/2, are significant

($p < .00001$ for both). However, when Clupeidae are removed, which are unlikely to have been retrieved from units screened with 1/4 in mesh, the results are no longer significant: $p = 0.2221$ for A1 vs. A2, and $p = 0.1191$ for A1 vs. A West 1/2. The two non-feature units are also not significantly different from each other ($p = 0.4086$). This suggests that, except for the lack of clupeids, taxonomic distributions in the units screened with 1/4 in mesh are similar.

Table 8.15. Taxonomic representation by numbers of identified specimens in various deposits at CA-MNT-834B. One additional *Rhacochilus vacca* specimen was recovered from the surface.

	1/8 in	1/4 in		
Taxon	**A1**	**A2**	**Feature 2**	**Unit A West 1/2**
Actinopterygii	78	177	187	111
Clupeidae	69	6	11	7
Sardinops sagax	5	2	0	5
Oncorhynchus sp.	0	0	3	0
Merluccius productus	0	0	1	2
Porichthys notatus	10	29	29	21
Atherinopsidae	0	2	1	0
Scorpaeniformes	1	1	1	0
Sebastes sp.	37	71	90	65
Hexagrammidae	0	0	3	0
Hexagrammos sp.	3	2	1	4
Ophiodon elongatus	1	1	2	2
Cottidae	1	0	0	0
Scorpaenichthys marmoratus	8	7	4	5
Embiotocidae	60	113	161	88
Embiotoca sp.	0	5	8	1
Embiotoca lateralis	0	2	0	0
Hypsurus caryi	0	2	1	0
Rhacochilus sp.	0	1	0	1
Rhacochilus toxotes	0	1	0	0
Rhacochilus vacca	16	10	18	4
Stichaeidae	18	19	5	12
Sphyraena argentea	0	0	1	3
Total NISP	**307**	**451**	**527**	**331**

Using the cumulative plotting technique described by Lyman and Ames (2004), I show in Figure 8.13 that I have not yet sampled to redundancy for taxonomic richness at MNT-834B. However, the last two samples considered add over 600 more specimens, but only result in the addition of one specimen of one taxon (Cottidae). Based on this information, combined with the similarities in taxonomic distributions between the non-feature levels at the site, my sample is reasonably representative of the MNT-834B assemblage.

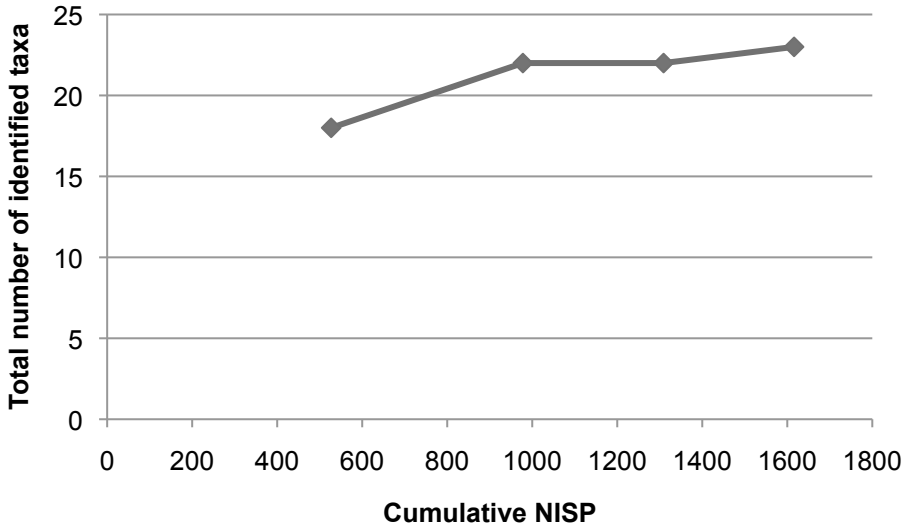


Figure 8.13. Total number of identified taxa compared to cumulative sample size for CA-MNT-834B. Samples were added from largest sample size to smallest, under the assumption more taxa would be identified in larger sample sizes (see Lyman and Ames 2004, 2007). The smallest sample was n=307.

Feature 2 was identified during excavation as "an extensive fire pit, lined with rocks, with an associated abalone feature and a small ash deposit" (Breschini and Haversat 2008:24-25). It is at the base of the site deposit, which suggests it was from an early occupation at the site, and its preservation may be due to its context in a

more clay-type sediment (Breschini and Haversat 2008). Two abalone samples from the feature dated to AD 1202 and 1229, and my fish bone sample dated to AD 1260.

The fish remains from Feature 2 are significantly different than the other proveniences excavated with 1/4 in mesh. Using the same criteria as above for clupeids and embiotocids, and removing Actinopterygii, a Fisher's Exact test results in $p = 0.0098$, and a chi-square test is also significant ($X^2 = 27.7133$, df = 12, $p = 0.006$). The most important factors based on chi-squared residuals are fewer pricklebacks, and more salmon, greenlings, and surfperches than in the non-feature units. These differences can be seen in Figure 8.14.

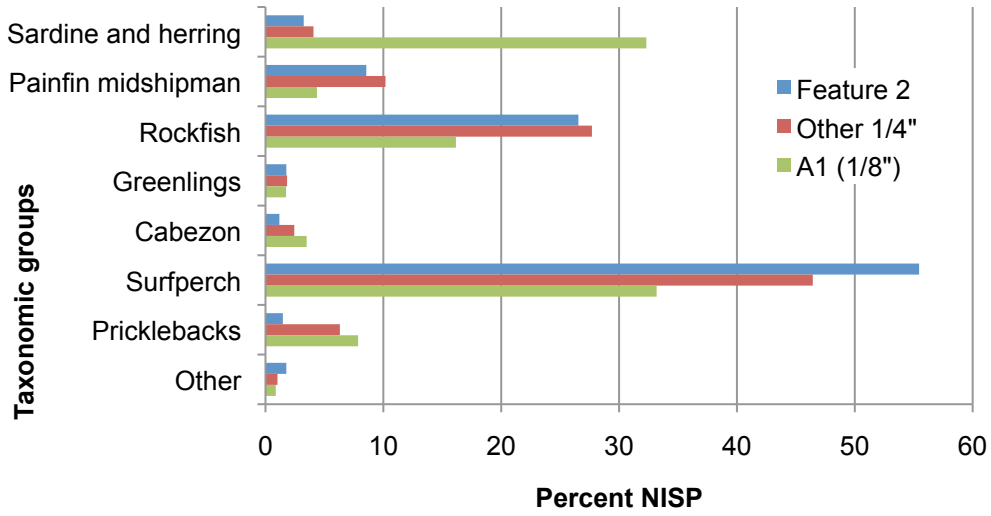


Figure 8.14. Percent NISP of taxonomic groups at MNT-834B, comparing Feature 2 to the other proveniences screened with 1/4 in mesh, and the unit screened with 1/8 in mesh. "Other" includes remaining species with NISP<5 in both periods. I removed unidentifiable ray-finned fishes from this figure, because their proportions were so different among proveniences.

MNT-17

At MNT-17a through -17c, only seven fish specimens came from MNT-17a/b. All of these specimens were from above 50 cm and all dates in MNT-17a/b above 50 cm were from the Late Period. I therefore assigned the fish material from MNT-17a/b to the Late Period. In MNT-17c, one sample at 34-40 cm dated to the Late Period, and several samples at 70-190 cm dated to the Early Period. I therefore called material above 40 cm Late Period, below 70 cm Early Period, and considered 40-70 cm unknown. In the southern part of MNT-17c, deep augers dated to the Millingstone/Archaic. While the auger samples with fish bone were not the same ones that were dated, I tentatively assigned that part of the assemblage to the Millingstone.

The Early Period component produced a higher sample size than all three other ones combined (Table 8.16). A Fisher's Exact test among all components is significant, as are tests between each pair of components, both with and without Actinopterygii. Overall at the site, sardine/herring, rockfish, and pricklebacks are the most abundant taxa, but their proportions vary substantially by component (Figure 8.15). Sardine/herring are heavily emphasized in the Millingstone, and somewhat again in the Late Period. By contrast, rockfish are the most abundant taxa from both the unknown and Early Periods. Pricklebacks increase in relative abundance over time, and by the Late Period were at about equal proportion with rockfish and sardine/herring.

Table 8.16. Taxonomic representation by numbers of identified specimens in different cultural components at CA-MNT-17.

Taxon	Millingstone	Early	Unknown	Late
Actinopterygii	167	893	256	123
Clupeidae	129	114	18	41
Sardinops sagax	9	11	0	0
Oncorhynchus sp.	0	5	9	8
Merluccius productus	3	4	1	0
Porichthys notatus	11	12	0	0
Atherinopsidae	5	12	0	0
Sebastes sp.	37	361	149	37
Hexagrammidae	0	11	1	0
Hexagrammos sp.	2	31	14	3
Ophiodon elongatus	0	25	21	1
Cottidae	0	2	4	6
Scorpaenichthys marmoratus	3	80	68	4
Archoplites interruptus	0	1	0	0
Carangidae	0	0	0	2
Embiotocidae	8	50	20	6
Embiotoca sp.	0	0	1	0
Embiotoca jacksoni	2	0	0	0
Rhacochilus vacca	1	8	5	4
Gibbonsia sp.	0	1	1	0
Stichaeidae	12	51	40	33
Scomber japonicus	0	0	0	1
Pleuronectiformes	0	1	1	0
Total NISP	**389**	**1673**	**609**	**269**

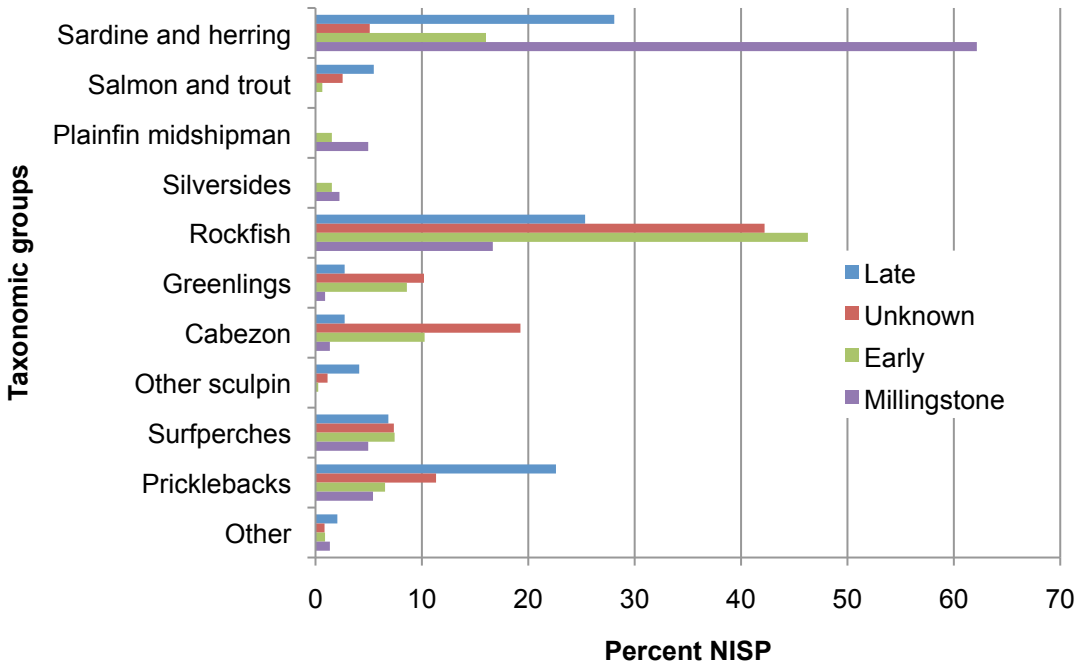


Figure 8.15. Percent NISP of taxonomic groups at MNT-17, by cultural components. "Other" includes remaining species with NISP<5 in all periods. I removed unidentifiable ray-finned fishes, because they were a high proportion of the assemblage (43-54%).

Results from an Inland Site

MNT-1701

MNT-1701 is a particularly interesting site, because it is 15 km inland from Carmel Bay, yet has high numbers of fish remains, most of which are sardine/herring (Table 8.17). It dates to AD 800-1450, with the majority of dates in the AD 800s through 1200s. These are all within Breschini and Haversat's (2011) definition of the Late Period and most of the dates fall within Jones et al.'s (2007) Middle-Late Transition, with some dates in the Middle and Late Periods. The Medieval Climatic Anomaly also occurred within the time span of most dates from this site.

Table 8.17. Taxonomic representation by numbers of identified specimens in different unit levels at CA-MNT-1701, from excavation area AC 1683.

	Unit 1	Unit 2			
Taxon	**080-090**	**030-040**	**050-060**	**090-100**	**Total**
Actinopterygii	182	430	572	38	1222
Clupeiformes	0	0	1	5	6
Engraulis mordax	0	0	2	1	3
Clupeidae	520	1969	2366	1212	6067
Sardinops sagax	32	122	134	87	375
Cypriniformes	0	1	0	0	1
Oncorhynchus sp.	2	4	2	1	9
Porichthys notatus	1	0	0	0	1
Atherinopsidae	2	19	16	2	39
Gasterosteus aculeatus	0	0	1	0	1
Sebastes sp.	0	5	3	0	8
Ophiodon elongatus	0	0	1	0	1
Carangidae	0	3	0	1	4
Trachurus symmetricus	1	2	2	0	5
Embiotocidae	1	0	1	1	3
Rhacochilus vacca	0	0	0	1	1
Stichaeidae	0	0	1	0	1
Sphyraena argentea	0	0	1	0	1
Total NISP	**741**	**2555**	**3103**	**1349**	**7748**

I sampled four unit levels from the site, resulting in 7748 analyzed fish specimens. Using the same cumulative richness plotting technique described for MNT-834B, I show in Figure 8.16 that MNT-1701 still has not been sampled to redundancy for capturing taxonomic richness. However, the sardine/herrings (Clupeidae and *Sardinops sagax*) comprise 84% of the total assemblage, rising to 99% when the unidentifiable ray-finned fishes are removed. Thus, although numerous different taxa from multiple habitats are present in the site, sardine/herring are by far the most important. Of the remaining species, most are usually found in schools, including silversides (Atherinopsidae), anchovies (*Engraulis mordax*), small

surfperches (Embiotocidae), scad/yellowtail/jackmackerel (Carangidae and *Trachurus symmetricus*), and even barracuda (*Sphyraena argentea*).

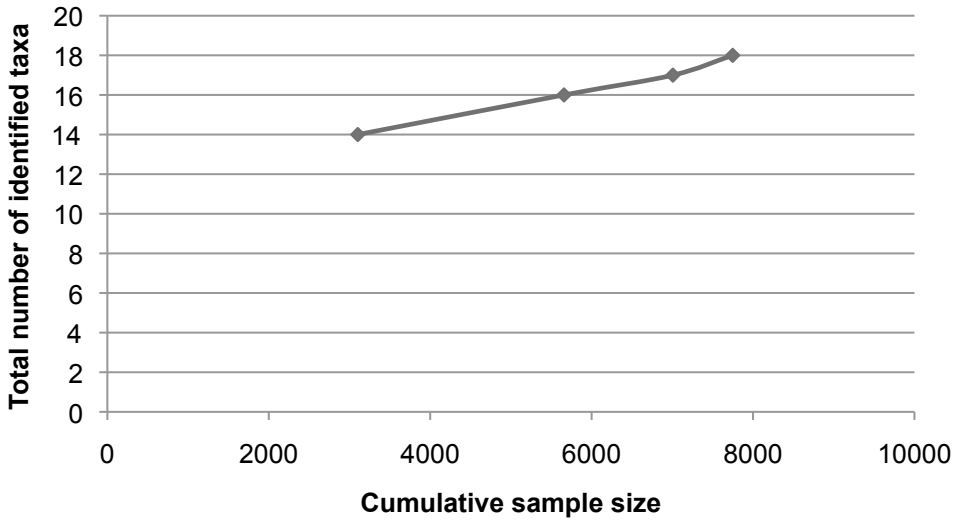


Figure 8.16. Total number of identified taxa compared to cumulative sample size for CA-MNT-1701. Samples were added from largest sample size to smallest, under the assumption more taxa would be identified in larger sample sizes (see Lyman and Ames 2004, 2007). The smallest sample was n=741.

A brief calculation of Minimum Numbers of Individuals (MNI) for MNT-1701 produces some striking results. Atlas and axis vertebrae are both distinguishable between sardine and herring, so I identified them to species. To calculate the following three MNI values, I considered all materials in the site as an aggregate, and only considered vertebrae with landmarks (i.e., more than 50% of the centrum present, and therefore no bone can be counted twice with two fragments). Based on atlas vertebrae for sardine, MNI=103, and using axis vertebrae, MNI=104. If the other vertebrae, which I identified as Clupeidae, are assumed to be sardine, then their MNI is between 110 and 121, depending on which number of total vertebrae is used

(they range from 49-54, as I discussed in Chapter 6). This close correlation among the different MNI calculations suggests that whole fish were being transported inland, as might be expected given their relatively small size.

Temporal and Habitat Comparisons

In this section, I compare fishes between sites, grouped according to their adjacent habitat types and by cultural period. I removed Actinopterygii from all of these comparisons to make differences between more specific taxonomic categories more evident. Taxa are grouped into different patch types based on habitat and most likely fishing method (Table 8.18). Some taxa could be caught in multiple habitats, in which case I placed them in the most likely category for the site location. Surfperches (Embiotocidae), for example, can be caught in estuaries, the surf zone, and along rocky shorelines, so for estuary sites, I placed them in the "estuary mass capture" category. However, I put surfperches in their own category for the rocky/sandy shoreline sites, and I explain why in that section.

Table 8.18. Taxa divided into patch types. “Mass capture” refers to multiple individuals being caught at once, such as with nets. “Single capture” might be hook-and-line fishing, spears, etc. For each patch type, taxa are listed in alphabetical order. *Marks taxa that are found in multiple habitats.

Patch type	Taxon
Freshwater	*Archoplites interruptus*
	Catostomus occidentalis
	Cyprinidae
	Cypriniformes
	Gasterosteus aculeatus
	Gila crassicauda
	Lavinia exilicauda
	Oncorhynchus kisutch[1]
	Oncorhynchus mykiss[1]
	Oncorhynchus sp.[1]
	Orthodon microlepidotus
Estuary mass capture	Atherinopsidae*
	Clupea pallasi
	Cottidae*
	Cymatogaster aggregata
	Embiotocidae*
	*Engraulis mordax**
	Gobiidae
	Hyperprosopon sp.
	Leptocottus armatus
Estuary single capture	Acipenseridae
	Chondrichthyes
	Chondrichthyes (ray)
	Chondrichthyes (shark)
	Myliobatis californica
	Platichthys stellatus
	Pleuronectiformes*
	*Porichthys notatus**
	Triakis semifasciata

(continued on next page)

Table 8.18. (continued)

Patch type	Taxon
Tidepool	Cottidae*
	Gibbonsia sp.
	*Porichthys notatus**
	Stichaeidae
Surf zone or nearshore mass capture	Atherinopsidae*
	Embiotocidae*
	*Engraulis mordax**
	Phanerodon furcatus
Onshore single capture	*Amphistichus sp.*
	Embiotoca jacksoni
	Embiotoca lateralis
	Embiotoca sp.
	Embiotocidae*
	Hexagrammidae
	Hexagrammos sp.
	Hypsurus caryi
	*Myliobatis californica**
	Ophiodon elongatus
	Phanerodon sp.
	Pleuronectiformes*
	Rhacochilus sp.
	Rhacochilus toxotes
	Rhacochilus vacca
	Scorpaenichthys marmoratus
	Scorpaeniformes[2]
	Sebastes sp.
Estuary or boat mass capture	Clupeidae
	Clupeiformes
Nearshore from boat	*Atractoscion nobilis*
	Carangidae
	Galeorhinus galeus
	Sardinops sagax
	Scomber japonicus
	Scombridae
	Sphyraena argentea
	Trachurus symmetricus
Offshore	*Merluccius productus*

1. *Oncorhynchus* species could also be caught in ocean, but most likely were caught in freshwater.
2. I only used "Scorpaeniformes" for indeterminate *Sebastes*/*Scorpaenichthys*/Hexagrammidae.

A closer look at the clupeid category is vital here, because the species in this group require very different acquisition strategies. Clupeids found in the Monterey Bay area include Pacific herring, which can be caught from shore in several habitats, including beaches and estuaries, and Pacific sardine, which is more typically found in nearshore and offshore marine contexts. Pacific herring can be caught in shallow waters in the Elkhorn Slough (Yoklavich et al. 1991), especially in the fall and winter when spawning (Barry and Cailliet 1981). Pacific sardine, on the other hand, would require a boat for exploitation.

Since Pacific herring would take less effort to catch, it is noteworthy that I identified only one Pacific herring specimen out of all of the assemblages I analyzed. In total, I identified 7117 specimens as clupeid, and 458 more were definitively identifiable as Pacific sardine. Given these numbers, I argue that most clupeid specimens from my analyses are probably sardine, rather than herring, and therefore signify the use of boats for their capture. I place clupeids in an "estuary or boat mass capture" patch type, as a reminder that they *could* be herring, but the data do suggest otherwise.

Estuary Sites

The Millingstone component at MNT-229 dates to 6400-4670 BC, at MNT-234 to 6060-5025 BC, and at MNT-228 to 5553-5314 BC. I have also included in this comparison ichthyofaunal data from the SCR-60 site, which dates to c. 5590-4710 BC within the unit from which fish remains were analyzed (Culleton et al. 2005). The Middle Period component at MNT-229 dates to 210 BC-AD 710 and the MNT-228

Middle Period dates fall within the last half of that span (see Table 8.3). All four sites are in estuarine environments, though MNT-228 and SCR-60 are approximately twice as far from the shore as the other two sites. These habitat variations seem to have made a significant difference in what kinds of fishes people exploited, as all four sites are different in both periods.

As I show in Figure 8.17, the most notable result is that MNT-229 has high proportion of freshwater fishes, over 50%, whereas MNT-228 has 18-27%, SCR-60/130 has 11%, and MNT-234 has none. Estuary taxa are very important at all sites in both time periods, which is expected given their locations. Interestingly, single-capture estuarine taxa decrease significantly from the Millingstone to Middle Period (Fisher's Exact $p = 0.0001272$ for MNT-228 and -229), mostly the result of a steep decline in the abundance of sharks and rays. For non-estuarine sites, only the occasional specimen or two of shark or ray is present. The importance of sharks and rays seems limited to Millingstone Period estuary sites, with a low representation in the Middle Period. Given that sharks and rays are cartilaginous fishes, their remains may be underrepresented in all periods, relative to those of bony fishes. However, taphonomic effects are unlikely to have created the pattern of representation reported here, as these taxa are more abundant in older, deeper strata.

Mass-captured taxa are important at estuary sites in both periods, particularly so at MNT-234 during the Millingstone Period and at MNT-228 in the Middle Period. Collection techniques during excavation may be part of the reason why MNT-229 has a lower abundance of small schooling fishes. Overall, given that mass-captured taxa

comprise >20% of all the assemblages, and would probably be an even higher proportion if 1/16 in screens were used consistently, small schooling fishes were clearly important food items from the very beginning of human occupation of the Elkhorn and Bennett Slough area in Monterey Bay.

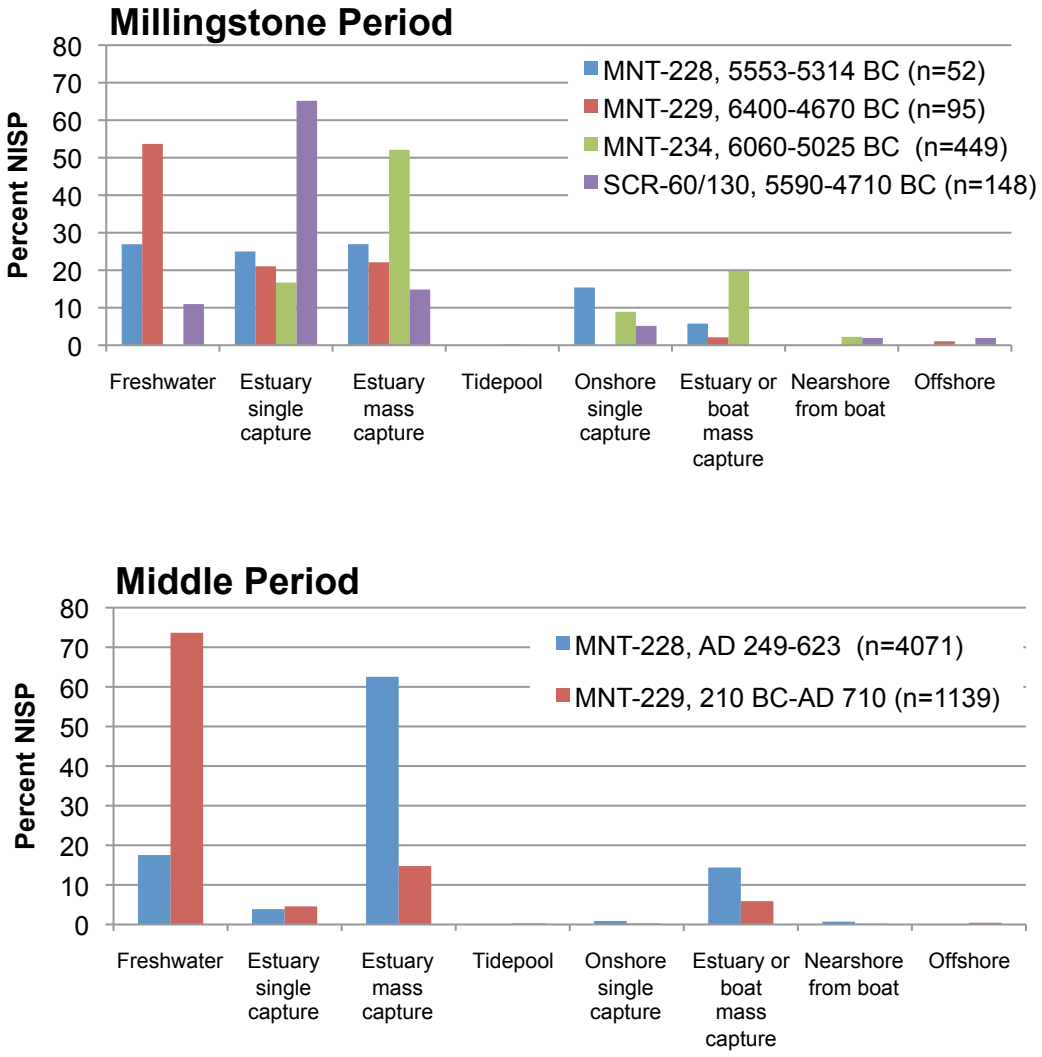


Figure 8.17. Comparison of patch exploitation at estuary sites between Millingstone Period (top) and Middle Period (bottom).

Sites with Rocky/Sandy Shoreline and Kelp Beds

I include in this section all other analyzed sites except for MNT-1701, and added SMA-18 data, though the site has less access to kelp beds. SMA-18, MNT-170, and MNT-125 could all be considered open coast, but their results seem close enough to the other sites that I included them in this discussion. MNT-125 also has an extremely small sample size, rendering it of limited usefulness.

Most taxa can be divided into patch types fairly easily, but I kept specimens identified as Embiotocidae separate, both because they can occupy a variety of habitats (Eschemeyer et al. 1983) and because larger ones can be caught individually, while smaller ones can be captured with nets. However, the majority of Embiotocidae were most likely mass captured, since most of their remains passed through 1/4 in mesh. In general, surfperches with vertebrae smaller than 1/4 in were less than 30 cm total length. Of sites excavated using only 1/8 in screens, 63-100% of surfperch specimens were caught in 1/8 in mesh or smaller. Therefore, in the following figures, a majority of the surfperches should be considered nearshore mass capture.

In Figures 8.18-8.19, I compare the exploitation of various patch types among the sites in each cultural period. Sample sizes and site dates are marked in the legends and I have noted which sites were all or mostly screened with 1/4 in mesh. For most of the periods, two or three sites have sample sizes in the hundreds and are screened with 1/8 in mesh. For the Late Period, MNT-17 essentially provides the only data point, since the other two sites have small sample sizes and one was also screened with 1/4 in mesh.

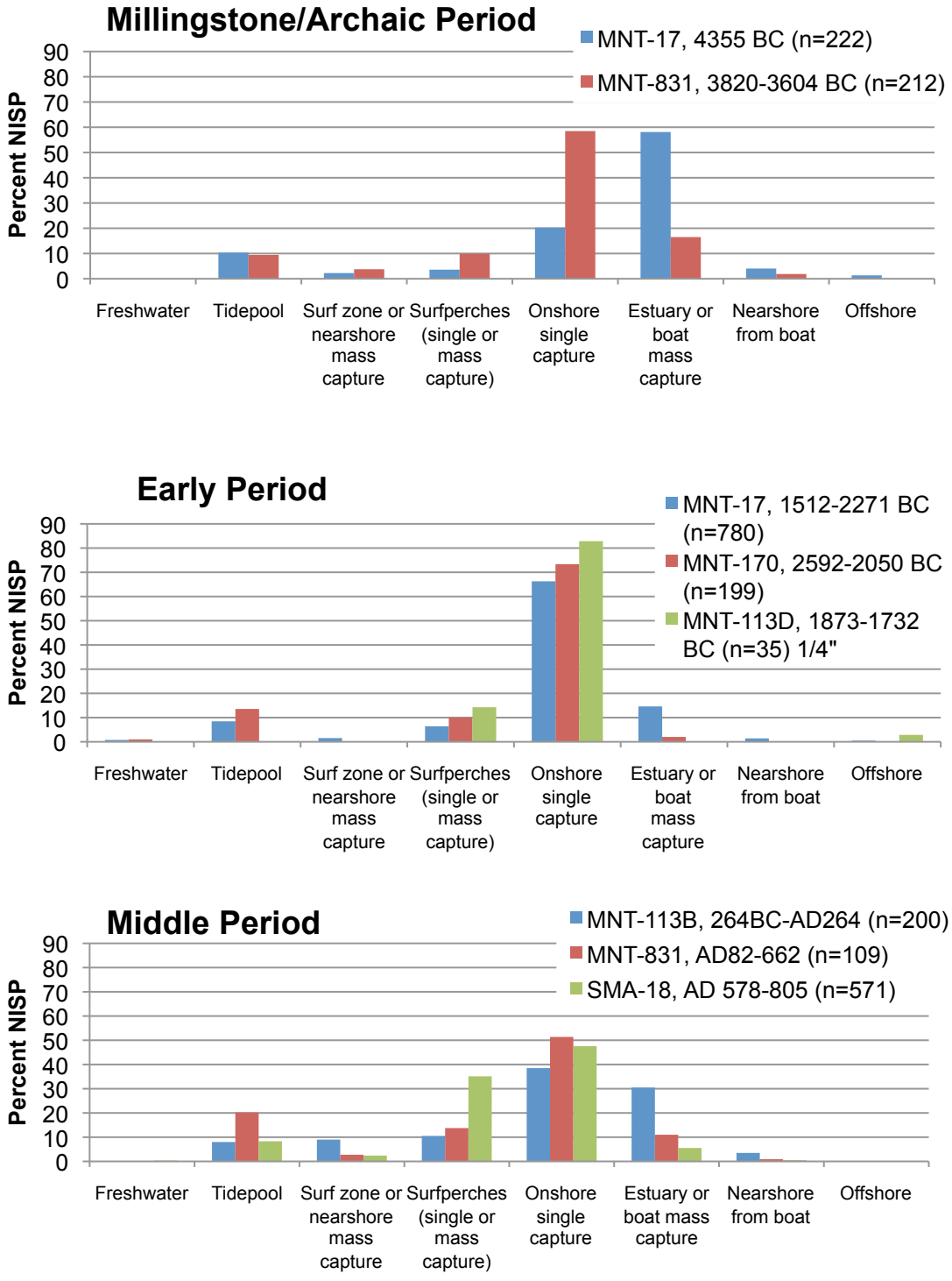


Figure 8.18. Comparison of patch exploitation at mixed rocky and sandy shoreline sites among Millingstone, Early, and Middle Periods.

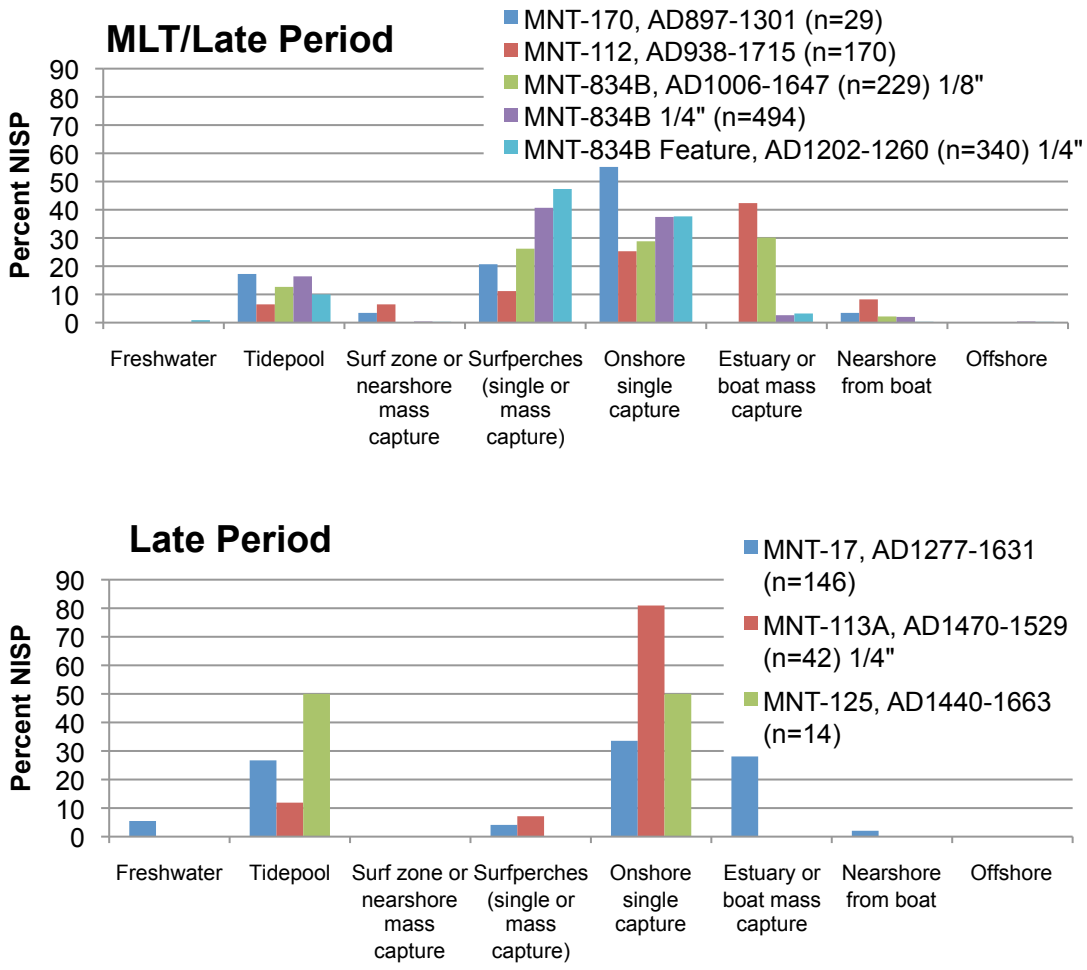


Figure 8.19. Comparison of patch exploitation at mixed rocky and sandy shoreline sites between Middle-Late Transition/Late and Late Periods.

Chi-squared analyses comparing the sites within each cultural period all produced statistically significant results, suggesting that each site's taxonomic distribution was independent of the others, even when limited to sites with only 1/8 in mesh and sample sizes greater than 100. Despite this, some patterns are evident from the data.

Overall, onshore single capture taxa have the highest relative abundance in most sites and time periods, though the percentage by which they are dominant varies. As I discussed above with the estuary sites, mass captured taxa may be underrepresented, and at 30% or more in multiple periods, they were clearly an important part of human subsistence. Tide pool fishes comprise approximately 10% of most assemblages, though they reach nearly 30% at MNT-17 in the Late Period, due to a greater proportion of pricklebacks.

MNT-17 has a consistently higher proportion of estuary/nearshore mass capture (comprising specimens identified as Clupeidae) than the other sites, even compared to others screened with 1/8 in mesh. However, the fragmentation data I presented at the beginning of this chapter suggests that MNT-17 has lower rates of fragmentation than most of the sites I use for comparison, so clupeids may be better represented. Furthermore, I only tentatively assigned certain MNT-17 proveniences to the Millingstone component, so it might not provide a valid comparison to MNT-831 for that cultural period. On the other hand if the results I have assigned to the Millingstone Period actually reflect Early or Late Period exploitation, the percentage of clupeids would still be substantially higher than any other site.

Given the degree to which clupeids characterize a greater proportion of the assemblage, I suggest that fragmentation might not entirely explain these results. People at MNT-17 may have emphasized exploitation of different patches than at other sites. As I maintained earlier in this chapter, the likelihood of the MNT-17 clupeid remains being mostly herring is quite small, which suggests they were taking

boats out to catch sardines. While the percentages are low, ranging from 1-5%, MNT-17 also has greater representation than other sites of non-clupeid taxa that would require boats to catch.

The Millingstone Period data are also more challenging to interpret because MNT-831 technically falls within the short time frame that Jones et al. (2007) called the Millingstone Period and Breschini and Haversat (2011) place in the Early Period. As noted above, the MNT-17 data are only questionably from the Millingstone Period; I included MNT-831 in the same span, to see whether and how they differed. However, the taxonomic distribution of MNT-831 resembles that of Early Period sites, which supports Breschini and Haversat's (2011) division. I leave MNT-831 in the Millingstone Period for analysis, because its latest date of occupation is 1,000 years before the earliest date for the first Early Period site. MNT-831 therefore provides a good temporal contrast as a very early site, regardless of which cultural chronology is applied.

Because of the diversity within sites during each cultural period, and because of my interest in predictively modeling patch choice, I also looked specifically at each patch type over time. Although each site has different values, Figures 8.20-8.21 show that patterns can be seen in the direction of change. For these figures, I removed the three combinations of site and period with sample sizes less than 100 and all proveniences screened with all or mostly 1/4 in mesh. I do not include graphs for the freshwater or offshore habitats, because the percentages are only 0-1%, except for freshwater at 6% in the Late Period.

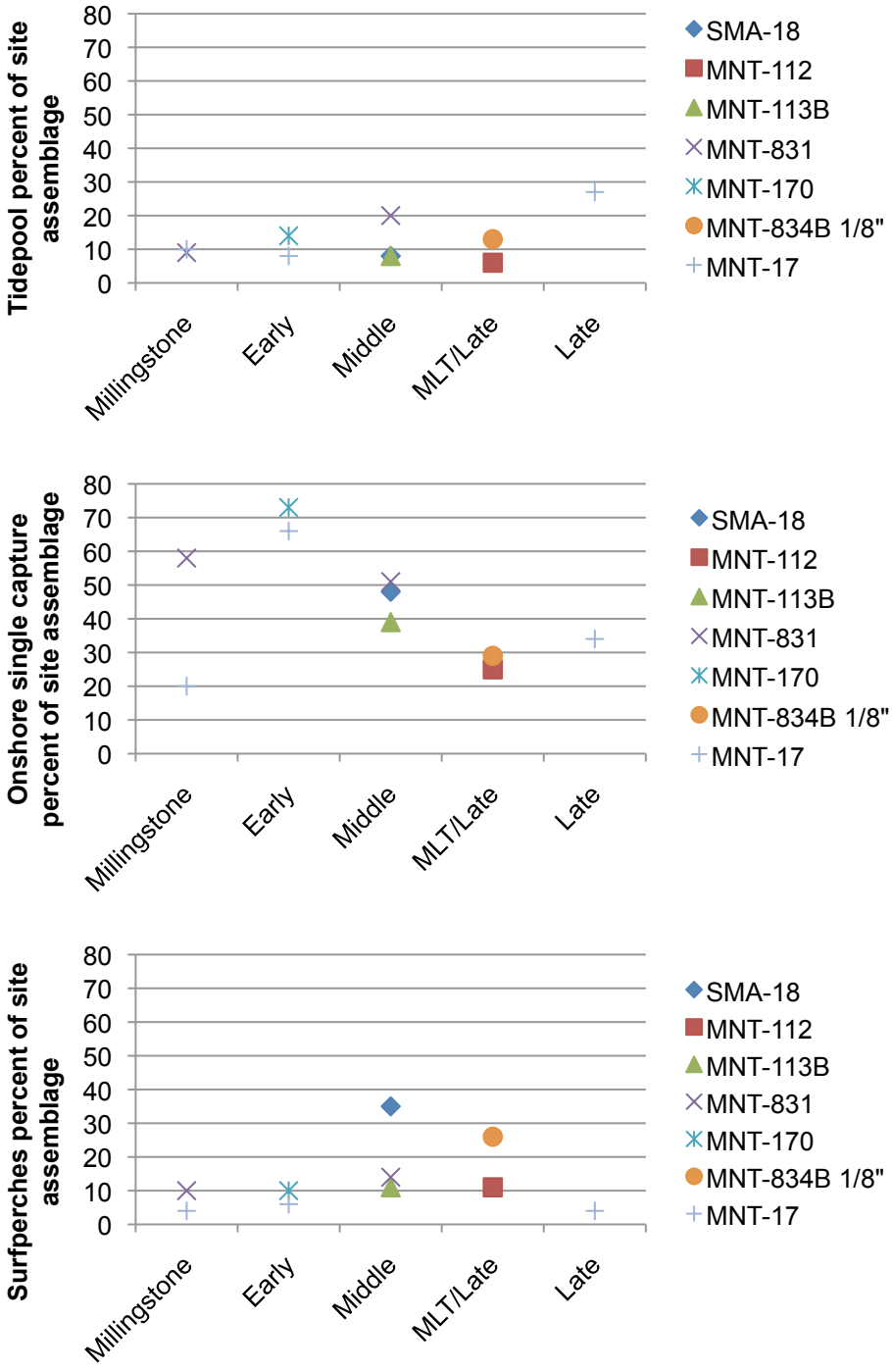


Figure 8.20. Percentages of single capture and surfperch patch types at rocky/sandy shoreline sites over time.

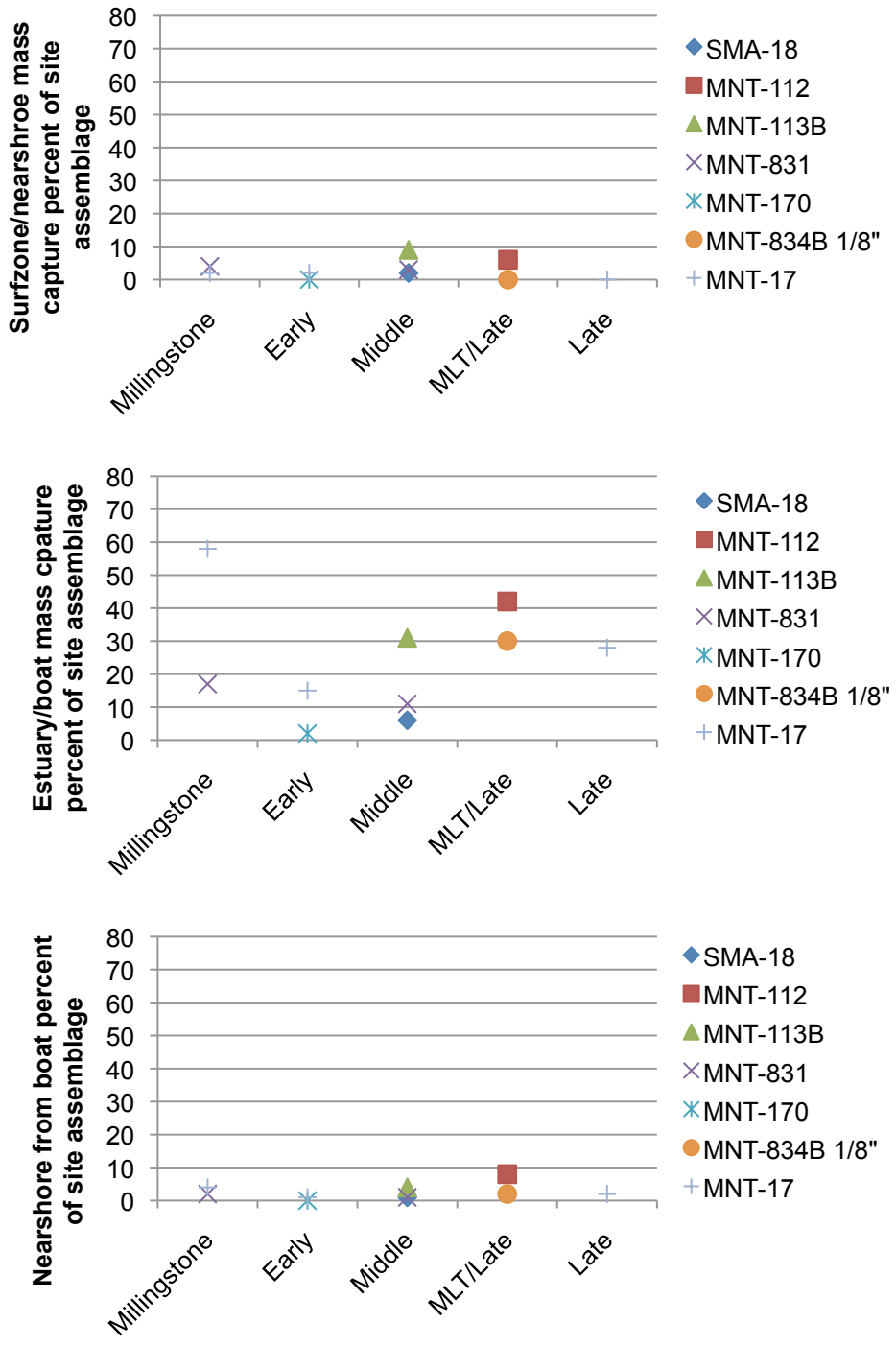


Figure 8.21. Percentages of mass capture and nearshore boat patch types at rocky/sandy shoreline sites over time.

The two patch types representing the highest proportions overall, onshore single capture and estuary/boat mass capture, are also those with the most obvious patterns of change over time. For the Millingstone Period, the inverse proportions of these two patch types make the range of values extremely large. However, this period is represented by MNT-17, which is only tentatively from the Millingstone Period, and by MNT-831, which could be Early Period by Breschini and Haversat's (2011) chronology. Still, it is noteworthy that MNT-831, over a thousand years before the next oldest site, has 17% clupeids and a high level of fragmentation, which suggests clupeids might be underrepresented in the identifiable assemblage.

If we assume the MNT-17 Millingstone component is appropriately defined, it shows a significant decrease between the Millingstone and Early Periods in estuary/boat mass capture mirrored by an increase in onshore single capture. When MNT-831 is compared to the second site for the Early Period (MNT-170), the same trends are present, though smaller. There is little difference, though, between MNT-831 in the Millingstone Period, and MNT-17 in the Early Period. Again, this may be due to variable divisions of the cultural chronology, but it is also possible that clupeids represented about 15-17% of the assemblages in both the Millingstone and Early Periods.

Aside from the issue with the Millingstone Period, the trends for the onshore single capture taxa and estuary/boat mass capture taxa are fairly clear. Onshore single capture taxa are high in the Early Period, then decrease in the Middle Period, even

further in the MLT/Late Period, and perhaps increase again in the Late Period, based only on MNT-17 data. The estuary/boat mass capture follows an opposite pattern.

In Figure 8.22, I combine Figures 8.20-8.21 on one chart, taking the average of the values for each patch type in each time period. Onshore single capture, estuary/boat mass capture, tidepool, and surfperches vary in rank order for the most abundant four patch types over time. The remaining three patches are the least abundant in all periods, though surfperches are less abundant than even freshwater fishes in the Late Period. Onshore single capture fishes are the most abundant for all time periods except for the MLT/Late Period, when estuary/boat mass capture is the highest. Surfperches are at similar proportions to tidepool fishes in the Millingstone and Early Periods, then more abundant in the Middle and MLT/Late Periods.

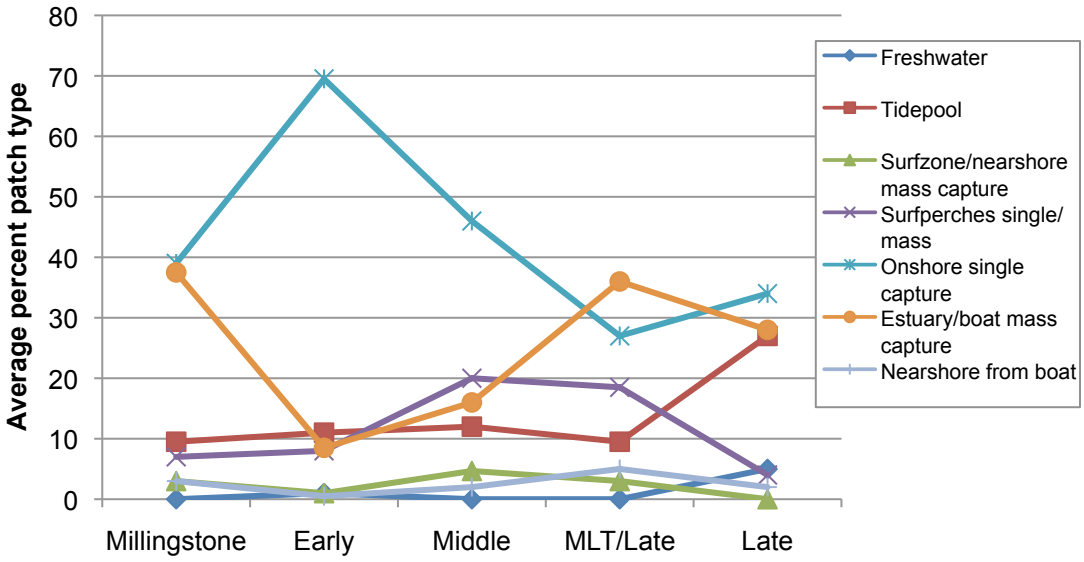


Figure 8.22. Relative proportions of each patch type over time. Y-axis values are the *average* of each patch type in each time period for multiple sites, so proportions in each time period will not add up to 100%.

I have not included MNT-1701 in this compilation of data, because its location several kilometers inland and part of a large village complex make its context substantially different from the other sites I have considered. However, dates from MNT-1701 span the MLT and Late Periods, and the assemblage comprises almost entirely clupeid remains. As a result, the site seems to be an extreme example of the trends noted in Figure 8.22: increased exploitation of the estuary/boat mass capture patch during the Middle-Late Transition.

As I acknowledged in the section on fragmentation, differential fragmentation of assemblages could influence the proportions of clupeid remains. For the sites with data portrayed in Figure 8.22, fragmentation rates would mostly further increase the percentage of clupeids overall. It might also make the MLT/Late and Late Period proportions more similar and shift the time of lowest abundance to the Middle instead of Early Period. Generally, however, clupeids would probably remain most abundant in the MLT/Late and Late Periods and least in the Early and Middle Periods.

In the next chapter, I discuss the implications of these results, in relation to my dynamic state variable modeling predictions and to various researchers' hypotheses regarding Central Coast subsistence over time.

Proximate Analysis

Because the Monterey Bay area is relatively low in terrestrial plant sources of carbohydrates and fats, such as edible nuts and seeds (Wohlgemuth 2010), oily fishes could be important components of forager diets. This would be especially true when

carrying capacity was approached, either through intrinsic population increase, as in the Middle Period, or through declines in terrestrial productivity due to drought, as in the MCA. In Table 8.19, I summarize the nutritional composition for twenty fish specimens I submitted for proximate analysis. The species display a fat content range of 0.3% - 4.2%. This is similar to rockfishes, which are typically only around 2% oil (Stansby 1976).

While fishes can provide an important source of Essential Fatty Acids (Otten et al. 2006), more oily fishes obviously provide more EFAs. None of the taxa submitted for analysis are especially fatty. However, Pacific sardine are reported to have an oil content of 8-17% (Dill 1926; Sidwell et al. 1974), steelhead/rainbow trout 9% (Stansby 1976), northern anchovy up to 9% (Tory Research Station 1989), and Pacific herring flesh up to 13%, while a whole herring can reach 24% (Stansby 1976). This last suggests the difference between a fillet and a whole fish can substantially change the fat content of at least some species. I only submitted flesh samples for all but one of my fishes, but if people were in situations where fat was extremely important, it is possible that they would have cooked small fishes whole.

Table 8.19. Proximate analysis results for assorted central California coastal fishes. Carbohydrate values are not shown, but were all <0.1 g, except for MonkP-2011-1, which was 0.1 g. *Amphistichus* through *Hyperprosopon* are all surfperches. *Cebedichthys* and *Xiphister* are both pricklebacks. BSB2 (*Embiotoca jacksoni*) may have been another surfperch species.

			Calories per 100 g		Grams per 100 g serving			
Species	**Sample name**	**Covance #**	**Calories**	**From fat**	**Fat**	**Protein**	**Ash**	**Moisture**
Atherinopsis californiensis	JS2010	870494	134.0	37.8	4.2	24.2	1.54	71.5
Atherinopsis californiensis	JS2009-1	870495	116.0	19.8	2.2	24.1	1.09	74.6
Atherinopsis californiensis	JS2009-2	870496	95.8	7.2	0.8	22.2	1.16	78.7
Scorpaenichthys marmoratus	Cab#1	870491	96.6	7.2	0.8	22.3	1.43	77.3
Scorpaenichthys marmoratus	Cab#2	870492	87.9	5.4	0.6	20.6	1.00	79.1
Scorpaenichthys marmoratus	Cab#3	870493	91.8	3.6	0.4	22.1	1.19	78.0
Amphistichus argenteus	BASB1	870501	118.0	22.5	2.5	23.9	2.30	74.7
Amphistichus koelzi	CSB1	870502	126.0	26.1	2.9	25.0	2.68	73.5
Amphistichus koelzi	CSB2	870503	113.0	25.2	2.8	21.9	2.19	74.9
Embiotoca jacksoni	BSB1	870504	104.0	5.4	0.6	24.7	3.39	76.4
Embiotoca jacksoni	BSB2	870505	110.0	25.2	2.8	21.1	1.19	75.2
Embiotoca lateralis	SSB2	870506	88.9	4.5	0.5	21.1	2.98	77.4
Embiotoca lateralis	SSB3	870507	96.0	12.6	1.4	20.8	2.01	77.7
Embiotoca lateralis	SSB4	870508	106.0	14.4	1.6	23.0	2.18	76.3
Hyperprosopon argenteum	WSB1	870509	106.0	11.7	1.3	23.7	2.01	76.7
Cebidichthys violaceus	MonkP-2011-1	870497	96.2	12.6	1.4	20.9	1.40	76.2
Cebidichthys violaceus	MonkP-2011-2	870498	89.5	7.2	0.8	20.6	1.47	78.0
Xiphister mucosus (fillets)	XM-1	870499	94.7	9.0	1.0	21.4	1.57	76.1
Xiphister mucosus (gutted)	XM-2	870500	96.5	9.9	1.1	21.6	5.36	73.8
Paralichthys californicus	CAHal-2010-1	870510	102.0	2.7	0.3	24.8	1.11	77.3

Based on my data and those available in the literature cited above, many of the species abundant in Monterey Bay archaeological sites are relatively low in oil content. Those common taxa that would provide the best source of fats for a forager are small schooling fishes: sardine, herring, and anchovy. Taxa that are less abundant in archaeological assemblages, but would also be good sources of fat, include various species of salmon (Sidwell et al. 1974; Stansby 1976) and chub mackerel (Tory Research Station 1989). Some cartilaginous fishes might also be fatty, based on an oil content of 13% for spiny dogfish and 6% for various species of skate (Stansby 1976).

The estuary/boat mass capture patch is mainly sardine/herring, so changes over time in the relative abundance of those species also represents a shift in the amount of fats people were acquiring from fishes. The Millingstone, MLT/Late, and Late Periods therefore have higher proportions of fattier fishes than the Early and Middle Periods.

Summary of Zooarchaeological Results

The analyses presented in this chapter indicate changes over time regarding which marine habitats people emphasized in their subsistence choices. In general, nearby habitats played a strong role in the patches people exploited. Pricklebacks, which are small-to-medium tidepool fishes, are the only taxon found in all of the sites analyzed. Small schooling fishes, both silversides and what are probably sardines, are present in all sites that used 1/8 in screens, except for MNT-125, which had an extremely small sample size.

Sharks and rays are mainly found in estuary sites and freshwater taxa are more abundant in those estuary sites farther from shore. The variation among estuary sites is high enough that it is difficult to identify other patterns in resource exploitation aside from a definite decrease in single captured taxa, especially sharks and rays, from the Millingstone to the Middle Period.

For the sites assigned to a habitat of mixed rocky/sandy shoreline with kelp beds, onshore taxa that could be caught with hook-and-line are common. Rockfishes and cabezon are found in all sites and surfperches in all but the one with the smallest sample size. While significant variation in patch exploitation occurred among sites within this habitat category as well, trends are more apparent than with the estuary sites, in part because more cultural periods were represented.

Onshore single-captured species are very abundant in the first three periods for the rocky/sandy shoreline sites, peaking in the Early Period. The estuary/boat mass capture patch, most likely sardines, has the highest representation of taxa in the Millingstone, then drastically declines for the Early and Middle Periods, then increases again in the MLT/Late Period, high enough to be more abundant than onshore single-capture species. Tidepool species, after ranging mostly between 8% and 14%, increase in the Late Period to 27%, based on data from MNT-17. Surfperches are most abundant in the Middle and MLT/Late Periods, declining to their lowest point in the Late Period. Taxa from the remaining habitats each comprise less than 10% of the assemblages in all time periods.

In both estuarine and rocky/sandy shoreline assemblages, anadromous fishes are very rare. Gobalet (2012) has identified both steelhead/rainbow trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*) in Central Coast archaeological assemblages, and argued they must have been common to appear at all. Salmonid remains have a very different texture than most bony fishes, and being less dense are more susceptible to density-mediated destruction (Casteel 1976; Partlow 2000; Wheeler and Jones 1989). Although poor preservation may depress their abundance in Monterey Bay area sites, it is unlikely to have reduced them to trace amounts in all assemblages if they had been an extremely abundant resource. Even in sites with preserved cartilaginous fish remains, salmonids still comprise a very small proportion of the assemblage. Thus, while *O. mykiss* and *O. kisutch* were clearly available in the past, the data suggest they were never a primary resource for Monterey Bay area foragers.

Deep water and large pelagic fishes are also nearly non-existent in my assemblages. These are much more costly resources to exploit in terms of time, energy, and technology, and are more dangerous and less predictable. My DSVM results suggest resources with such characteristics are predicted to be exploited only in desperate conditions, which explains their scarcity in Monterey Bay area assemblages.

The abundances of most of the common taxa seem unaffected by fragmentation rates, but the percentage of clupeid remains shows a strong positive correlation with the proportion of whole specimens. This has an important implication

for interpretations of fish remains from Monterey Bay area sites, since in addition to the effects of screen size, more fragmented assemblages may cause further underrepresentation of small schooling fishes. Fortunately, it appears that for the sites analyzed in this dissertation, the effects of fragmentation should mainly cause an even greater proportion of clupeids in most sites, and not overly affect the general trends through time.

Proximate composition data indicate that while many identified fishes are low in fat content, the small schooling species provide a high percentage of oils. An increase in the estuary/boat mass capture category, in this case, also implies a relative increase in the collection of fatty fishes. If people were faced with situations where terrestrial resources were poor, sardine, herring, and anchovies would be highly valued resources.

In Chapter 7, I developed a dynamic state variable model to determine which patch parameters are predicted to be the most important for making optimal subsistence decisions. I describe in the final chapter how the zooarchaeological results relate to the modeling predictions, the climatic history, and the cultural chronologies for the region.

CHAPTER 9

Behavioral Ecology and Monterey Bay Prehistory

In previous chapters, I developed a dynamic state variable model to look at predictions of optimal foraging decisions, and presented zooarchaeological results of ichthyofauna from multiple sites in the Monterey Bay area. In this chapter, I first describe the relationship between the modeling predictions and specific resources available on the Central Coast. Second, I discuss how my results inform our understanding of Monterey Bay culture history, and the implications for research on coastal hunter-gatherers. Finally, I present some considerations for future work.

Zooarchaeology and Modeling

Using the criteria defined by the dynamic state variable model developed in Chapter 7, most of the fish patches represented in the archaeological assemblages have good reasons to be exploited by prehistoric people. Their probability of successful exploitation tends to be high, which the model predicts will make them frequently visited patches. Patches that have a lower probability of success, or a noticeably higher cost or risk, are usually lower proportions of the assemblage, but still present. The model does predict partial preferences, meaning that multiple patches are exploited because the forager's energetic state changes, which influences her optimal decision. Higher cost, more dangerous patches might then be visited when the forager is willing to take a greater risk for higher benefit.

As was originally indicated by Gobalet and Jones' (1995) survey of coastal California sites, the strong patterning of species exploitation by site location in the Monterey Bay area suggests foremost that people emphasized the most easily accessible species. However, changes in taxonomic distributions over time indicate that what was most available changed *and* that people sometimes exploited more difficult patches. Within the category of fishes, I predicted that tidepool and estuarine taxa would be the most commonly exploited, followed by rocky shoreline fishes, first from shore and then from boats, and finally offshore fishes. Results show that tidepool fishes are less abundant than other onshore taxa (fishes that can be caught from shore, as defined in Chapter 8), but represent a respectable 10% in most time periods. A significant increase in the proportion of tidepool species in the Late Period is intriguing and may represent a greater need for predictable resources. Overall, the representation of multiple habitats in each location demonstrates that resources were valued for different reasons.

Estuary Sites

The estuary site aassemblages have a variety of single and mass captured species. In modern times, fish abundance and diversity in Elkhorn Slough peak in the summer, though several species can be caught year-round (Barry and Cailliet 1981; Yoklavich et al. 1991, 2002). Four main patches comprise the majority of these sites' ichthyofaunal assemblages.

Single captured taxa are mainly sharks and rays. Based on current species distributions, leopard shark is the most common shark found in Elkhorn Slough

(Yoklavich et al. 2002) and probably represents a large portion of the triakid vertebrae identified in the archaeological assemblages. Leopard sharks would be most common in spring and summer when they give birth in the creeks (Yoklavich et al. 2002) and today, anglers along the California coast catch leopard sharks both from boats and from shore (Smith 2001). Bat rays can also be caught from shore or boats and are present in their highest numbers when breeding in the summer (Love 1996). Both of these large species, despite being most abundant when spawning, can be found in the slough year-round (Yoklavich et al. 2002) and probably represented low-risk, low-cost, high-benefit resources with a medium probability of successful exploitation.

Mass captured estuarine species were probably even more easily caught, since nets can be dragged along the shoreline of the estuary. Anchovies, silversides (topsmelt and jacksmelt), surfperches, and sculpin are the main taxa included in this group. Northern anchovies spawn in the slough in fall and winter, in shallow depths (Yoklavich et al. 2002), and can be caught in beach seines in tidal creeks along with topsmelt and gobies (Yoklavich et al. 1991). Certain species of surfperches and sculpin are present in the slough in all seasons (Yoklavich et al. 1991). Overall, these mass captured species would have also been low-risk, low-cost, high-benefit, and probably had a higher probability of successful exploitation than the sharks and rays.

As I covered in Chapter 8, the clupeid remains from Monterey Bay area sites are most likely sardines. While sardines are listed as having been caught in the slough (Yoklavich et al. 2002), they are not included in the 40 most abundant species

(Yoklavich et al. 1991), which means they comprise <0.1% of the individuals caught. Furthermore, sardines are usually found near or offshore (Eschmeyer et al. 1983), making their presence in sloughs less plausible. Thus, sardine remains found in archaeological assemblages were most likely acquired from boats near or past the kelp beds. In my analyses of estuary site material, I identified ten sardine specimens at MNT-228, one sardine and one herring at MNT-229, and eight sardines at MNT-234. Jones et al. (1996) reported 21 herring and 28 sardine specimens for Middle Period deposits, but I was unable to check specimen identifications. Clupeid specimens unidentifiable to species are far more abundant at all of these sites, but since they are probably sardines and not herring based on my analyses, I refer to clupeid specimens mostly as sardines in the remainder of this chapter.

Freshwater taxa were probably predictable and low in cost, as they would be available year-round. However, their energetic benefit would vary significantly by season; the minnow and sucker species found archaeologically spawn in groups in the spring, but otherwise mostly swim singly. If they were mass captured while spawning, they would provide a higher benefit than if caught individually. Hook-and-line fishing of freshwater fishes would provide a lower benefit than fishing for sharks and rays in the estuary, because they are much smaller. Only the site at the mouth of Elkhorn Slough (MNT-234) lacks freshwater fishes, and it has the highest proportion of mass captured estuary species. For the other sites at Elkhorn Slough, freshwater fishes represent 27-54% of the ichthyofauna in the Millingstone Period, and 18-74% in the Middle Period. Their abundance implies a significant, strong freshwater source

nearby, and though it is hard to say whether this was the Salinas or the Pajaro River, the Pajaro's modern location to the north of Elkorn Slough, and nearer the sites with freshwater fishes, suggests it might be the source.

Overall, the presence of all of these taxa fits well with the dynamic state variable model's predictions. They are relatively predictable resources, with high benefits and low energetic costs and risks to exploit. A forager is predicted to differentially value probability of success and level of benefit under various state conditions, which explains the higher proportions of freshwater, single and mass captured estuary taxa. However, the abundance of sardine remains suggests that even during early occupations, people were taking boats out into the bay to fish with nets.

Mixed Rocky and Sandy Shoreline Sites

Similar to the estuary sites, assemblages from the mixed rocky/sandy shoreline sites have a wide variety of resource patches represented. Freshwater taxa are scarce, but tidepool fishes comprise 10-30% of the assemblages, increasing over time. The most common tidepool fishes are pricklebacks and plainfin midshipmen, which are large-bodied for tidepool species, but still smaller than most individually caught fishes. On the other hand, it is also possible that smaller fishes would be more common in sites excavated with 1/16 in mesh. While pricklebacks live in the tidepools, midshipmen mainly come inshore for spawning in the spring and summer, when the females lay eggs in the rocky intertidal and the males guard the eggs and larvae for about a month and a half (Love 1996). Spawning season is clearly identifiable, because the males make a loud humming noise at night (Love 1996).

Overall, the tidepool patch would be very predictable, very low cost and low risk, but also of relatively low benefit, since the species are usually small in comparison to other single captured fishes.

The most common taxa found in archaeological sites from the onshore single capture patch are rockfishes, cabezon, some species of surfperch and greenlings. All of them are available year-round and are abundant in the Monterey Bay region. As summarized in Chapter 7, this fishing patch would have a medium probability of success, a medium benefit since the fishes are medium-to-large sized, and a low cost and risk since they can be fished from shore. Very large rockfishes may more likely be caught from boats, since many species are found deeper as they age.

Surfperches can be caught with beach seines, gill nets, or hook-and-line (Rick and Erlandson 2000; Rick and Glassow 1999), and several species are abundant along the Monterey Bay coast year-round. Hudson and Blackburn (1982 in Rick and Glassow 1999) reported ethnographic descriptions of the Chumash in the Santa Barbara Channel area netting small fishes, including sardines and surfperches. As noted in Chapter 8, the smaller size of many individuals in the archaeological assemblages suggests they were caught with nets. In general, depending on their method of capture, surfperches would have a medium or high probability of capture and benefit, with low cost and low risk, making them a valued resource.

As with the estuary sites, the other most commonly exploited fishes were clupeids. In addition to the taxonomic data indicating the clupeids are probably sardines, a lack of nearby estuarine habitats for the rocky/sandy shoreline sites

suggests clupeids were more likely caught from boats. This makes their exploitation more costly and risky, since sardines require boat trips farther off shore.

Even if the MNT-17 material does not date to the Millingsone Period, the nearly 20% proportion of clupeids beginning in the earliest occupations of the rocky/sandy shoreline sites implies that they were a resource with a high probability of successful exploitation, or a reasonably large benefit. Under most circumstances, a larger benefit is predicted to be worth more risk when the forager is struggling, but relatively less commonly utilized than resources that are more predictable. In the first three cultural periods, clupeids are less abundant than onshore single captured taxa and sometimes than other taxa as well, suggesting they were exploited for a high benefit rather than as a dependable resource. I believe their greater abundance in the MLT and Late Periods reflects increased effort expended to acquire their nutritional content, as I discuss below.

DSVM and Mammals

I also described the characteristics of some other broad prey type categories in Chapter 7. For mammals, I argued that pinnipeds in rookeries would be exploited especially frequently, because of their high probability of success accompanied with a large benefit. The next most common taxa would be rabbits and other smaller mammals, due to their low risk, medium cost and benefit, and medium probability of success. Deer would be a higher risk activity, with higher cost and lower success rate, but their large per-animal benefit would still result in foragers exploiting them on a

regular basis. Finally, pinnipeds in water would be similar to deer, except with even higher costs and risk.

In Figure 9.1, I display percentages of five mammalian taxonomic groups over time for sites which had mammal data available and sample sizes of NISP>50. Two sites included in the graph had sample sizes of less than 100: MNT-112 with NISP=81 and MNT-170 with NISP=77. The fairly high proportion of leporids (rabbits and hares) in all periods bears out the predictions of my DSVM. However, rabbits and hares are also extremely lean animals, so while they can be easy to catch, their consumption must be balanced with intake of carbohydrates or fats from other sources (Speth and Spielmann 1983). Pinnipeds would certainly function in this capacity, as a whole northern fur seal averages 14.7% fat (Stansby 1976).

The peak in pinnipeds in the Middle Period is driven by MNT-234, where over 80% of the identified mammal remains, excluding rodents, are marine mammals, and most of those are northern fur seal (Sunseri 2009). At the other three sites, leporids and ruminant bones both outnumber pinnipeds, though pinnipeds are still abundant (Dietz et al. 1988; Gifford-Gonzalez et al. 2006; Jones et al. 1996). As I described in Chapter 3, characteristics of the northern fur seal assemblage at MNT-234 suggest a rookery was located near MNT-234 (Gifford-Gonzalez and Sunseri 2009), and the DSVM predicts such a patch is frequently exploited. The Middle Period peak in pinniped abundance corresponds with a low proportion of sardines in the Monterey Bay fish assemblages (see Figure 8.22), and the subsequent decrease with a greater percentage of sardines. Although earlier periods do not have as clear of

a pattern, these results suggest a more extensive regional study comparing pinniped and sardine exploitation could help determine if animal fats were a foundational part of forager diets on the Central Coast.

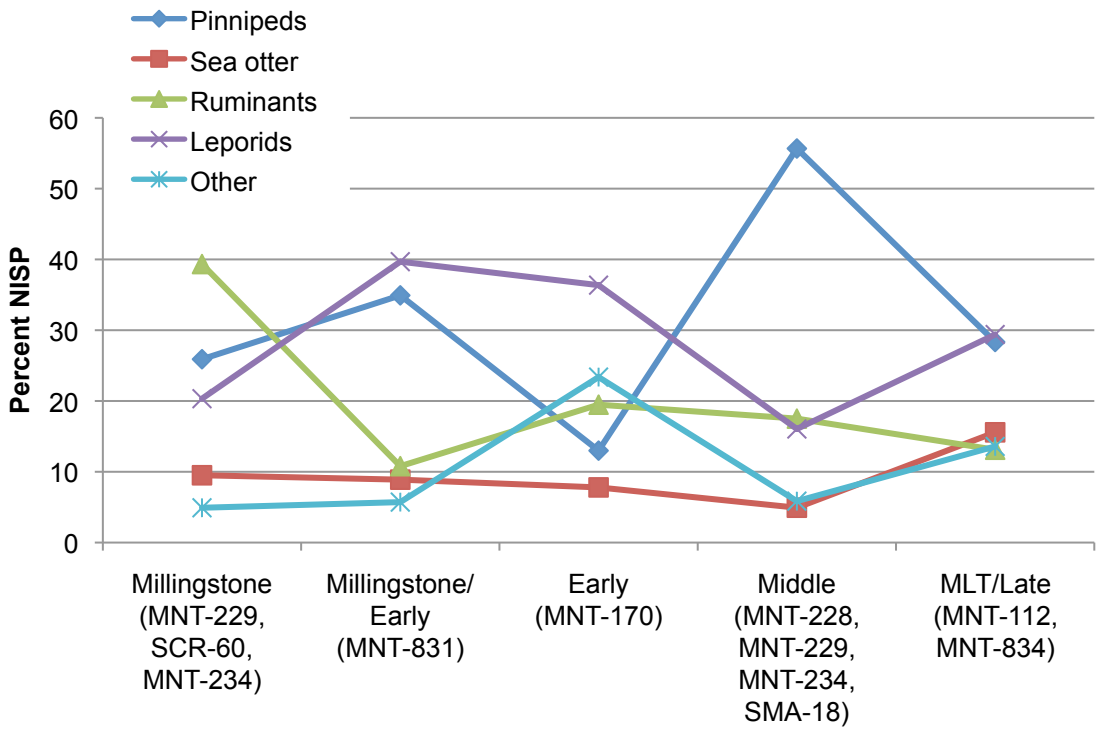


Figure 9.1. Percentages of mammal groups (excluding rodents) over time in sites from the Monterey Bay area. In most of these sites, the pinnipeds are mainly fur seals and sea lions.

Subsistence in Monterey Bay Culture History

In this section, I discuss how fishing changes over time, contextualized within the climatic sequence summarized in Table 3.2, the cultural sequences described in Table 3.3, and the nutritional data presented in Chapter 8. Gobalet and Jones (1995), in their overview of fish remains at central California sites, summarized that for rocky

coast sites, large inshore taxa comprised about 58%, small schooling species 27%, and surfperches 12% of the total collections, with a small proportion of other fishes such as flatfish and sharks or rays. While these proportions may on average be correct, my data do suggest shifts over time in the degree to which each of these groups were important.

Millingstone/Archaic Period

Jones et al. (2007) define the Millingstone Period as lasting 8000-3500 BC, while Breschini and Haversat (2011) refer to the period between 8000 BC and 4000 BC as the Archaic. Terrestrial climate in the Monterey Bay area during the first part of the Millingstone Period (8000-6250 BC) was mainly warm and wet, with warmer SST in the ocean and increasing upwelling. In the later part of the Millingstone (6250-3500 BC), climate became drier and cooler, and the ocean had higher productivity and upwelling, accompanied by cooler SST (Myers 2007). During 6250-3500 BC and extending to 2550 BC, ocean conditions were probably at their best of the entire Holocene. All of the Millingstone Period sites from the Monterey Bay area date to within that 6250-3500 time span.

Faunal assemblages from the Millingstone Period, as it manifested in coastal California, typically reflect a broad-spectrum diet with an emphasis on marine resources. On the Central Coast, sites from this period are mostly close to shore and the faunal collections tend to be small (Jones et al. 2007). In the Monterey Bay area, estuarine and rocky shoreline sites both have abundant shellfish remains, but

emphasize different taxa according to those most abundant in nearby habitats (Breschini and Haversat 2011).

Differences are apparent between the Monterey Bay and areas further south. The human bone stable isotope analysis from one individual in a Big Sur site suggests a broad diet with fairly equal emphasis on terrestrial and marine foods (Jones 2004), while some archaeofaunal assemblages from San Luis Obispo have high proportions of deer or rabbits, others of shellfish and probably terrestrial resources (Jones et al. 2007). In contrast, in the Monterey Bay area, the stable isotope analyses of human bones from seven burials at SCR-60, near the mouth of the Pajaro River, indicates a heavily marine diet composed of 70-84% marine mammals, fishes, and shellfish. Because they can be combined in different ways to reach the total marine diet composition, each of these has a wide range of potential values. The possible biomass proportion of marine fishes ranges from 0-68%, with a mean of 36% (Newsome et al. 2004). In addition, 10% of the ichthyofauna from the site comprises freshwater fishes (Culleton et al. 2005), so their value may be even higher.

My results from Millingstone Period estuarine sites indicate a wide variety of fish taxa were exploited, consistent with the interpretation of a broad-spectrum diet. Furthermore, local habitat clearly played a large role in fishing decisions, based on the significant differences in relative patch exploitation among the sites analyzed. Overall, mass captured fishes are relatively abundant, consisting mainly of species that could be easily caught within the estuary. However, taxa that would require boats to catch, including sardines, are still well represented, comprising 20% of the MNT-

234 Millingstone Period assemblage. Combined, the most abundant taxonomic category contains sharks and rays, large species that could be caught individually.

While I was unable to find relevant nutritional information for the shark and ray species identified in these assemblages, they may have a higher fat content, and proximate composition data should be collected. Only a couple of sharks and skates had data available in the literature, and none were taxa common in Monterey Bay archaeological sites. However, the small schooling clupeids in these sites are particularly rich in fats and they comprise up to 20% of the assemblages.

For the rocky and sandy shoreline sites, I tentatively assigned the auger deposits at MNT-17 to the Millingstone Period, as I discussed in Chapter 8. Sardines represent almost 60% of the MNT-17 component and 17% of the MNT-831 material, while proportions of onshore single capture species are nearly opposite for the two sites.

With or without MNT-17, Millingstone Period estuarine and rocky/sandy shoreline sites from the Monterey Bay area indicate a wide variety of patches exploited. Based on the types of fishes present in the archaeofaunas, people probably depended both on netting and hook-and-line or spearing technology. The abundance of sardines, 17-20% in two sites and almost 60% in another, reflects a level of boat-based fishing not typically identified for Millingstone Period subsistence. Jones et al. (2007) commented that the heavily marine diet described by stable isotope analyses probably emphasized shellfish, given their relative abundance compared to fish and marine mammal remains in Millingstone Period sites. However, dietary

reconstructions from the stable isotope analyses showed that both the mean and maximum biomass percentages were higher for marine fishes and marine mammals than for shellfish (Newsome et al. 2004). While faunal remains may indeed be rare in deposits from the Millingstone Period, Newsome et al.'s (2004) stable isotope analyses, combined with the results on clupeids presented here, suggest that people in the Monterey Bay area did not emphasize shellfish and seeds over other resources.

The cool temperatures and high productivity of the ocean during the latter part of the Millingstone Period support such a significant level of marine resource consumption. To further elucidate the role of fishing from boats in early human history, however, further radiocarbon dating of the MNT-17 assemblage is important, as is more closely examining all Millingstone Period fish remains from the Monterey Bay area.

Early Period

Breschini and Haversat (2011) defined the Early Period as 4000-1200 BC, followed by their "gap," while Jones et al. (2007) called 3500-600 BC the Early Period. MNT-831 falls within the 4000-3500 BC span where the chronologies disagree, and is much earlier than the next rocky/sandy shoreline site from which I had material. However, the patch use pattern reflected by the MNT-831 fish assemblage is very similar to the Early Period sites, thus supporting Breschini and Haversat's (2011) chronology for the Monterey Peninsula. The only other rocky/sandy shoreline Millingstone Period site for this dissertation is MNT-17, so whether fishing practices before 4000 BC were truly substantially different is at

present difficult to determine. Very few Millingstone/Archaic sites have been identified in the region, and thorough analysis of any future discoveries on the Monterey Peninsula should be a priority.

The various proposed times for Elkhorn Slough abandonment all fall within the Early Period, two starting c. 4000 BC (Jones 2002b; Jones and Jones 1992) and one beginning at 3000 BC (Jones and Waugh 1997). None of my specimens from estuarine sites dated to within the various proposed abandonment spans, so the fish data so far support the idea that people moved away from the coast and do not contradict any of the timing possibilities.

Both terrestrial and oceanic climate during the Early Period were markedly variable, based on Myers' (2007) cores from the Monterey Bay area. Terrestrial climate was dry and cool and highly productive until 1750 BC, and the ocean was cool, productive, and with high upwelling in the beginning of the Early Period, followed by a time of variable productivity also until 1750 BC. At that point, a 200-year span of warm and wet climate with low terrestrial productivity, and potentially very low ocean productivity occurred. At 1550 BC, ocean productivity was still low, but increasing, associated with warming SST, while the atmospheric climate might have been cool and dry again for 200 years, followed by another warm and wet span. Also during the Early Period, the ENSO system became influential again c. 2050 BC and has continued through the rest of the Holocene (Myers 2007).

The Early Period's climatic oscillations, combined with our presently coarse degree of temporal and environmental resolution in the Monterey Bay region, make it

difficult to connect well-defined ocean or terrestrial conditions with subsistence decisions. The variable ocean productivity in the first thousand years of the Early Period might have encouraged reduced dependence on fishes and shellfish, and mammals do increase in importance. Cold SST and higher productivity usually create a richer environment for fishes, including for anchovies, whereas warmer SST and low productivity are typically better conditions for sardines (Chavez et al. 2003). Therefore, while multi-decadal shifts between sardine and anchovy populations probably still occurred, ocean conditions overall became better for sardines starting in the second part of the Early Period, which is also when the radiocarbon date gap exists.

Jones et al. (2007) described the Early Period as also the beginning of the broadly defined "Hunting Culture," which lasts through the Middle Period. The Hunting Culture is defined in large part by having significantly more projectile points and bifaces, and therefore a greater emphasis on hunting. In the Early Period, increased hunting is represented as high proportions of deer and sometimes of rabbits. Jones et al. (2007) noted that a shift toward hunting might result from population circumscription, better climate, or the movement of populations from the interior to the coast.

In contrast to these interpretations, some Early Period Monterey Bay area sites indicate a diet still high in marine resources – stable isotope analyses of human bone reflect 80-92% marine resources from two burials at MNT-831 (Breschini and Haversat 2006) and 55% at SCR-60/130 from two more burials (Newsome et al.

2004). MNT-831 faunal material also includes a high proportion of marine mammals, though rabbits are more abundant than pinnipeds by NISP and nearly as abundant as pinnipeds and sea otters combined (Breschini and Haversat 2006). At MNT-391, sea otters were the most abundant (Jones et al. 2007).

My zooarchaeological results suggest a continued heavy emphasis on single capture fish species. Fish acquisition technologies recovered from the Early Period sites are limited to bone gorges, which are fairly common (Breschini and Haversat 2011; Jones et al. 2007). Importantly, both of the sites in my analyses that were screened with 1/8 in mesh also had fairly high fragmentation rates (about 40-55%), which might mean small schooling fishes are underrepresented. MNT-17, the less fragmented assemblage, still has over 15% of these mass captured taxa. Furthermore, high numbers of sea otters at MNT-391 (Jones et al. 2007) suggests people were exploiting nearshore environments by boat. Currently, however, the fish taxa definitively representative of boat capture, including sardines, are rare in Early Period material.

The prevalence of onshore single capture species and lower reliance on sardines suggests that fat content was not an important factor in fishing subsistence decisions during the Early Period. With more abundant pinnipeds in the mammal assemblages, people may have needed to acquire little fat from other sources. However, SST is cooler in the first part of the Early Period, when the Monterey Peninsula was occupied, and such conditions favor anchovy populations over sardines. In the future, more samples screened with 1/16 in mesh could elucidate

whether anchovies are also relatively scarce during this time, which would support the hypothesis that pinnipeds were providing the majority of required fats.

The relative abundances of fish taxa in the Monterey Bay area are strikingly different than those of the San Simeon Reef south of Big Sur. In three San Simeon Reef sites analyzed by Joslin (2010), pricklebacks are about 50% of the fish assemblage. While pricklebacks comprise most of the tidepool fishes in my results, the tidepool taxa are only 8-14% of the total assemblages in the Early Period. In relation to the rest of the faunal assemblage, Joslin (2010:391) describes San Simeon Reef subsistence as emphasizing nearshore resources, "with apparently minor hunting of marine and terrestrial mammals." Unfortunately, these sites have extremely high proportions of unidentifiable mammals, making it difficult to generalize about terrestrial versus marine mammal hunting. Prevalent remains of small black turban snails suggest people considered abundant, predictable resources high-ranked (Joslin 2010), and the high numbers of pricklebacks might also reflect this approach. Regardless, Early Period people in the Monterey Bay area emphasized larger species than did people on San Simeon Reef.

Early Period sites overall still suggest generalized foraging of numerous resources. Breschini and Haversat (2011) argued subsistence is based on a "forager" strategy, where people "map on" to different seasonal residences, with a limited radius of foraging around each one and no use of longer-term storage (Binford 1980). Binford (1980) contrasted this strategy to that of "logistical collectors," whose

environments and nutritional needs require movement of resources to residential sites during at least part of the year and the frequent use of longer-term storage.

Assessing Breschini and Haversat's Radiocarbon Date "Gap"

Breschini and Haversat (2011) identified a gap in radiocarbon dates 1200-200 BC on the Monterey Peninsula. They acknowledged that most of their dates are on shellfish, which means it is possible people simply stopped gathering shellfish during this span. They thus encouraged more dates on vertebrate remains and charcoal to determine the robustness of their inferred gap. Sites in the area around Elkhorn Slough already had a high number of non-shellfish dates, but the Monterey Peninsula only had 14 dates on vertebrates or charcoal out of 445 total (Breschini and Haversat 2011). Of my successful radiocarbon dates from the Monterey Bay area, none of the ten dates from the estuary sites or eight dates from the rocky/sandy shoreline sites fell within the gap period. My results so far therefore support the interpretation that people may have moved away from the coastline, rather than that they simply stopped gathering shellfish while remaining in place.

Breschini and Haversat (2011) suggested that the posited gap was cultural and not climate-related, since the coastal abandonment does not extend to the areas just north and south. While this may be true, a more detailed consideration of paleoclimate is necessary to rule out potential localized effects. Based on Myer's (2007) reconstruction, Monterey Bay terrestrial climate reached close-to-modern conditions around 1250 BC, as did ocean conditions c. 1550 BC. Though I have discussed the difficulties with using Big Sur as a proxy for Monterey Bay, stable

isotope data from Big Sur suggest a cooler period of SST c. AD 1-1300 (Jones and Kennett 1999), which might be associated with increased productivity. The span from 1550 to 0 BC could therefore encompass less productive ocean conditions, encouraging much reduced use of the coastline for resources. The present paleoclimatic data are not spatially and temporally constrained enough to make a clear case for a relationship between ocean conditions and coastal abandonment. However, they do support my contention that more detailed terrestrial and oceanic paleoclimatic data are imperative for understanding the Monterey Bay area's culture history.

Middle Period

Jones et al. (2007) placed the Middle Period at 600 BC-AD 1000, while Breschini and Haversat (2011) put it at 200 BC-AD 700. Climate was like that described above for the last third of the gap, although AD 650-900 may have been a period of low precipitation (Plater et al. 2006). It is possible, based on the Big Sur stable isotopes on shellfish, that SST was slightly cooler during AD 1 to 1300.

A greater number of large residential bases are documented during the Middle Period on the Central Coast, though they are not very common on the Monterey Peninsula (Breschini and Haversat 2011). Middle Period sites on the peninsula were usually at different locations than those inhabited in the Early Period. Some support exists for a shift from a forager to a logistical collector subsistence strategy around this time (Breschini and Haversat 2011; Dietz and Jackson 1981; Dietz et al. 1988). In a logistical collector system, people can still be seasonally mobile, but have wider

foraging ranges, spend multiple days away from their residential bases, and store resources (Binford 1980).

Jones et al. (2007), described the Middle Period as similar to the Early Period, having abundant deer in assemblages, with some sites high in rabbit. The Monterey Bay area may again be unusually marine-oriented. For example, sea otters dominated at MNT-101, and SMA-218 was mostly northern fur seal (Jones et al. 2007). MNT-234 was also nearly 50% northern fur seal and the numerous mammal specimens dated suggest the mammals can dependably be assigned to the Middle Period (Gifford-Gonzalez and Sunseri 2009). Stable isotope analyses on the Middle Period burial at MNT-831 indicated a continued extremely high percentage of marine foods in the diet, at 80% (Breschini and Haversat 2006). North of the bay, SMA-18 produced an assemblage more like that described by Jones et al. (2007), with 48% leporids, 23% deer or other ruminants, and 19% pinnipeds, most of which were northern fur seal (Gifford-Gonzalez et al. 2006).

Shellfish representation in the Middle Period continued to decrease in relation to vertebrates. Circular shell fishhooks appeared during the Middle Period (Jones et al. 2007; Breschini and Haversat 2011), but interestingly, my results suggest onshore single capture taxa started declining in relative abundance in the rocky/sandy shoreline sites. The addition of the shell fishhook to the bone gorge might mainly be a sign of increased exploitation of fishes overall, rather than a relative increase in hook-and-line fishing. Grooved stone netsinkers also occur in artifact assemblages from the

Middle Period (Jones et al. 2007) and mass captured taxa, including surfperches, sardines, and silversides, noticeably increased.

Ethnographic accounts of the Tolowa in Northwestern California described them drying smelt whole on logs or the beach in the sunshine (Gould 1975; Halperin 1980). Smelt are another small schooling fish that can be captured with nets in large quantities. If the small schooling fishes found in Monterey Bay area assemblages were dried and stored, their abundance supports a transition to a collector organization and perhaps to a more exchange-based system of subsistence. Their presence alone, however, does not definitively indicate storage.

Estuary sites in the Monterey Bay area once again had occupations during the Middle Period. The most striking trend in the fish data between the Millingstone and Middle Periods is the substantial decrease in sharks and rays. The parsimonious explanation at this point is habitat degradation rather than over-fishing. The two most common cartilaginous taxa identified in the Millingstone Period sites were leopard shark and bat ray, both of which are categorized as partial residents in Elkhorn Slough today (Yoklavich et al. 1991). The abundance of these two species in estuarine environments is seasonally affected by both temperature and salinity (Carlisle and Starr 2009; Hopkins and Cech 2003). In Tomales Bay, north of San Francisco Bay, most leopard sharks and bat rays left during the winter, when temperatures decreased below 10-12ºC and salinity levels were at their lowest (Hopkins and Cech 2003). Carlisle and Starr (2009) have identified similar behaviors with leopard sharks in Elkhorn Slough.

Longer-term changes in temperature and salinity levels could have affected these species' abundances in the past. Elkhorn Slough was a high-energy tidal inlet for thousands of years in its early history (Schwartz 2002; Schwartz et al. 1986), when sharks and rays are most abundant in archaeological samples. During the latter span from which fish remains are available, Elkhorn Slough was infilling and becoming a quiet estuary, potentially undergoing multiple freshwater events. Shark and ray remains are very rare at this time. Today, with the modern artificial opening of Elkhorn Slough to the sea, a high-energy, saline environment once again exists, and sharks and rays are again abundant. Given the sensitivity of leopard sharks and bat rays to seasonal variations in temperature and salinity conditions, their near-absence in Middle Period archaeological sites is best explained by a decrease in suitable habitat.

Proportionate increases in mass captured species, including sardines, surfperches, and silversides, parallels that evidenced at the rocky/sandy sites. Anchovies comprise 6% of the MNT-228 assemblage, but because this is the only site with some use of 1/16 in mesh, it is impossible to tell whether this reflects more fishing for anchovy or simply the use of sufficiently small screens.

The San Simeon Reef archaeofaunas also have more small migratory fishes than in the Early Period (Joslin 2010). Several traits of the large primary and secondary residential bases suggest this region was also characterized by a collector subsistence strategy.

Breschini and Haversat (2005) argued that in the Middle Period, Penutian speakers from the interior arrived in the Monterey Bay area, mixing with the Hokan speakers already present. This argument is partly supported by mtDNA evidence linking some burials at MNT-831 to Penutian speaking groups and earlier ones to Hokan speakers (Breschini and Haversat 2006). A modern descendent of a local Monterey Bay area tribal group had mtDNA of the basal form of haplogroup A, which matches that of the earlier burials, supporting the idea that both populations persisted, genetically if not culturally. However, while linguistic studies support such an influx of Penutian speakers, the timing is debated (see Breschini and Haversat 2005; Golla 2007; Jones et al. 2007). My zooarchaeological results do not show an especially great shift in marine patch exploitation between the Early and Middle Periods. If the Penutian speakers arrived at this time, the increase in mass captured fishes from boats does support the argument that inland-adapted groups did not completely replace the coastal Hokan groups nor erase their technological knowledge, since a relatively high level of marine resource acquisition was maintained.

Is there a Middle-Late Transition?

Jones et al. (2007:135) define the MLT as "a distinctive period during which tiny saucer (G1), G2, and K beads co-occurred," lasting AD 1000-1250, but they admit it has so far not been identified in either the Santa Cruz or Monterey Peninsula areas. Atmospheric climate may have been warm and wet during this period, as it was in the Middle and Late Periods. Alternatively, based on Plater et al.'s (2006) results, this might have been relatively normal, with earlier and later centuries receiving low

precipitation. The greatest overlap in droughts documented in other regions of California occurred AD 1000-1300 and especially AD 1100-1250, which overlaps well with the proposed Middle-Late Transition Period. Ocean conditions are similarly vague. In general, productivity was lower, as was upwelling, and SST was warmer. On the other hand, Big Sur data suggest SST might be colder until AD 1300.

Of the sites I analyzed, MNT-834 dates mostly to AD 1200-1325, MNT-170 to AD 900-1300, and MNT-1701 mostly to the AD 800s through 1200s. MNT-112 also has a fish specimen dated to AD 938, though the remaining dates place it fully in the Late Period.

My results definitely show an emphasis on different fish patches in the MLT compared to the Middle Period. Mass captured species on average are more abundant than single captured taxa. Sardines are particularly common and were probably caught from tule reed balsas out past the kelp beds, a higher-risk and more costly activity than fishing from shore. This shift in relative taxonomic abundances also indicates that the fish assemblage was providing a much higher percentage of fats than in previous periods, suggesting that terrestrial mammals and other resources might have been in poorer condition or much lower in abundance due to climatic stress.

My DSVM predicts that the probability in successful prey exploitation is an important factor in subsistence decisions and lower abundance could cause successful hunting trips to decline. Moreover, if drought directly affected levels of terrestrial plant productivity, a drop in available carbohydrates would have driven a greater need

for animal fats (Outram 2004; Speth and Spielman 1983). Based on the mammal assemblages portrayed in Figure 9.1, a decrease in pinniped abundance from the Middle to MLT/Late Period, and a corresponding increase in sea otters and leporids, supports the interpretation that fish oils would be more important. Such a possibility is further corroborated by increased grease production from mammal bones at other MLT sites in the region (Sunseri 2009). On San Simeon Reef, clupeids, anchovy, and silversides also continue to increase in abundance, though pricklebacks still comprise most of the assemblage (Joslin 2010).

At MNT-1701, the most inland of all sites analyzed, I identified a wide variety of fish species, but all were present in trace amounts compared to clupeids, which encompassed almost 99% of the assemblage by NISP, and were probably sardines. From a sample of four 10 cm levels from the site, over 6500 specimens were taxonomically identifiable. Specimens identifiable to Pacific sardine included at least 106 individuals. Silversides were the next most abundant, at about 0.6%. If people living more to the interior were struggling to obtain sufficient nutrition from terrestrial resources, the sardines in the site would have been an excellent source of fats. As discussed in Chapter 8, the MNI data for MNT-1701 suggested whole fish were being transported from the coast. Sunseri (2009) also argued for the production of surplus goods during the MLT, as people intensified exchange to build alliances during a difficult climatic episode. High numbers of fishes at a more interior site lends further support this argument.

The significant changes in the taxonomic composition of the fish assemblages support the contention that the terrestrial resource base was poor for extended periods, probably due to drought. People expanded their exploitation of open water habitats and fattier fishes as part of their strategies to compensate for the poor terrestrial conditions. Fish remains identified as sardine/herring in these assemblages are most likely sardines and their high abundance indicates the ocean conditions were probably warmer and less productive, contrary to the stable isotope data from Big Sur. This interpretation might change with a greater use of 1/16 in mesh, which are necessary to retrieve anchovy remains. As it stands, the ichthyofaunal data support the presence of Medieval Climatic Anomaly effects on the Central Coast.

Whether the Late Period continues from the MLT, as Breschini and Haversat (2011) suggested, or is another separate period, as posited by Jones et al. (2007), is a more difficult question, because the Late Period data presented here mainly derive from one site. By the nature of the settlement system in the Late Period, larger sample sizes are hard to come by. I discuss this in the next section.

Late Period

According to Breschini and Haversat (2011), the Late Period began AD 700, whereas Jones et al. (2007) placed it after the MLT, thus beginning in AD 1250. Regardless of either beginning date, climate was warm and wet in general, but I presented evidence in the previous section that supports the presence of drought conditions sometime within c. AD 800-1300. Additionally, clusters of droughts occurred in the AD 1400s-1600s, based on the chronologically well defined and most

geographically relevant study of blue oak tree rings in the Salinas Valley (Griffin 2007). While it is possible the MCA represented the most severe droughts, the blue oak sequence suggests that people must still have contended with spans of lower terrestrial productivity during the Late Period. Ocean conditions continue to have lower upwelling, warmer SST, and lower productivity. Based on the Big Sur stable isotope analyses, SST might have been variable AD 1300-1500, and then cooler (Jones and Kennett 1999).

Breschini and Haversat (2011:18) argued that, "because of the local microclimate, the conditions that led to drought in some areas of California are more likely to have brought an increase in summer fog to the Monterey Peninsula." Defining the beginning of the Late Period at AD 700, they suggest there is "no evidence of a reduction in population or a change in subsistence/settlement strategies around AD 900-1350" (Breschini and Haversat 2011:18), during the possible Middle-Late Transition. The results of my ichthyofaunal analyses as described in the last section show a shift in patch exploitation by the AD 800s, probably at least partly in response to poorer terrestrial conditions.

While this contradicts Breschini and Haversat's assertion that drought most likely did not affect the Monterey Peninsula, it is possible that the effects of the Medieval Climatic Anomaly began *early* in the region, even during their defined transition between Middle and Late Periods. The independent climatic data are simply not specific enough to determine the timing. Archaeological site dates, while not indicating any break in occupation, also do not provide temporal resolution fine-

grained enough to determine exactly when fishing shifted to a relatively greater emphasis on small schooling fishes.

Part of the difficulty with interpreting the Late Period is that, along the Central Coast, including around Monterey Bay, Late Period sites on the coast are much smaller than earlier ones. Large residential sites become more common in the interior, whereas the coast has evidence for numerous, smaller, single component sites (Breschini and Haversat 2011; Jones et al. 2007). On the Monterey Peninsula and south around Carmel, the most common Late Period sites are what Breschini and Haversat (1991b:31) call abalone processing sites, characterized by dense layers of "abalone pavement." Vertebrate faunal assemblages in these sites are usually small and focused on marine animals (Breschini and Haversat 1991b). Because of the small quantity of vertebrate remains, however, more detailed functional interpretations are difficult. Of the three sites I analyzed that dated only to the Late Period by either chronology, the largest sample was 139 identifiable specimens at MNT-17.

Based mainly on the MNT-17 material, clupeids and onshore single captured fishes both comprised about 30% of the assemblages, with sardines slightly lower and onshore fishes higher in abundance than during the Middle Late Transition. Surfperches were relatively less common than earlier. Tidepool fishes, mainly pricklebacks, increased drastically to about 30%. Prickleback abundance is similarly reflected in fish remains from SMA-113, a site on the open coast north of Monterey Bay occupied c. AD 660-1710. Pricklebacks represented over 23% of that assemblage (Boone and Gifford-Gonzalez 2011). Pricklebacks also retained their dominance at

San Simeon Reef sites, and large quantities of fire-cracked rock associated with fish remains might signify the preservation of small dried fishes (Joslin 2006; 2010).

My DSVM results indicated that tidepool fishes are predicted to be valued for their high probability of successful capture. Their relative abundance of about 10% during most time periods is a logical result of their being predictable and easily caught, but typically small and difficult to acquire in large quantities. Pricklebacks, monkeyface in particular, reach larger sizes up to 76 cm (Love 1996), but the majority of remains from sites I analyzed appear to be from smaller individuals. Their increase in the Monterey Bay area in the Late Period, possibly within Jones et al.'s (2007) Middle-Late Transition or even Middle Period, might be related to continued poor terrestrial conditions. Since exploitation of sardines remained high into the Late Period, people were still putting significant effort into exploiting resources from costlier, more dangerous patches. The increased acquisition of small tidepool fishes also suggests that aquatic foods were more dependable than terrestrial ones. One potential explanation is that, along with greater fishing from boats past the kelp by adults, children's foraging of onshore habitats increased, focusing on tidepools as the easiest and least risky to exploit. Future modeling work could explore the effects of division of labor by gender and age on such subsistence choices.

Abalone found in the Late Period processing sites are probably also a predictable resource, but higher risk, usually requiring diving into the intertidal zone to pry them off rocks. Abalone have a low fat content, <1%, but are 6% carbohydrates (U.S. Department of Agriculture 2011). Although plant foods are much higher in

carbohydrates, people dealing with a poor terrestrial environment might exploit whatever sources were available, and vertebrate flesh does not provide any carbohydrates.

While my zooarchaeological results show a potential increase in tidepool fishes in the Late Period compared to the MLT, that interpretation is based on only one site. The SMA-113 assemblage also includes high proportions of tidepool species and is occupied over the MLT-Late period transition. The archaeological deposits at SMA-113 might be discrete enough that future comparison of deposit dates with the fish assemblage could clarify when tidepool exploitation increased. However, this dissertation has also shown a significant variability among sites in the Monterey Bay region within each time period, so further analysis of Late Period material from the Monterey Peninsula is also needed.

Future Considerations for DSVM in Archaeology

Dynamic state variable modeling has helped account for the variety of resources exploited by earlier inhabitants of the Monterey Bay area. I have shown that when multiple variables are considered simultaneously, energetic rate of return is only one factor predicted to influence a forager's subsistence decisions, and often not the most important one. Many marine resources are easily caught or collected, with minimal cost and danger to the forager, thus explaining their plentiful remains in Monterey Bay archaeological sites, even if their rates of energetic return might be low. Beyond the Monterey Bay, similar interpretations would apply to many coastal

areas, especially those in areas with a productive marine environment. Resources in non-coastal areas could also easily be modeled.

The DSVM developed for this dissertation is just a beginning, however, and I acknowledge that it does not include other factors that are known to influence subsistence decisions. Long-term storage, for example, could affect the model's predictions. Rather than only exploiting large mobile prey when energetic reserves are low, a forager might be predicted to hunt them when reserves are high, to bolster stored or exchangeable resources. At that point, a low probability of success would have less of an effect, because reserves are high, and the upper state constraint would not exist, because the extra yield could be stored. In such a context, the most commonly exploited resources might still be the most predictable ones, but larger, storable resources might be included in the diet at higher levels than they would be otherwise. As I discussed above, while an abundance of small schooling fishes does not necessarily indicate storage, they are resources that *can* be easily dried and transported. With the current state of research, however, Monterey Bay Area archaeological sites have little direct evidence for storage (Jones and Ferneau 2002).

Gender and age roles and costly signaling are other factors that could influence modeling predictions. Men, women, and children can have varying goals and skills (e.g., Bird and Bliege Bird 2002; Bliege Bird 2007; Bliege Bird and Bird 2008), which would require different sets of values for the variables used in my DSVM. Ethnographic research shows that men often select large resources that do not provision their families as well as they could if taking smaller, more predictable prey

(Bird and O'Connell 2006). If a relationship between prestige and fitness were defined, then this kind of costly signaling could be included in a DSVM as another state variable. In the meantime, with my model predicting people exploit relatively lower abundances of large prey, such as deer, that have a low probability of success, higher proportions in coastal sites could indicate that (a) terrestrial environmental conditions are *extremely* good, or the marine environment bad, to the point where deer are easily and dependably caught, or (b) more variables than energetic state are influencing forager fitness.

Summary of Research

Archaeological approaches to the study of subsistence have recognized for some time that prey body size and energetic rates of return are not the only important factors in making decisions about resource use. In fact, the probability of successful exploitation is a significant variable, implying that smaller, more predictable taxa are more valuable than they would be by simple rate-maximization terms. Through the development of a dynamic state variable model, I have shown that a model that does not emphasize rate-maximization above other factors can help explain the archaeological record of subsistence in the Monterey Bay area. Predictions from the model have implications for broader studies of foraging groups, especially those in other coastal locations.

I have also attempted here to describe the climatic context in which Holocene foragers lived in the Monterey Bay area, both for terrestrial and environmental

conditions. So far, it appears ocean conditions are not a strong predictor for how much people were fishing or what kinds of fish they focused on. It is possible that an ocean with relatively warm SST and lower upwelling conditions is still productive enough to keep marine resources high ranked. We also need to acquire much more fine-grained climatic data for the Monterey Bay region itself.

Nutritional analyses provided insight into the selection of certain marine resources, supporting the need for further research into the proximate composition of local foods. One of the most important implications of the nutritional analyses covered in this dissertation is that the small schooling fishes, especially sardines, herring, and anchovies, are also the species with the highest percentage of oil. These fishes would thus provide an excellent source of fats, essential fatty acids and calories, and therefore be important to a forager physiologically, especially in an environment where high-carbohydrate plants are relatively scarce, like the Monterey Bay area. As discussed in Chapter 4, aquatic foods are a source of polyunsaturated fatty acids, so fishes could be particularly important for pregnant and lactating women. Moreover, small, mass captured fatty fishes are easily dried and converted into products for exchange with inland groups with more access to high-quality plant resources.

My zooarchaeological results have also shown that taxonomic emphases changed over time in the Monterey Bay area, and that fishing was not as simple as just taking species from the nearest habitats. Fish remains support a broad-spectrum diet during the Millingstone Period with a focus on individually caught taxa including

sharks and rays. The solid presence of sardines, however, also suggests people were fishing beyond the kelp beds from early in the human occupation of the region. Mass captured species started to increase in abundance in the Middle Period, and sharks and rays nearly disappeared as their estuary habitat quality declined. By the Middle-Late Transition, sardines were especially common, probably caught for their fat content when the terrestrial environment deteriorated. In the Late Period assemblages, onshore single captured taxa, sardines, and tidepool fishes were all similarly abundant, suggesting people continued to deal with poor terrestrial climate. Overall, people sometimes fished for species that were not the nearest and easiest to exploit, and sometimes the nearest and easiest resources changed over time.

The results presented in this dissertation also address several regional questions. The perceived radiocarbon date gap on the Monterey Peninsula, previously defined mainly by shellfish dates, has been further supported by dates on fish remains, suggesting that the peninsula was indeed mostly abandoned. Despite our present lack of local paleoclimate data, major changes in fish taxonomic distributions suggest the Medieval Climatic Anomaly did influence the lives of people in the Monterey Bay area. The "deintensification" described by Jones and Ferneau (2002) and Codding and Jones (2007b) for the Central Coast farther south in the Late Period does not appear to have occurred in the Monterey Bay area. Instead, the much-increased abundance of tidepool fishes and continued high proportion of sardines supports evidence from Hildebrandt (1997) and Sunseri (2009) that populations in this part of California remained territorially circumscribed.

Many recent ethnographic studies have made clear that foraging decisions are far more complicated than simply pursuing the largest animal in the environment. While zooarchaeological analyses have also advanced, more sophisticated approaches are necessary to incorporate our developing understanding of foraging theory. In this dissertation, I have introduced to archaeology a now widely applied method for integrating multiple variables into a single foraging model, and shown how such a model can lead to a more nuanced understanding of past human subsistence.

APPENDIX 1

Radiocarbon Dates as Reported in Original Sources

Radiocarbon dates that required transformation from the format as reported in original sources, organized alphabetically by author. For dates reported as uncalibrated, I list here both the original version and my calibrated date. For sources that used calibrated BP dates, I simply note as much, because the conversion to BC/AD only requires subtracting 1950. Sources that used calibrated BC/AD dates are not listed here, because I did not transform their dates. *Included because article used both uncalibrated and calibrated dates.

Author	Original Date	Converted Date
Adam and West 1983	9500-2800 ^{14}C years bp	8810-940 BC
Alley et al. 1993	BP dates	
Alley et al. 1997	BP dates	
Alley et al. 2003	BP dates	
Anderson 1990	10,000 ^{14}C years bp	9500 BC
Anderson 1990	3000-2500 ^{14}C years bp	1250-650 BC
Anderson 1990	6000 ^{14}C years bp	4900 BC
Anderson 1990	6500 ^{14}C years bp	5460 BC
Anderson 1990	8000-5500 ^{14}C years bp	6910-4350 BC
Anderson 1990	9000-7500 ^{14}C years bp	8140-6390 BC
Anderson and Smith 1994	6000-4500 ^{14}C years bp	4900-3220 BC
Anderson and Smith 1994	7000-5500 ^{14}C years ago	5890-4350 BC
Barron and Bukry 2007	BP dates	
Barron et al. 2003	BP dates	
Benson et al. 2002	BP dates	
Birks and Ammann 2000	BP dates	
Birks et al. 2000	BP dates	
Booth et al. 2005	BP dates	
Braje et al. 2009	BP dates	
Broughton and Bayham 2003	BP dates	
Byrne et al. 2001	BP dates	
Carbone 1991	6000 ^{14}C years bp	4900 BC
Cartier 1988	10,000 ^{14}C years bp	9500 BC
Casteel et al. 1977	9500-2800 ^{14}C years bp	8810-940 BC
Cole and Liu 1994	BP and AD dates	
Cole and Wahl 2000	BP dates	
Culleton et al. 2005	BP dates	
Daniels et al. 2005	BP dates	
Davis 1992	BP dates	
Davis 1999a	11,600-7000 ^{14}C years bp	11,470-5890 BC
Davis 1999a	1100 ^{14}C years bp	AD 940
Davis 1999a	2400 ^{14}C years bp	480 BC

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Appendix 1. (continued)

Author	Original Date	Converted Date
Davis 1999a	4000 ^{14}C years bp	2530 BC
Davis 1999a	7000 ^{14}C years bp	5890 BC
Davis 1999a	7000-4000 ^{14}C years bp	5890-2530 BC
Davis 1999a	8800 ^{14}C years bp	7860 BC
Davis 1999b	3500-2500 ^{14}C years bp	1840-650 BC
Davis 1999b	7000-4000 ^{14}C years bp	5890-2530 BC
Davis 1999b	8200 ^{14}C years bp	7210 BC
Davis 1999b	8500 ^{14}C years bp	7530 BC
Davis 1999b	9200-7000 ^{14}C years bp	8390-5890 BC
Diffenbaugh et al. 2003	BP dates	
Erlandson 1991b	BP dates	
Erlandson et al. 2011	BP dates	
Feng and Epstein 1994	BP dates	
Fiedell 1999	BP dates	
Gajewski and Atkinson 2003	9500 ^{14}C years bp	8810 BC
Gifford-Gonzalez and Sunseri 2009	BP dates	
Glassow 1992	BP dates	
Glassow et al. 1994	BP dates	
Grayson 2000	8000-5000 ^{14}C years bp	6910-3760 BC
Gulliksen et al. 1998	BP dates	
Hansen and Engstrom 1996	BP dates	
Harrison et al. 2003	6000 ^{14}C years bp	4900 BC
Hendy and Kennett 2000	BP dates	
Heusser 1978	BP dates	
Heusser and Barron 2002	BP dates	
Heusser and Sirocko 1997	8800-3900 ^{14}C years bp	7860-2380 BC
Hildebrandt 1997	BP dates	
Hildebrandt and Jones 2002	BP dates	
Hildebrandt and McGuire 2002	BP dates	
Ingram 1998	BP dates	
Ingram et al. 1996a	BP dates	
Ingram et al. 1996b	BP dates	
Jones 2002	BP dates	
Kennett and Ingram 1995	BP dates	
Kennett et al. 1997	BP dates	
Kennett et al. 2007	BP dates	
Kienast and McKay 2001	BP dates	
Kutzbach and Guetter 1986	BP dates	
MacDonald et al. 2008	BP dates	
Madsen et al. 2001	10,100 ^{14}C years bp	9760 BC
Madsen et al. 2001	10,100-8000 ^{14}C years bp	9760-6910 BC
Madsen et al. 2001	2950-2400 ^{14}C years bp	1160-480 BC
Madsen et al. 2001	4400-2950 ^{14}C years bp	3010-1160 BC
Madsen et al. 2001	550 ^{14}C years bp	AD 1370

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Appendix 1. (continued)

Author	Original Date	Converted Date
Madsen et al. 2001	6000 ^{14}C years bp	4900 BC
Madsen et al. 2001	700-600 ^{14}C years bp	AD 1270-1350
Madsen et al. 2001	7000-5300 ^{14}C years bp	5890-4140 BC
Madsen et al. 2001	8,000 ^{14}C years bp	6910 BC
Madsen et al. 2001	2400-580 BP*	450 BC-AD 1370
Malamud-Roam et al. 2006	BP dates	
Masters and Aiello 2007	BP dates	
Mathewes 1993	10,700-10,000 ^{14}C years bp	10,680-9500 BC
Mayewski et al. 2004	BP dates	
MBAF 1997	BP dates	
McGuire and Hildebrandt 2004	BP dates	
Milliken et al. 1999	BP dates	
Mix et al. 1999	BP dates	
Mock and Brunelle-Daines 1999	6000 ^{14}C years bp	4900 BC
Mock and Brunelle-Daines 1999	9000 ^{14}C years bp	8140 BC
Myers 2007	BP dates	
Newsome et al. 2004	BP dates	
Palmer et al. 2002	BP dates	
Peteet 2000	10,000 ^{14}C years bp	9500 BC
Peteet 2000	13,000-11,600 BP*	11,050-9650 BC
Peteet 2009	BP dates	
Peteet et al. 1990	11,000-10,000 ^{14}C years bp	10,910-9500 BC
Peteet et al. 1993	10,000 ^{14}C years bp	9500 BC
Peteet et al. 1993	10,800-10,000 ^{14}C years bp	10,730-9500 BC
Pisias 1978	BP dates	
Pisias et al. 2001	BP dates	
Porinchu et al. 2003	BP dates	
Potito et al. 2006	BP dates	
Reinemann et al. 2009	BP dates	
Rick and Erlandson 2000	BP dates	
Rick and Glassow 1999	BP dates	
Rick et al. 2002	BP dates	
Rick et al. 2006	BP dates	
Roberts 2009	BP dates	
Rypins et al. 1989	10,000-7000 ^{14}C years bp	9500-5890 BC
Rypins et al. 1989	12,000-10,000 ^{14}C years bp	11,910-9500 BC
Sandweiss et al. 1999	BP dates	
Schwartz 2002	BP dates	
Schwartz et al. 1986	BP dates	
Severinghaus et al. 1998	BP dates	
Smith and Anderson 1992	10,000-6500 ^{14}C years bp	9500-5460 BC
Smith and Anderson 1992	12,000 ^{14}C years bp	11,910 BC
Smith and Anderson 1992	12,000-10,000 ^{14}C years bp	11,910-9500 BC
Smith and Anderson 1992	16,000-13,700 ^{14}C years bp	17,230-14,880 BC

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Appendix 1. (continued)

Author	Original Date	Converted Date
Smith and Anderson 1992	3700 ^{14}C years bp	2800 BC
Smith and Anderson 1992	6500-3700 ^{14}C years bp	5460-2080 BC
Thompson and Anderson 2000	6000 ^{14}C years bp	4900 BC
Thompson et al. 1993	BP dates	
Viau et al. 2006	BP dates	
Walker 1989	BP dates	
Wanner et al. 2008	BP dates	
Webb et al. 1993	BP dates	
Wohlgemuth 1996	BP dates	
Yu and Eicher 1998	11,000-10,000 ^{14}C years bp	10,910-9500 BC
Yu and Eicher 1998	12,500-11,000 ^{14}C years bp	12,760-10,910 BC
Zheng et al. 2000	BP dates	

APPENDIX 2

Evidence for Holocene Paleoclimate

Overview of Holocene paleoclimate, emphasizing western North America. Data are sorted by earliest date. See Chapter 2 for further detail, and for explanation of why wetter and drier conditions in different parts of San Francisco Bay may be overlapping in time. *Date was published in original source as uncalibrated.

Dates	Place	Climate	Evidence	Source
AD 1850-1950	San Joaquin drainage	No frequent droughts	Giant Sequoia tree ring widths	Hughes and Brown 1992
AD 1850-1870	Southern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 1810-1850	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 1800-1860	Northern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1730-1790	Northern San Francisco Bay	Low freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1675-1730	Northern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1660-1790	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 1600-1700	San Joaquin drainage	No frequent droughts.	Giant Sequoia tree ring widths	Hughes and Brown 1992
AD 1600-1650	Southern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
c. AD 1600	White Mountains, SW Great Basin	Temperatures cool for 100-300 years	Deuterium:hydrogen in bristlecone pine rings, 50-year averages	Feng and Epstein 1994
AD 1573-1593	Southern CA, into Nevada, Colorado	Drought	Tree ring widths	Antevs 1948

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
AD 1568-1589	California	Extreme precipitation events (dry and wet)	Tree ring chronologies from several species in California	Haston and Michaelson 1997
AD 1490-1660	Northern San Francisco Bay	Low freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1480-1580	San Joaquin drainage	Frequent droughts	Giant sequoia tree rings, three sites have correlated low-growth periods	Hughes and Brown 1992
Late 1400s	Santa Barbara Channel, CA	Below normal rainfall for over 50 years	Tree ring analysis of big-cone spruce	Haston and Michaelson 1994
AD 1450-1850	Sierra Nevada crest	Anomalous cool period	Tree rings from foxtail pine and western juniper	Graumlich 1993
AD 1410-1450	Northern San Francisco Bay	Low freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1400-1500	Southern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 1350-1400	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 1300-1850	Alaska	Glaciers advance	Multiple proxies	Wanner et al. 2008
AD 1300-1450	San Joaquin drainage	No frequent droughts	Giant Sequoia tree ring widths	Hughes and Brown 1992
Late AD 1200s-1312	Northern Central Valley, CA	Long droughts, 20-50 years based on severity	Tree ring analysis	Meko et al. 2001
AD 1276-1299	Southwest	Drought	Tree ring widths	Antevs 1948
AD 1276-1299	Sierra Nevada	Normal	Tree ring widths	Antevs 1948
AD 1270-1380	Northern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1270-1350*	Bonneville Basin, NE Great Basin	Significant droughts	Archaeological and pollen data	Madsen et al. 2001

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
AD c. 1209-1350	Tenaya and Mono Lakes, western and eastern Sierra Nevada	Drought, lake levels very low	Tree ring analysis and date of death on drowned stumps	Stine 1994
AD 1200-1930	San Francisco Estuary	Very high freshwater inflow	Pollen, $\delta^{13}C$, and diatoms from sediment cores in brackish marsh	Byrne et al. 2001
AD 1200-1240	Northern San Francisco Bay	Low freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996b
AD 1200	White Mountains, SW Great Basin	Very warm period around this time	Tree ring widths from bristlecone pines	LaMarche 1974
c. AD 1150	Sierra Nevada	Anomolously warm	Tree rings widths	Hughes and Diaz 1994
AD 1112-c. 1209	Mono Lake and Tenaya Lake, central Sierra, CA	High precipitation, lake levels very high	Tree ring analysis and date of death on drowned stumps	Stine 1994
AD c. 1100-1375	Sierra Nevada crest	High temperatures spanning multiple periods of >20 years	Tree rings from foxtail pine and western juniper	Graumlich 1993
AD 1100-1250	Transverse Ranges, Santa Barbara, southern California	Drought, worst AD 1120-1150	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997
AD 1030-1100	Transverse Ranges, Santa Barbara, southern California	Moderate rainfall	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997
AD 1000-1200	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
AD 980-1030	Transverse Ranges, Santa Barbara, southern California	Developing drought	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
c. AD 980	Northern Central Valley, CA	~7 year extreme drought	Tree ring analysis	Meko et al. 2001
AD 940*	Mono Lake, eastern Sierra Nevada	Drought, lake level at or below historic minimum	Major vegetation changes and sand layers in pollen cores	Davis 1999a
AD 900-1400	Great Basin	Persistant droughts	Tree ring widths from conifers	Hughes and Funkhouser 1998
AD 10th-13th centuries	Europe and North Atlantic	Warmer	Ice cores, tree rings, boreholes, glacial geology	Hughes and Diaz 1994
AD c. 892-1112	Tenaya and Mono Lakes, western and eastern Sierra Nevada	Drought, lake levels very low	Tree ring analysis and date of death on drowned stumps	Stine 1994
AD 9th-15th centuries	Global	Temperature highly variable regionally; warmer in many places, but also cold anomalies	Ice cores, tree rings, boreholes, glacial geology	Hughes and Diaz 1994
AD 800-980	Transverse Ranges, Santa Barbara, southern California	High rainfall, higher than any other time in last 1600 years	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997
AD 770-850	Southern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a; Malamud-Roam et al. 2006
AD 720-800	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a; Malamud-Roam et al. 2006
AD 700-850	San Joaquin drainage	Frequent droughts; abrupt shift from low- to high-frequency	Giant sequoia tree rings, three study sites have correlated low-growth periods	Hughes and Brown 1992
AD 699-823	San Joaquin Drainage	Frequent drought	Low growth in sequoia tree rings	Hughes and Brown 1992; Woodhouse and Overpeck 1998

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
AD 650-1250	Northwest California coast	Decreased effective moisture, warmer and drier summers	Redwood and alder pollen decrease, pine increases	Heusser and Barron 2002
AD 650-800	Transverse Ranges, Santa Barbara, southern California	Really low rainfall; extreme drought AD 750-770	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997
AD 550-650	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a; Malamud-Roam et al. 2006
AD 500-650	Transverse Ranges, Santa Barbara, southern California	Low rainfall	Tree ring analysis	Jones et al. 1999; Raab and Larson 1997
AD 450	Northern California	Coastal upwelling intensifies further, to fully modern conditions	Higher abundance of *Distephanus speculum* diatoms in ocean cores	Barron and Bukry 2007
AD 400-500	San Joaquin drainage	No frequent droughts	Giant Sequoia tree rings	Hughes and Brown 1992
AD 300-present	White Mountains, SW Great Basin	Cooler summers, except ~AD 1250	Tree ring widths from bristlecone pines	LaMarche 1974
AD 250-350	San Joaquin drainage	Frequent droughts	Giant sequoia tree rings, three study sites have correlated low-growth periods	Hughes and Brown 1992
AD 236-377	San Joaquin Drainage	Frequent drought	Low growth in sequoia tree rings	Hughes and Brown 1992; Woodhouse and Overpeck 1998
AD 200-1200	San Francisco Estuary	Low freshwater inflow	Pollen, $\delta^{13}C$, and diatoms from cores in brackish marsh	Byrne et al. 2001
AD 150-present	Stella Lake, central Great Basin	Increasing temperatures	Chironomid community composition	Reinemann et al. 2009

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
50 BC-AD 1550	White Mountains, SW Great Basin	Cool temperatures, little change in this period	Deuterium:hydrogen ratios (δD) in bristlecone pine rings, 50-year averages	Feng and Epstein 1994
50 BC-AD 50	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a
100 BC-AD 100	San Joaquin drainage	No frequent droughts	Giant Sequoia tree rings	Hughes and Brown 1992
200 BC-AD 300	White Mountains, SW Great Basin	Warmer summers	Tree ring widths from bristlecone pines	LaMarche 1974
350 BC	Newport Bay, Orange County, CA	Cool, wet, freshwater event in marsh	Peak in freshwater plant pollen	Davis 1992
450 BC-AD 1370	Bonneville Basin, NE Great Basin	Climate similar to today	Vegetation reaches modern patterns	Madsen et al. 2001
450-250 BC	Southern San Francisco Bay	High freshwater inflow	Higher $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a; Malamud-Roam et al. 2006
480 BC*	Mono Lake, eastern Sierra Nevada	Drought, lake level at or below historic minimum	Major vegetation changes and sand layers in pollen cores	Davis 1999a
650 BC	San Diego, CA	Climate starts becoming more moist	Increased cottonwood and fern pollen	Cole and Wahl 2000
750-650 BC	Southern San Francisco Bay	Lower freshwater inflow	Lower $\delta^{18}O$ and $\delta^{13}C$ in shells from sediment cores in bay	Ingram et al. 1996a; Malamud-Roam et al. 2006
790 BC-AD 1840	Pyramid Lake, western Great Basin	Climate oscillates on decadal and centennial scales, lake shallow 2740-1600 BP	Magnetic susceptibility, TIC, and $\delta^{18}O$ oscillate	Benson et al. 2002
850 BC	Newport Bay, Orange County, CA	Cool, wet, freshwater event in marsh	Peak in freshwater plant pollen	Davis 1992
940 BC*	Clear Lake, CA	Cooler lake water	Decreased growth rates in tule perch scales	Casteel et al. 1977

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
1050-550 BC	San Francisco Estuary	Low freshwater inflow	Pollen, $\delta^{13}C$, and diatoms from cores in brackish marsh	Byrne et al. 2001
1160-480 BC*	Bonneville Basin, NE Great Basin	Strong cooling event	Juniper continues to be found at lower elevations, isotopes show lakes more fresh	Madsen et al. 2001
c. 1250 BC	Northern California	SST increases quickly about 1ºC, stays warm for rest of Holocene	Warmer water diatom species increase	Barron et al. 2003; Barron and Bukry 2007
1300 BC-AD 1800	Santa Barbara Channel, CA	Wetter period, more freshwater input in marsh	Abundant carbonate and sedge pollen, low $\delta^{13}C$	Cole and Liu 1994
1450-1150 BC	San Francisco Bay	Wetter period	Sediment analysis, more freshwater inflow into the bay	Malamud-Roam et al. 2006
1550-1250 BC	Northern California and Oregon	Essentially modern ocean conditions: upwelling in spring-summer, SST warmer in fall	Higher abundance of *Distephanus speculum* diatoms in ocean cores	Barron and Bukry 2007
1750-1500 BC	San Francisco Bay	Drier period	Sediment anlaysis, showing less freshwater inflow into the bay	Malamud-Roam et al. 2006
1840-650 BC	Tulare Lake, southwest-central CA	Low temperatures, high precipitation, lake level peaks	Peak percentage of pelagic algae, low pollen, mostly *Pinus*	Davis 1999b
1850 BC	Newport Bay, Orange Co., CA	Cool and wet, freshwater event in marsh	Peak in pollen from freshwater plants	Davis 1992
2000 BC-present	Great Basin	*Relatively* cool and moist	More water in desert lakes, glaciers in mountains, clay and silt deposition in arroyos and valleys, vegetation on dunes, moisture-friendly vegetation	Antevs 1948
2050 BC-AD 650	Northwest California coast	Increasing effective moisture	Conifers gain dominance, more redwood and alder pollen	Heusser and Barron 2002

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
2380 BC*	Santa Barbara Basin, CA	Climate becomes more moderate from here on	Mesic conifers expand in range	Heusser and Sirocko 1997
2530 BC-present*	Mono Lake, eastern Sierra Nevada	Modern climate, lake level fluctuating	Modern vegetation established ~2000 BP	Davis 1999a
2530 BC*	Mono Lake, eastern Sierra Nevada	Drought, lake level at or below historic minimum	Major vegetation changes and sand layers in pollen cores	Davis 1999a
2530 BC*	Tulare Lake, southwest-central CA	Drought, lake level low	Peak percentage of littoral algae, low pelagic algae	Davis 1999b
2800 BC*	Yosemite Valley, western Sierra Nevada	Beginning of transition into warmer and drier climate similar to today	Increased fir and cypress, decreased oak and rose pollen	Smith and Anderson 1992
2850-1650 BC	Northern California and Oregon	Weaker coastal upwelling	Lower abundance of *Distephanus speculum* diatoms in ocean cores	Barron and Bukry 2007
3010-1160 BC*	Bonneville Basin, northeastern Great Basin	Cooler and more effective moisture than previous millennia	Increased sagebrush and conifers, juniper at lower elevations, more waterfowl, woodrats, greater taxonomic richness	Madsen et al. 2001
3150-1850 BC	San Francisco Bay	Wetter period	Sediment anlaysis, more freshwater inflow into the bay	Malamud-Roam et al. 2006
3250-1300 BC	Santa Barbara Channel, CA	Arid climate (core only goes back to 5200 BP, aridity may start earlier)	Chenopodiaceae pollen dominates, abundant ragweed, low aster and sedge	Cole and Liu 1994
3450 BC-AD 150	Stella Lake, central Great Basin	Temperatures decrease to low of 9.4ºC	Chironomid community composition	Reinemann et al. 2009
3500-1300 BC	White Mountains, SW Great Basin	Warm summers	Tree ring widths	LaMarche 1974
4050 BC	Northern California	Ocean salinity decreases	Low $\delta^{18}O$ values in planktonic foraminifera	Mix et al. 1999

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
4850-50 BC	White Mountains, SW Great Basin	Warm until 6800 BP, then cooling until 2000 BP	Deuterium to hydrogen ratios (δD) in bristlecone pine rings, 50-year averages	Feng and Epstein 1994
4900-3220 BC*	Western Sierra Nevada	More moist	Fir, mountain hemlock, and sequoia replace drier environment species	Anderson and Smith 1994
4900 BC*	Sierra Nevada crest	Increased effective precipitation	Pollen cores show forest becomes more closed, dominated by conifers	Anderson 1990
4900 BC*	American Southwest	Increased monsoons	Multiple proxies: pollen cores, packrat middens, etc.	Harrison et al. 2003; Mock and Brunelle-Daines 1999; Thompson and Anderson 2000
5000-2000 BC	Great Basin	Much warmer than present, Summer Lake basin dry	Lake salinity levels, channel and wind erosion in southern U.S., pollen profiles from peat in Oregon and Washington	Antevs 1948
5050-3450 BC	Stella Lake, central Great Basin	Warmer and drier than today, warmest mean summer temperature 11ºC	Chironomid community composition	Reinemann et al. 2009
5250-2550 BC	Hidden Lake, eastern Sierra Nevada	Warm climate, lake level drops and warms	Chironomid community composition, peak warmth at 6500 BP	Potito et al. 2006
5680-3650 BC	Pyramid Lake, western Great Basin	Very arid	TIC and δ^{18}O from cores and drowned tree stumps	Benson et al. 2002
5750-1250 BC	Owens Lake, SW Great Basin	More arid	Tree ring analysis	Benson et al. 2002
5850-4050 BC	Santa Barbara Basin, CA	Shift from cool and wet climate to semi-arid	Coastal sage and chapparal pollen peak at 6000 BP	Heusser 1978

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
5890-2530 BC*	Tulare Lake, southwest-central CA	Warmer, more droughts, lake level lower than early Holocene	Low pelagic algae, high charcoal concentrations, less oak pollen	Davis 1999b
5890-2530 BC*	Mono Lake, eastern Sierra Nevada	Drier, lake levels constant, intermediate	No sand layers, low charcoal, more ostracods	Davis 1999a
5890-4140 BC*	Bonneville Basin, NE Great Basin	Warmer and drier than today, but with moisture peak at 6000 rcy bp	Decreased pine, conifers, except for 6000 rcy bp, few waterfowl	Madsen et al. 2001
6050-3050 BC	Northern California and Oregon	Increased coastal upwelling	More *Distephanus speculum* diatoms in ocean cores	Barron and Bukry 2007
6250-1250 BC	Northern California	SST colder, decreases to <11ºC	Warm water diatom species decrease to <5% of assemblage	Barron and Bukry 2007
6910-3760 BC*	Homestead Cave, NE Great Basin	Warmer and drier than today	Decline in small mammal richness and evenness in owl roost deposit	Grayson 2000
6910 BC*	Bonneville Basin, NE Great Basin	Rapid warming	Fewer waterfowl, decreased animal and maybe plant diversity, many upland small mammals disappear	Madsen et al. 2001
7000-5000 BC	Great Basin	Starts like modern climate, but warming, subhumid, semiarid, high lake levels	Peat deposits, pollen from yellow and white pines	Antevs 1948
7050-2050 BC	Northern California	Higher temperatures, more aridity and summer droughts	Increasing pine and oak, dereasing redwood and cedar	Heusser and Barron 2002
7530 BC*	Tulare Lake, southwest-central CA	Drought, lake level low	Low pelagic algae percentages	Davis 1999b
7860-2380 BC*	Santa Barbara Basin, CA	Possibly more arid climate	Xeric vegetation dominates	Heusser and Sirocko 1997

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
7860 BC*	Mono Lake, eastern Sierra Nevada	Drought, lake level at or below historic minimum	Sand layer in pollen core	Davis 1999a
8140-6390 BC*	Starkweather Pond, Sierra Nevada crest	Lower lake levels, lower effective moisture	Pollen cores have abundant montane chaparral shrubs	Anderson 1990
8390-5890 BC*	Tulare Lake, southwest-central CA	Cool climate, high precipitation	Green algae show lake level high but fluctuating, get oak woodland plants at 8000 rcy bp	Davis 1999b
8810-940 BC*	Clear Lake, CA	Warmer water temperature	Pollen changes and increased tule perch growth rates	Adam and West 1983; Casteel et al. 1977
9050-5950 BC	Northwest California	Warm and dry	Pollen cores open forest with chaparral, high charcoal indices	Daniels et al. 2005
9050 BC	Vancouver Island, British Columbia	5ºC SST increase in <400 years, then down 2ºC for rest of Holocene	Changes in an SST index based on unsaturated C_{37} alkenones	Kienast and McKay 2001
9500-5460 BC*	Swamp Lake, western Sierra Nevada	Warm and dry	Abundant oak, little fir, high charcoal concentrations	Smith and Anderson 1992
9500 BC*	Sierra Nevada crest	Trees are established after deglaciation	Pollen cores show trees appear - open forest with chapparral	Anderson 1990
c. 9500 BC*	Southern New England	Forest composition warmer	Increased pine pollen, lose boreal species	Peteet 2000 Peteet et al. 1993
9550 BC	Northern California and Oregon	SST warms 2-3ºC	Decrease in left-coiling *Neogloboquadrina pachyderma*	Mix et al. 1999
9580 BC	Norway	Warming atmosphere	Chironomids, beetles, pollen, plant macrofossils, crustaceans, diatoms, lithography, etc.	Birks and Ammann 2000; Birks et al. 2000; Gulliksen et al. 1998
9650-6250 BC	Northern California	SST at 12-13ºC	Warmer water diatom species >15% of the assemblage	Barron and Bukry 2007
9690 BC	Greenland	Beginning of Holocene, warmer atmosphere	Ice cores show increased ice accumulation, less dust, particular isotope composition	Alley et al. 1993

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Appendix 2. (continued)

Dates	Place	Climate	Evidence	Source
9760-6910 BC*	Bonneville Basin, NE Great Basin	3ºC cooler and moister than today	High % of voles, pygmy rabbits, etc., preferring cool, moist habitats	Madsen et al. 2001
11,470-5890 BC*	Mono Lake, eastern Sierra Nevada	High effective precipitation, lake level high	Holocene vegetation appears ~11,000 rcy bp, low temperatures and precipitation after 9000 rcy bp	Davis 1999a
Early Holocene	Clear Lake, CA	Cool, higher effective moisture than today	Oak percentages low, but increasing in pollen cores	Adam et al. 1981
Transition to Holocene	Switzerland	Warming atmosphere	Chironomids, plant macrofossils, pollen, crustaceans, beetles, etc.	Birks and Ammann 2000
Holocene	Santa Barbara Channel, CA	7ºC warmer SST than in LGM	Lower $\delta^{18}O$ from planktonic foraminifera	Hendy and Kennett 2000
Holocene	Santa Barbara Channel, CA	6-10ºC warmer SST than in LGM	Lower $\delta^{18}O$ from planktonic foraminifera, increase in dextral-coiling *Neogloboquadrina pachyderma*	Mortyn et al. 1996

APPENDIX 3

Details of Radiocarbon Date Samples

Samples were submitted to the Center for Accelerator Mass Spectrometry (CAMS) at the Lawrence Livermore National Lab. Table 1 lists the samples with their proveniences and taxonomic information, starting with the site name, then the catalog number, then the sample number I submitted to CAMS. Table 2 summarizes the radiocarbon dating results. I repeat the site name and my sample number, adding the CAMS sample number and the CAMS results to the left of the vertical solid line. To the right of the solid line are recalibrated dates and intercepts as calculated for me by Gary Breschini (personal communication 2011), using a ΔR of 225±35 and a $\delta^{13}C$ estimate of -14.0±0.4.

Samples without data were submitted but determined to be too small and with poor backgrounds, thereby not yielding useful results. CAMS provided the following explanation of their data: "1) $\delta^{13}C$ values are the assumed values according to Stuiver and Polach (Radiocarbon, v. 19, p.355, 1977) when given without decimal places. Values measured for the material itself are given with a single decimal place. 2) The quoted age is in radiocarbon years using the Libby half-life of 5568 years and following the conventions of Stuiver and Polach (ibid.). 3) Radiocarbon concentration is given as fraction Modern, $D^{14}C$, and conventional radiocarbon age. 4) Sample preparation backgrounds have been subtracted, based on measurements of samples of ^{14}C-free collagen extracted/prepared at UCSC."

Table 1. Radiocarbon date sample descriptions.

Site	Catalog#	Sample #	Unit	Level (cm)	*Species*	Element
MNT-17	000073	17-73	AC899B 2	110-120	*Scorpaenichthys marmoratus*	Precaudal vertebra
MNT-17	001163	17-1163	AC899B 1	50-60	*Scorpaenichthys marmoratus*	Caudal vertebra
MNT-17	000990	17-990	AC2400 X	220-230	*Sebastes* sp.	Atlas vertebra
MNT-17	001073	17-1073	AC2400 X	210-220	*Sebastes* sp.	Precaudal vertebra
MNT-112	000001	112-1	3	60-70	*Scorpaenichthys marmoratus*	Basioccipital
MNT-112	000003	112-3	8	100-110	*Sebastes* sp.	Quadrate
MNT-113	000004	113-4	2	50-60	*Sebastes* sp.	Maxilla
MNT-114	000005	114-5	6	55-65	*Scorpaenichthys marmoratus*	Precaudal vertebra
MNT-115	000006	115-6	2	120-130	*Sebastes* sp.	Precaudal vertebra
MNT-115	000007	115-7	2	60-70	*Scorpaenichthys marmoratus*	Precaudal vertebra
MNT-116	000010	116-10	24	60-70	*Sebastes* sp.	Precaudal vertebra
MNT-116	000009	116-9	24	130-140	*Scorpaenichthys marmoratus*	Precaudal vertebra
MNT-125	000020	125-20	AC27369	30-40	*Sebastes* sp.	Caudal vertebra
MNT-148	AMS-148-1	148-1	5	90-100	*Sebastes* sp.	Precaudal vertebra
MNT-148	AMS-148-2	148-2	4	150-160	*Scorpaenichthys marmoratus*	Caudal vertebra
MNT-170	000134	170-134	AC1230C B	90-100	*Sebastes* sp.	Caudal vertebra
MNT-170	000332	170-332	AC1230C C	60-70	*Sebastes* sp.	Atlas vertebra
MNT-228	200001	228-1	9	60-70	*Atractoscion nobilis*	Caudal vertebra
MNT-229	200008	229-8	4	150-160	*Merluccius productus*	Thoracic vertebra
MNT-229	200452	229-452	15	90-100	*Scombridae* c.f. *Thunnus alalunga*	Precaudal vertebra
MNT-234	200127	234-127	CC4	50-60	c.f. *Hexagrammos* sp.	Ceratohyal
MNT-234	200271	234-271	CC2	20-30	*Amphistichus* sp.	Lower pharyngeal
MNT-831	000565	831-565	4	30-40	*Sebastes* sp.	Precaudal vertebra
MNT-831	000291	831-291	5	30-40	*Sebastes* sp.	Precaudal vertebra
MNT-831	000146	831-146	5	60-70	*Scorpaenichthys marmoratus*	Precaudal vertebra
MNT-831	000676	831-676	7	0-bottom	*Sebastes* sp.	Precaudal vertebra
MNT-834	000752	834-752	A1	40-50	*Sebastes* sp.	Precaudal vertebra
MNT-834	000753	834-753	B3	50-60	*Scorpaenichthys marmoratus*	Caudal vertebra
MNT-834	000213	834-213	Area A Feature 2	60+	*Scorpaenichthys marmoratus*	Axis Vertebra
MNT-1701	000366	1701-366	AC 1683 1	30-40	*Sebastes* sp.	Precaudal vertebra

Table 2. Radiocarbon date results.

Site	Sample #	CAMS #	$d^{13}C$	Fraction Modern	±	$D^{14}C$	±	^{14}C age	±	Recalibrated	Intercept
MNT-17	17-73	-	-	-	-	-	-	-	-	-	-
MNT-17	17-1163	-	-	-	-	-	-	-	-	-	-
MNT-17	17-990	-	-	-	-	-	-	-	-	-	-
MNT-17	17-1073	-	-	-	-	-	-	-	-	-	-
MNT-112	112-1	153778	-14	0.8789	0.0077	-121.1	7.7	1040	80	556-280 BP	AD 1491
MNT-112	112-3	153941	-14	0.8085	0.0032	-191.5	3.2	1705	35	1142-921 BP	AD 938
MNT-113A	113-4	153942	-14	0.8785	0.0036	-121.5	3.6	1040	35	515-329 BP	AD 1491
MNT-113B	114-5	-	-	-	-	-	-	-	-	-	-
MNT-113C	115-6	-	-	-	-	-	-	-	-	-	-
MNT-113C	115-7	-	-	-	-	-	-	-	-	-	-
MNT-113D	116-10	-	-	-	-	-	-	-	-	-	-
MNT-113D	116-9	-	-	-	-	-	-	-	-	-	-
MNT-125	125-20	153943	-14	0.8963	0.0031	-103.7	3.1	880	30	409-242 BP	AD 1663
MNT-148	148-1	153944	-14	0.6236	0.0025	-376.4	2.5	3795	35	3569-3344 BP	1499 BC
MNT-148	148-2	-	-	-	-	-	-	-	-	-	-
MNT-170	170-134	153945	-14	0.5916	0.0047	-408.4	4.7	4220	70	4222-3802 BP	2029 BC
MNT-170	170-332	-	-	-	-	-	-	-	-	-	-
MNT-228	228-1	153777	-14	0.7981	0.0029	-201.9	2.9	1810	30	1243-1040 BP	AD 802
MNT-229	229-8	153775	-14	0.7560	0.0061	-244.0	6.1	2250	70	1782-1396 BP	AD 381
MNT-229	229-452	-	-	-	-	-	-	-	-	-	-
MNT-234	234-127	-	-	-	-	-	-	-	-	-	-
MNT-234	234-271	153774	-14	0.4047	0.0101	-595.3	10.1	7270	210	7927-7156 BP	5594 BC
MNT-831	831-565	153946	-14	0.7679	0.0030	-232.1	3.0	2120	35	1538-1318 BP	AD 531
MNT-831	831-291	-	-	-	-	-	-	-	-	-	-
MNT-831	831-146	-	-	-	-	-	-	-	-	-	-
MNT-831	831-676	153773	-14	0.7873	0.0100	-212.7	10.0	1920	110	1482-986 BP	AD 695
MNT-834	834-752	-	-	-	-	-	-	-	-	-	-
MNT-834	834-753	-	-	-	-	-	-	-	-	-	-
MNT-834	834-213	153776	-14	0.8414	0.0108	-158.6	10.8	1390	110	930-523 BP	AD 1260
MNT-1701	1701-366	-	-	-	-	-	-	-	-	-	-

APPENDIX 4

Programming Code in R for Dynamic State Variable Model

This code was written for R Version 1.16.

```
par(mfrow=c(2,2)) #make two by two set of plots

tmax<<-50   #number of time steps in model
xmax<<-20  #maximum state value
xcrit<<-6      #value at or below which forager dies
xo<<-(0.5*xmax)   #parameter to make fitness non-linear
gamma<<-4 #parameter used in end condition
patches<<-3#patches in model

ybarb<<-6   #mean benefit of finding food in region b
betab<<-0.004       #probability of mortality in region b
lambda.b<<-0.7     #probability of finding food in region b
alpha.b<<-2 #cost of foraging in region b
tm<<-2        #time steps required to move to region b

alpha.m=array(0,dim=c(1,tmax))
alpha.m[tm]=tm     #cost of moving to region B

f=array(0,dim=c(xmax,2,tmax)) #stores fitness values
istar=array(0,dim=c(xmax,tmax))        #stores optimal patch decisions
v=array(0,dim=c(patches,xmax,tmax))         #stores value of foraging in each patch at state x
and time t
vm=array(0,dim=c(xmax,tmax))#stores values of moving to region b at state x and time t
x=array(0,dim=c(1,xmax))         #stores state values
l=array(0,dim=c(1,2))      #stores which region forager is in
benefit=array(0,dim=c(patches,1))      #stores values of food benefit in each patch

cat("\nParameters are these:\n")
cat("xcrit=",xcrit, "xmax=",xmax, "xo=",xo, "tmax=",tmax,"\n")

i<<-c(1,2,3)  #patch labels
alpha<<-c(1,2,2)    #cost of foraging in patch i
beta<<-c(0,.004,.004)      #probability of mortality in patch i
lambda<<-c(0,0.8,0.7)     #probability of finding food in patch i
benefit.bar<<-c(0,4,9)      #mean benefit of finding food in patch i

for(j in 2:patches)
        {benefit[j]=benefit.bar[j]/lambda[j]
                }

cat("\n")
parameters<-data.frame(i,alpha,beta,lambda,benefit)
```

```
parameters

#fitness at tmax for both regions
for(l in 1:2)
{
	for(x in 1:xmax)
	{
		if(x>xcrit)
		{
			f[x,l,tmax]=1/(1+((xo-xcrit)/(x-xcrit))^gamma)
		}

	}	#end x loop

}	#end l loop

cat("Fitness at tmax")
f[1:xmax,1:2,tmax]

sink("region2fitness")
cat("time","x","l","f[x,2,t]","\n")
sink()

for(t in (tmax-1):1)
{
	for(x in (xcrit+1):xmax)
	{
		xp=min(x-alpha.b+ybarb,xmax)
		xpp=max(x-alpha.b,xcrit)

		xpl=max(floor(xp),xcrit)
		xpu=min(xpl+1,xmax)

		xppl=max(floor(xpp),xcrit)
		xppu=min(xppl+1,xmax)

		qxp=xp-xpl
		qxpp=xpp-xppl

		f[x,2,t]=(1-betab)*(lambda.b*((1-qxp)*f[xpl,2,t+1]+(qxp)*f[xpu,2,t+1])+(1-
lambda.b)*((1-qxpp)*f[xppl,2,t+1]+(qxpp)*f[xppu,2,t+1]))

		sink("region2fitness",append=TRUE)
		cat(t," ",x," ",l," ",f[x,l,t],"\n")
		sink()

	}	#end x loop

}	#end t loop

#Need to add or subtract patches if change model
sink("patchtable")
```

```
cat("t","x","istar[x,t]","f[x,1,t]","v[1,x,t]","v[2,x,t]","v[3,x,t]","\n")
sink()

for(t in (tmax-1):1)
{
	for(x in (xcrit+1):xmax)
	{
		for(i in 1:patches)
		{
			xp=min(x-alpha[i]+benefit[i],xmax)
			xpp=max(x-alpha[i],xcrit)

			xpl=max(floor(xp),xcrit)
			xpu=min(xpl+1,xmax)

			xppl=max(floor(xpp),xcrit)
			xppu=min(xppl+1,xmax)

			qxp=xp-xpl
			qxpp=xpp-xppl

			v[i,x,t]=(1-beta[i])*(lambda[i]*((1-qxp)*f[xpl,1,t+1]+(qxp)*f[xpu,1,t+1])+(1-
lambda[i])*((1-qxpp)*f[xppl,1,t+1]+(qxpp)*f[xppu,1,t+1]))

		}	#end of i loop

		vmax=v[1,x,t]
		istar[x,t]=1

		if(v[2,x,t]>vmax)
		{
			vmax=v[2,x,t]
			istar[x,t]=2
		}

		if(v[3,x,t]>vmax)
		{
			vmax=v[3,x,t]
			istar[x,t]=3
		}


		if((t+tm)<tmax)
		{	xm=max(x-alpha.m[tm],xcrit)
			xml=max(floor(xm),xcrit)
			xmu=min(xml+1,xmax)
			qxm=xm-xml

			if(((1-qxm)*f[xml,2,t+tm]+(qxm)*f[xmu,2,t+tm])>vmax)
			{
				vmax=((1-qxm)*f[xml,2,t+tm]+(qxm)*f[xmu,2,t+tm])
				istar[x,t]=5
```

```
                }
        }       #end of t+tm loop

        f[x,1,t]=vmax

        #Need to add or subtract patches here if change model
        sink("patchtable",append=TRUE)
        cat(t," ",x," ",istar[x,t]," ",f[x,1,t]," ",v[1,x,t]," ",v[2,x,t]," ",v[3,x,t], "\n")
        sink()

    }       #end of x loop

}       #end of t loop

decision=read.table("patchtable", header=TRUE)
decision

plot("",xlim=c(1,tmax),ylim=c(xcrit,xmax),xlab="Time t", ylab="State x", main="Optimal patch
choice")

for(t in 1:tmax)
{
    for(x in xcrit:xmax)
    {
        if(istar[x,t]==1) points(t,x,pch="1",col="blue")
        if(istar[x,t]==2) points(t,x,pch="2",col="red")
        if(istar[x,t]==3) points(t,x,pch="3",col="green")
        if(istar[x,t]==0) points(t,x,pch="0",col="orange")
        if(istar[x,t]==5) points(t,x,pch="B",col="black")
    }       #end x loop
}       #end t loop

#forwards simulation
#W(t) = energy reserves at time t in forwards iteration

kmax=100   #number of loops
w=array(0,dim=c(tmax,kmax))  #stores w[t,k] values, w(t) = energy reserves at time t in
forwards part
i.star=array(0,dim=c(tmax,kmax))      #stores i.star[t,k] values. Note i.star is different from
istar matrix in forwards part
visits=array(0,dim=c(patches+1,kmax))       #stores tallies of total trips to each patch
success=array(0,dim=c(patches+1,kmax))   #stores tallies of successful trips to each patch

    #create header for abandon table
    sink("abandon")
    cat("k t w[t,k] \n")
    sink()

    #create header for wchoice table
    sink("wchoice")
    cat("t w[t,k] wl wu qw i.star \n")
    sink()
```

```
        #create header for patchchoice table
        sink("patchchoice")
        cat("k t w[t,k] i.star \n")
        sink()

        #create header for reserves table
        sink("reserves")
        cat(1:(tmax-1), "\n")
        sink()

        #create header for successes table
        sink("successtally")
        cat("k patch visits successes survival\n")
        sink()

        #create header for location table
        sink("location")
        cat("k t w[t,k] i.star l good \n")
        sink()

        #create header for survival table
        sink("survival")
        cat("k survive \n")
        sink()

for(k in 1:kmax)
{

        for(t in 1)
        {
                l=1     #start in region A
                w[t,k]=18     #state as which forager is assigned to start
        }       #end t=1 loop

        for(t in 1:(tmax-1))
        {
                        if(l<2)
                        {
                        if(w[t,k]<(xcrit+1)) w[t+1,k]=0

                        if(w[t,k]>xcrit)
                        {

                                sink("wchoice", append=TRUE)
                                cat(t, " ", w[t,k], " ")
                                sink()

                                wl=floor(w[t,k])
                                wu=wl+1
                                qw=w[t,k]-wl
```

```
        if(qw<=0.5)
                {
                        i.star=decision[(xmax-xcrit)*((tmax-1)-t)+(wl-xcrit),3]
                        visits[i.star,k]=(visits[i.star,k]+1)
                }
        if(qw>0.5)
                {
                        i.star=decision[(xmax-xcrit)*((tmax-1)-t)+(wu-xcrit),3]
                        visits[i.star,k]=(visits[i.star,k]+1)
                }

        sink("wchoice", append=TRUE)
        cat(wl, " ", wu, " ", qw, " ", i.star, "\n")
        sink()

        sink("patchchoice", append=TRUE)
        cat(k,t,w[t,k],i.star,"\n")
        sink()

        if(i.star<=patches) {l=1}
        if(i.star>patches) {l=2}

if(l<2)
{
        #generate a random number between 0 and 1
        random=runif(1,min=0,max=1)
        if(random<=lambda[i.star])
        {
                w[(t+1),k]=min(w[t,k]+benefit[i.star]-alpha[i.star],xmax)
                good="yes"
                success[i.star,k]=(success[i.star,k]+1)
        }       #end random<lambda loop

        if(random>lambda[i.star])
        {
                w[(t+1),k]=w[t,k]-alpha[i.star]
                good="no"
        }       #end random>lambda loop

}       #end second l=1 loop

if(l>1)
{
        good="migrate"
        sink("abandon", append=TRUE)
        cat(k, " ", t, " ", w[t,k], " ", "\n")
        sink()
}

sink("location", append=TRUE)
cat(k, t, w[t,k], i.star, l, good, "\n")
sink()
```

```
                }       #end w[t,k]>xcrit loop

                sink("reserves", append=TRUE)
                cat(w[t,k]," ")
                sink()


        } #end l=1 loop

}       #end t loop

if(w[t,k]<(xcrit+1))
        {
                live=0
        }
else(live=1)

sink("successtally", append=TRUE)
for(i.star in 1:patches)
{
        cat(k," ",i.star," ",visits[i.star,k]," ", success[i.star,k], live,"\n")
}
sink()

sink("reserves", append=TRUE)
cat("\n")
sink()

sink("survival", append=TRUE)
cat(k, live, "\n")
sink()

}       #end k loop


reserves=read.table("reserves", header=TRUE)
successtally=read.table("successtally", header=TRUE)
patchchoice=read.table("patchchoice", header=TRUE)
reserves
successtally
patchchoice

#plot reserves at time t by run k
#pdf("reserveplots.pdf")  #uncomment to save to file
for(row in 1) plot(1:(tmax-1),reserves[row,],ylim=c(0,xmax),xlab="Time t",ylab="Energetic
reserves",main="Reserves at time t by run k",type="l",col=1)
for(row in 2:kmax) lines(1:(tmax-1),reserves[row,],type="l",col=row)
#dev.off()    #uncomment to save to file

#read patch successes only from file
```

```
#use kmax*patches so that can change kmax and number of patches easily
patch2success=successstally[seq(2,((kmax*patches)-1),by=patches),4]
patch3success=successstally[seq(3,(kmax*patches),by=patches),4]

#read patch visits from file
patch2visits=successstally[seq(2,((kmax*patches)-1),by=patches),3]
patch3visits=successstally[seq(3,(kmax*patches),by=patches),3]


#read simulation run # from file
simulation=successstally[seq(3,(kmax*patches),by=patches),1]

#make sure location is working
location=read.table("location", header=TRUE)
location

#record abandonment
abandon=read.table("abandon", header=TRUE)
abandon

summary<-
data.frame(simulation,patch2visits,patch3visits,patch4visits,patch2success,patch3success,pa
tch4success)
summary

mean(patch2visits)
var(patch2visits)
mean(patch2success)
var(patch2success)
mean(patch3visits)
var(patch3visits)
mean(patch3success)
var(patch3success)

sink("patch_successes", append=TRUE)
        cat("\nmean number of patch 2 successes in", tmax, "time steps\n")
        mean(patch2success)

        cat("variance in patch 2 success\n")
        var(patch2success)

        cat("\nmean number of patch 3 successes in", tmax, "time steps\n")
        mean(patch3success)

        cat("variance in patch 3 success\n")
        var(patch3success)

sink()


#plot successful trips by patch and simulation run
plot(simulation, patch2success, col="red", pch="2",  xlab="Simulation run", ylab="Number
```

```
successful trips to patch", ylim=c(0,tmax), xlim=c(0,kmax), main="Successful trips by patch")
points(simulation, patch3success, col="green", pch="3")

#plot time and state at abaondonment
plot(abandon[,2], abandon[,3], xlab="time step", ylab="state", xlim=c(0,tmax), ylim=c(0,xmax),
main="time and state at abandonment")

percentages=function()
{
#percentage of times abandon out of k simulations
cat("abandon", length(abandon[,1]), "out of", kmax, "simulations \n")
percentabandon=(length(abandon[,1]))/kmax*100
cat(percentabandon,"% of times abandon out of", kmax, "simulations \n")

#percentage of times survive out of k simulations where stay in region 1
stay=kmax-(length(abandon[,1]))
survive=read.table("survival", header=TRUE)
cat("survive", sum(survive[,2]), "out of", stay, "simulations where stay in region 1 \n")
percentsurvive=sum(survive[,2])/stay*100
cat(percentsurvive,"% survival out of", stay, "simulations where stay in region 1 \n")
}

cat(percentages())

#save to file information about what patch and parameters
sink("patch_explore", append=TRUE)
cat(mean(patch2visits)," ",var(patch2visits)," ",mean(patch2success)," ",var(patch2success),"
",mean(patch3visits)," ",var(patch3visits)," ",mean(patch3success)," ",var(patch3success),"
",alpha[3]," ",lambda[3]," ",benefit.bar[3],"\n")
sink()
```

APPENDIX 5

Sensitivity Analysis for DSVM

To conduct a sensitivity analysis, I held one patch's values constant, and then varied the others from zero to maximum (or high enough that increasing them further no longer made a difference). For example, holding the values of Patch 2 constant, I set $\alpha_3 = \alpha_2$ and $\beta_3 = \beta_2 + .002$, then for every value of λ from 0.1-0.9 I also cycled $\bar{y}$ from 1-14. Afterward, I changed α_3 and cycled through λ and $\bar{y}$ values again. This allowed me to see which parameters made the most difference in the decision matrix. The matrices I include here are both representative of the variety of results, and display the most interesting effects of changing the patch parameters. A summary of the results can be found in Chapter 7, Table 7.2.

In Figure 1, I show a decision matrix where Patch 2 is a much more desirable patch to exploit than Patch 3, as evidenced by Patch 3 only being the optimal choice when $t = 49$ and $x = 7$. Patch 1 is still considered a safe patch, where a forager can rest without possibility of predation, but will not acquire any food. In Table 1, I summarize the parameters for Patch 2 and 3, with the mortality rate and the cost of foraging being the same for both. The mean benefit and the actual benefit of catching prey are over twice as high in Patch 3 as in Patch 2, which if using a rate-maximizing model would indicate that Patch 3 should be a higher-ranked patch. Since the cost of foraging is the same, the mean benefit is essentially the same as an average return rate. However, Patch 2 has a higher probability of finding prey compared to Patch 3.

The dominance of Patch 2 as the optimal patch choice at most combinations of state and time suggests that the probability of finding prey appears to be a more important factor than mean benefit in determining an optimal patch.

Table 1. Parameters for decision matrix in Figure 1.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.7	0.5
$\overline{y}_i$ [mean benefit]	4	9
$\overline{y}_i$ / λ_i [benefit]	5.7	18
β_i [mortality rate]	.004	.004
α_i [cost of foraging]	2	2

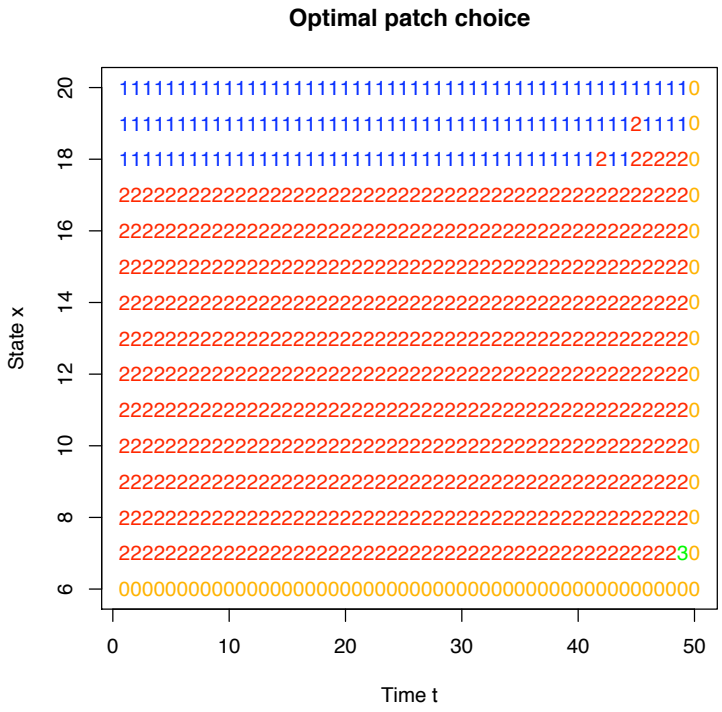


Figure 1. Decision matrix resulting from the parameters in Table 1.

I then left the mortality rate, cost of foraging, and mean benefit the same as in Figure 1, but increased λ for the result shown in Figure 2. This *decreases the variance* of the benefit of acquiring prey, but *does not change the mean benefit* (as the benefit equation makes possible). Similarly to Figure 1, despite the lower mean benefit in Patch 2, it is the optimal patch to exploit at almost every value of *x* and *t*. With the cost of foraging at $x = 2$, a forager only gains a net value of $x = 3.7$ when successfully foraging in Patch 2, a fairly low value in comparison with a net gain of x=13 when successful at exploiting Patch 3. A successful trip to Patch 3 will result in a state gain bringing the forager near or to $x_{\max}$. Yet, with its lower probability of finding prey (60% vs. 70%), Patch 3 suddenly becomes a less desirable decision for exploitation. However, Figure 2 also shows how the forager's knowledge of when her final fitness will be calculated affects her decision-making – as *t* approaches *T*, the possibility of a large state gain makes Patch 3 a more frequent optimal choice.

Table 2. Parameter values for Figure 2.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.7	0.6
$\overline{y}_i$ [mean benefit]	4	9
$\overline{y}_i$ / λ_i [benefit]	5.7	15
β_i [mortality rate]	.004	.004
α_i [cost of foraging]	2	2

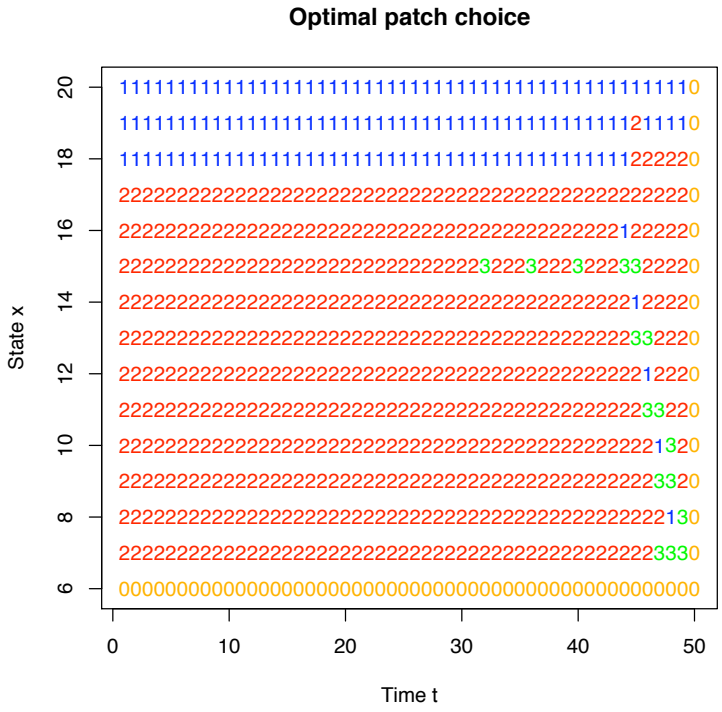


Figure 2. Decision matrix resulting from the parameters in Table 2.

As λ (the probability of finding prey) is increased further in Patch 3 by increments of .01, the patch becomes a more frequent optimal choice, until when $\lambda_3 = \lambda_2$, Patch 3 becomes the optimal choice for most times and states. This makes logical sense, because at that point the two patches are identical except for their

benefit values. A few 2's are still seen in the decision matrix at high values of *x* as the model approaches *T*, when the higher benefit of Patch 3 becomes unnecessary because it would put the forager so far over her highest possible state value. In such a context, both Patch 2 and 3 have the same fitness value, and I have written the model so the forager chooses Patch 2.

A slight shift of λ (Table 3) in both patches creates a very different matrix (Figure 3). The probability of finding prey has become 0.8 in Patch 2 and 0.7 in Patch 3, which also affects the benefit through the mean benefit equation. Because the probability of finding prey in each patch is now higher, and the mean benefit value has been left the same, the actual benefit from successfully exploiting a patch is now somewhat lower for both patches, though still much higher for Patch 3. The very different layout of this decision matrix suggests that, with mortality rate and foraging cost staying the same, there is a threshold above which the probability of finding prey is high enough to make mean benefit a more important variable at middle state values. In this case, once $\lambda_3 = 0.7$, Patch 3 becomes the better choice for exploitation at middle values of the forager's state, regardless of to what degree λ_2 is higher. The difference in λ is small, but enough so that Patch 2 is still the optimal choice at lower state values.

Table 3. Parameter values for Figure 3.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.8	0.7
$\overline{y}_i$ [mean benefit]	4	9
$\overline{y}_i$ / λ_i [benefit]	5	12.8
β_i [mortality rate]	.004	.004
α_i [cost of foraging]	2	2

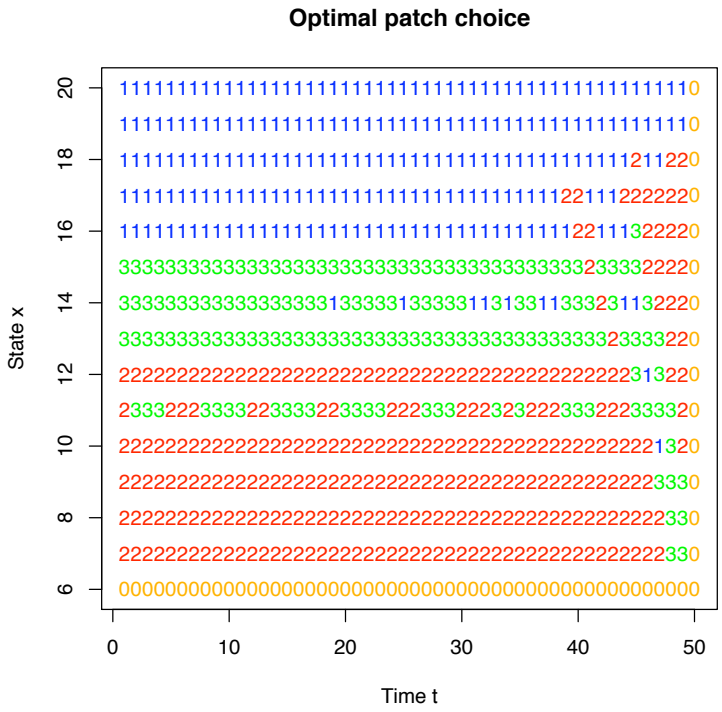


Figure 3. Decision matrix resulting from the parameters in Table 3.

In nature, patches may not always possess such comparable conditions. One variable that might differ is the cost or effort of hunting in a patch; for example, a forager might have to expend far more energy to chase deer than to watch a fishing line. From the parameters in Figure 3, I changed the cost of foraging in Patch 3 to

$\alpha_3 = 3$ instead of $\alpha_3 = 2$, and show in Figure 4 how Patch 3 very quickly again becomes much less attractive for exploitation. Patch 3 is still an optimal choice in some of the middle state values, leftover from that large block of 3's in Figure 3, and representing those few conditions when attempting the larger return is still appropriate.

Table 4. Parameter values for Figure 4.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.8	0.7
$\overline{y}_i$ [mean benefit]	4	9
$\overline{y}_i$ / λ_i [benefit]	5	12.8
β_i [mortality rate]	.004	.004
α_i [cost of foraging]	2	3

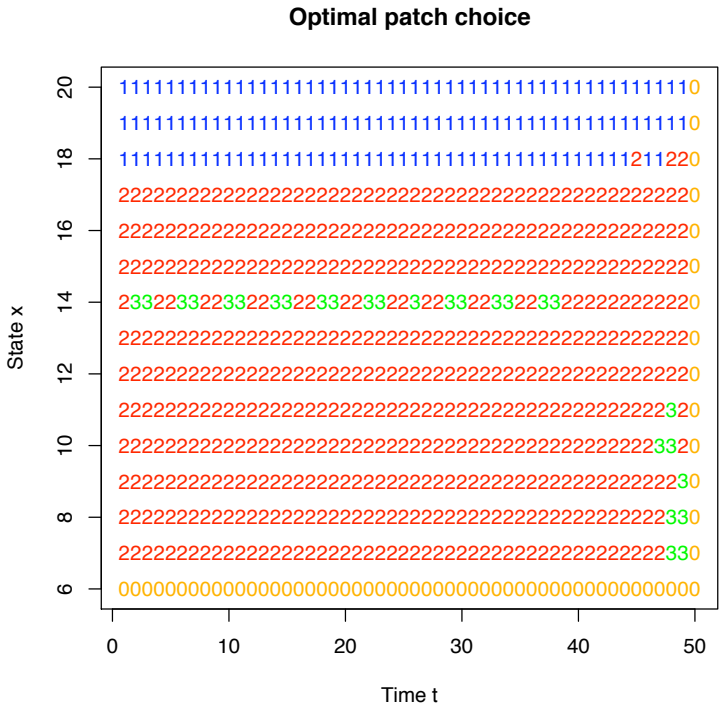


Figure 4. Decision matrix resulting from the parameters in Table 4.

If I keep the foraging costs for Patches 2 and 3 at slightly different levels, like they were for Figure 4, but set $\lambda = 0.7$ for both patches, the matrix again tells a very different story (Figure 5). When the probability of finding prey is the same in both patches, but Patch 3 costs a little bit more to exploit, the higher potential reward in Patch 3 is worth exploiting at middle or lower state values, whereas the patch with the lesser cost is chosen at upper or middle values. In essence, the forager is predicted to expend more energy only when the higher return will make a greater difference in her fitness. At lower levels of energetic reserves, it is more important for her to acquire the higher benefit to return to near-maximum values of state.

The alternating lines of optimal patch choice that can be seen in Figure 5 are most common when the probability of finding prey is the same in both Patch 2 and 3. In this particular case, the cost of foraging in Patch 2 is $x = 2$, so a forager starting at $x = 13$ will, if unsuccessful in all patch visits, stay in Patch 2 until $x = 7$. On the other hand, if she starts in Patch 3, where it costs $x = 3$ to forage, she will only stay in Patch 3 for one unsuccessful foraging try before moving to Patch 2 or starving. In each patch, a higher state value results in the forager having more fitness, but the places where fitness increases more quickly in each patch varies, which produces the alternating lines. In Table 6, I show the fitness value by state for each resource patch at $t = 1$. A graph can be found in Chapter 8, Figure 7.5, of the relationship in fitness between the two patches for $x = 7$ to $x = 12$, to emphasize the area of the decision matrix where the optimal patch choice fluctuates.

Table 5. Parameter values for Figure 5.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.7	0.7
$\overline{y}_i$ [mean benefit]	4	9
$\overline{y}_i$ / λ_i [benefit]	5.7	12.8
β_i [mortality rate]	.004	.004
α_i [cost of foraging]	2	3

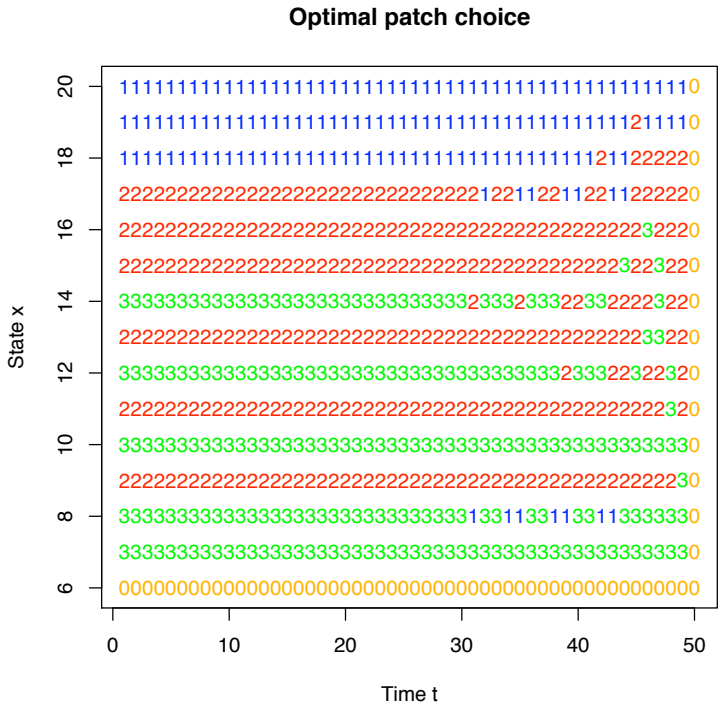


Figure 5. Decision matrix resulting from the parameters in Table 5.

Table 6. Fitness values for each state value in each patch, for Figure 5, at $t = 1$.

State	Patch 2	Patch 3
7	0.5970132	0.6300991
8	0.6097511	0.6311416
9	0.8069903	0.6321747
10	0.8120660	0.8219233
11	0.8679394	0.8224154
12	0.8745500	0.8750488
13	0.8897101	0.8795447
14	0.8929303	0.8933202
15	0.8983042	0.8954527
16	0.9005713	0.8997995
17	0.9024120	0.9009137
18	0.9030815	0.9024120
19	0.9036444	0.9030815
20	0.9040719	0.9036444

If I reduce the cost of foraging to $\alpha = 2$ for both patches, but raise the mortality rate slightly to $\beta = .006$ for Patch 3, a similar phenomenon emerges. Patch 3 becomes a very rare optimal choice, except for some middle values of x across the decision matrix, and lower state values as t approaches T. Once I raise mortality rates further, Patch 3 essentially disappears throughout the decision matrix.

As I show in Figure 6, if Patch 3 is riskier overall, with a lower probability of finding prey, a higher cost, and a higher mortality rate, but still has a much higher mean benefit, then Patch 3 becomes the optimal choice at low forager state levels. At those lower levels, a forager might be willing to take greater risks for greater rewards, agreeing with the general principle that an organism should prioritize low-variance resources when doing well, but, when desperate, be more prone to risk failure by pursuing high-variance, high-value resources (Mangel and Clark 1988).

Table 7. Parameter values for Figure 6.

Parameters	Patch 2	Patch 3
λ_i [prob finding prey]	0.8	0.7
$\bar{y}_i$ [mean benefit]	3	9
$\bar{y}_i$ / λ_i [benefit]	3.75	12.8
β_i [mortality rate]	.004	.008
α_i [cost of foraging]	2	3

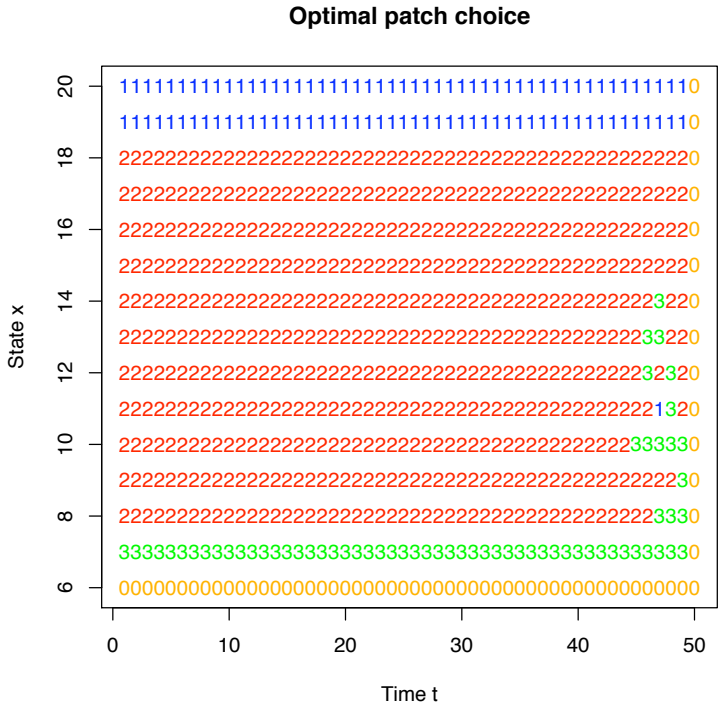


Figure 6. Decision matrix resulting from the parameters in Table 7.

Winterhalder et al. (1999) provided extensive summary tables showing how many organisms, including humans, appear to exhibit this risk sensitivity. In that sense, if the forager is close to starving, she might trade the lower probability of finding food for the possibility of drastically increasing her fitness. This is only true, however, if Patch 2 has a fairly low mean benefit – in this case it needs to be lowered to 3. Otherwise, Patch 3 is only a reasonable option as the model approaches *T*.

Abandoning a Region

Abandoning a region costs time, as in this model, no resources are collected during travel between foraging contexts. It also costs the forager in state, and is more costly to the energy reserves the longer the migration takes. The model is structured so that the forager cannot decide to abandon, if it will take her past the last time step.

In Figure 7, I show a forager's optimal decisions when Region B has fitness values competitive with the patches in Region A. The B's in the decision matrix represent the forager's choice to abandon Region A and move to Region B. In this case, Region B has a very high probability of finding prey, but the benefit of finding prey is only slightly higher than Patch 2. The rate of mortality and cost of foraging are the same in both prey patches and in Region B. The patterning of the decision matrix suggests that the probability of finding prey is high enough in Region B that the forager does not need to expend time and energy to get there until the model is approaching *T.* As the time horizon is reached, the forager is predicted to move to Region B where finding prey is almost guaranteed, thereby resulting in a higher expected fitness, even though the benefit from finding prey is much lower than in Patch 3. I predict that a forager will not abandon Region A when her energy reserves are low, because she requires a certain level to migrate and then to forage.

Table 8. Parameter values for Figure 7.

Parameters	Patch 2	Patch 3	Region B
λ_i [prob finding prey]	0.8	0.7	0.9
$\bar{y}_i$ [mean benefit]	4	9	6
$\bar{y}_i$ / λ_i [benefit]	5	12.86	6.67
β_i [mortality rate]	.004	.004	.004
α_i [cost of foraging]	2	2	2

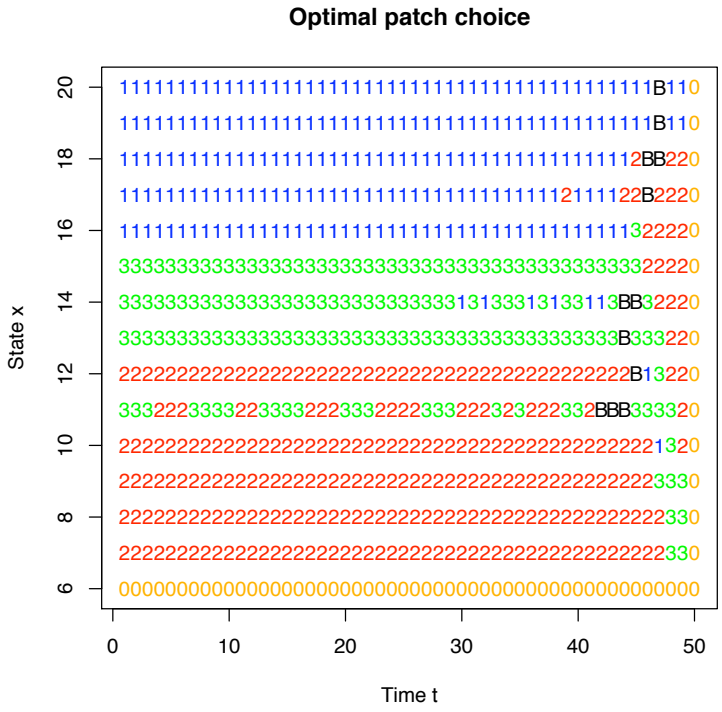


Figure 7. Decision matrix resulting from the parameters in Table 8. I set $t_m = \alpha_m = 2$.

When I decrease the probability of finding prey in both patches to make them less attractive, the forager is more frequently predicted to choose abandonment, especially at *lower* state values (Figure 8). Taking the time and energy to get to a region with a high probability of finding prey is a more reasonable trade-off when the

forager's current region has a poor probability of finding prey. However, she cannot leave Region A when her state levels are $x < 9$, because in this case, she would starve before reaching Region B. Note also that in Figure 8, the forager is predicted to *always* abandon at some point in a simulation run, unless she starves. If her initial state level is anywhere from 9-20 at $t = 1$, she is predicted to abandon Region A either after failing to successfully forage and eventually reaching $x = 9$, or if she is successful, she will eventually get close enough to the end of the simulation that she is predicted to abandon between $t = 40$ and $t = 47$. Because the cost of foraging in Patch 2 is set at $\alpha_2 = 2$ in this case, and the cost of staying in Patch 1 is $\alpha_1 = 1$, the forager's state value has no way of skipping from above to below that lowest line of B's in the matrix. If the forager's initial state level is $x = 7$ or $x = 8$, she could successfully forage in that first time step, and have her state level raised above $x = 9$, at which point the same criteria apply as if her state level was that high in the beginning. If she is unsuccessful at foraging, her state value is already so low that she is predicted to starve by $t = 2$.

As I increase the cost of migrating to Region B, the lower line indicating abandonment on the decision matrix moves further up. This is logical, because the forager has to have high enough energetic reserves to make the migration. In other words, the model underlines that a forager cannot move unless she has enough stored reserves to travel to the new locale and to search for prey once there. For example, under really poor environmental conditions, if the distance (cost) to better conditions is high, then migrating somewhere new will be especially difficult.

Table 9. Parameter values for Figure 8.

Parameters	Patch 2	Patch 3	Region B
λ_i [prob finding prey]	0.6	0.5	0.9
$\overline{y}_i$ [mean benefit]	4	9	6
$\overline{y}_i$ / λ_i [benefit]	6.67	18	6.67
β_i [mortality rate]	.004	.004	.004
α_i [cost of foraging]	2	2	2

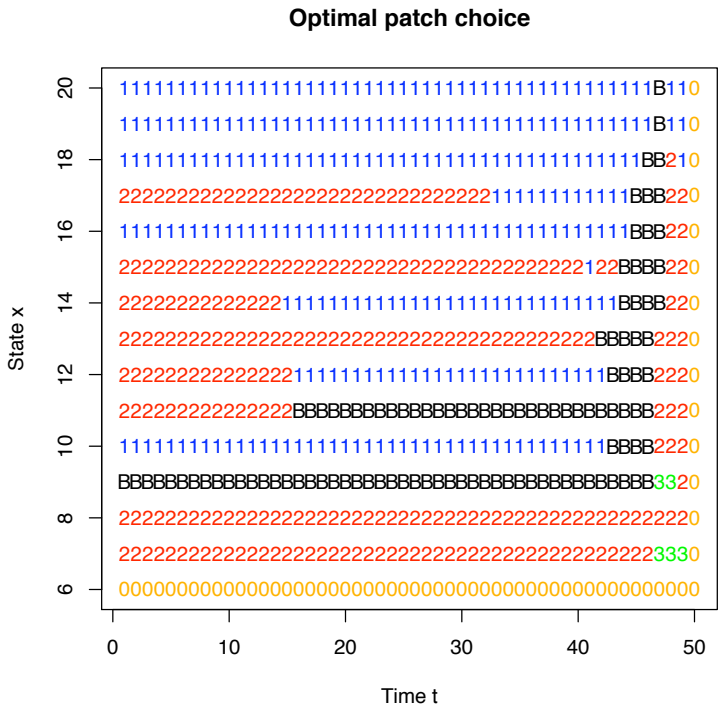


Figure 8. Decision matrix resulting from the parameters in Table 8. As in Figure 7, I set $t_m = \alpha_m = 2$.

Summary

These decision matrices show that the benefit from acquiring a resource is only one factor that can affect which patch a forager might choose to exploit, and is not necessarily the most important one. Even when a patch has a much higher benefit, another patch with more predictability, less danger, or less cost is likely to be chosen instead under most circumstances. While rate-maximization models assume that a forager will always experience a patch's *average* conditions, the stochastic component of the DSVM acknowledges that a forager will experience variability in such conditions and will make decisions in part knowing that a foraging trip might be unsuccessful.

These matrices also indicate that, *without any change in the resources themselves*, foragers have different optimal decisions, depending upon their own energetic state, a situation that rate-maximization models cannot take into account

APPENDIX 6

Zooarchaeological Results

I present here summary tables of my zooarchaeological results. Taxonomic data are available in Chapter 8 and are not replicated here. See Chapter 5 for further explanation of values used for each data category. The tables in this appendix are as follows:

Table 1a. Elements for estuary sites and MNT-112 through MNT-113D

Table 1b. Elements for remaining rocky shoreline sites and MNT-1701

Table 2. Portion (fragmentation)

Table 3. Landmarks

Table 4. Colors

Table 5. Pitting

Table 6. Rounding

Table 7. Deformation

Table 1a. NISP of elements for estuary sites and MNT-112 through MNT-113D. Elements are ordered alphabetically, sites geographically.

Element	MNT-228	MNT-229	MNT-234	MNT-112	MNT-113A	MNT-113B	MNT-113D
3rd vertebra	0	14	0	0	0	0	0
3rd vertebra lateral process	0	2	0	0	0	0	0
4th vertebra	0	15	0	0	0	0	0
4th vertebra lateral process	0	6	0	0	0	0	0
Angular	1	1	3	1	1	2	1
Articular	0	0	0	0	0	0	0
Atlas vertebra	7	45	10	8	0	6	15
Atlas/Axis vertebra	0	0	0	0	0	0	0
Axial neural crest	0	1	0	0	0	0	0
Axis vertebra	0	10	2	2	0	5	0
Basioccipital	2	4	3	5	1	3	3
Basipterygium	8	5	0	0	0	1	0
Branchial indeterminate	1	2	0	0	1	1	0
Branchiostegal ray	0	2	0	0	0	0	2
Caudal vertebra	85	528	153	59	9	74	18
Central tooth (bat ray)	0	0	6	0	0	0	0
Ceratohyal	0	2	3	0	0	0	0
Cleithrum	1	11	0	0	3	0	1
Coracoid	1	0	0	0	1	0	0
Dentary	0	1	0	1	0	0	2
Dentigerous bone	0	1	5	2	1	0	0
Ectopterygoid	0	0	0	0	0	0	1
Epibranchial	0	0	0	0	0	0	0
Epihyal	0	0	0	0	0	0	1
Epiotic	0	0	1	0	1	1	0
Ethmoid	0	0	0	0	0	0	0
Exoccipital	1	2	2	4	1	2	1
Fin ray	0	0	1	0	0	0	0
Fin spine	5	4	5	5	2	11	2
Frontal	0	0	0	0	0	0	0
Haemal spine (salmon)	1	0	0	0	0	0	0
Hyomandibular	1	2	0	0	1	1	3
Hypohyal	0	0	0	0	0	0	0
Hypural	1	1	0	0	0	0	0
Indeterminate element	22	45	52	9	19	10	5
Indeterminate ray/spine	0	0	0	0	0	0	0
Indeterminate ray/spine/rib	2	4	37	2	3	4	2
Interhaemal spine	0	1	0	0	0	0	0
Interopercle	0	0	1	0	0	0	0
Lateral tooth (bat ray)	3	0	12	0	0	0	0
Lower hypohyal	0	0	1	0	0	0	0
Lower pharyngeal	5	25	6	1	0	0	0
Maxilla	1	1	0	0	1	0	4
Metapterygoid	0	0	0	0	0	0	0
Neurocranium fragment	3	1	6	0	1	0	2

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Table 1a. (continued)

Element	MNT-228	MNT-229	MNT-234	MNT-112	MNT-113A	MNT-113B	MNT-113D
Opercle	2	1	0	0	0	0	2
Orbitosphenoid	0	0	0	0	0	0	0
Otolith	0	0	3	0	0	0	0
Palatine	0	0	0	0	2	1	2
Parasphenoid	0	1	4	0	0	0	0
Parietal	0	0	0	0	0	0	0
Penultimate vertebra	2	14	4	0	0	1	0
Pharyngeal plate	0	0	0	0	0	0	0
Pharyngeal plate (lower/upper indet)	0	1	0	0	0	0	0
Pharyngeal tooth	2	1	28	1	0	1	0
Pharyngobranchial	0	0	0	0	0	0	0
Pharyngobranchial (upper pharyngeal)	0	2	5	0	0	0	0
Possibly identifiable	0	0	0	0	0	0	0
Postcleithrum	0	0	0	0	0	0	0
Postcleithrum (lower)	0	0	0	0	0	0	0
Postcleithrum (upper)	0	0	0	0	0	0	0
Posttemporal	4	0	0	1	0	4	0
Precaudal vertebra	76	525	103	68	12	85	37
Prefrontal	0	0	0	1	0	0	0
Premaxilla	0	0	1	0	2	1	5
Preopercle	0	0	1	0	1	0	3
Prootic	4	1	0	0	0	0	1
Pterosphenoid	0	0	0	0	0	0	0
Pterotic	1	1	0	0	0	0	0
Pterygiophore	1	1	2	0	3	0	3
Quadrate	1	0	2	2	0	2	2
Radial	0	0	0	0	1	0	0
Retroarticular	0	0	0	0	0	0	0
Scale	0	0	26	0	0	0	0
Scapula	0	6	2	1	1	0	0
Scute	0	1	1	0	0	0	0
Sphenotic	0	1	0	0	0	0	0
Subopercle	0	0	0	0	0	0	0
Suborbital	0	0	0	0	0	0	0
Supracleithrum	1	1	0	0	0	0	0
Supramaxilla	0	0	0	0	0	0	0
Supraoccipital	0	0	0	0	0	0	0
Thoracic vertebra	9	15	15	23	0	21	0
Tooth	0	2	1	0	0	1	0
Ultimate vertebra	0	7	3	1	2	2	0
Unidentifiable	0	0	0	0	0	0	0
Urohyal	0	2	2	0	2	0	0

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Table 1a. (continued)

Element	MNT-228	MNT-229	MNT-234	MNT-112	MNT-113A	MNT-113B	MNT-113D
Uroneural	0	0	1	0	0	0	0
Ventral hypural	0	0	0	0	0	0	0
Ventral hypural (sardine)	0	0	2	0	0	0	0
Vertebra 2 and 3	0	3	0	0	0	0	0
Vertebra 3 or 4	0	11	0	0	0	0	0
Vertebra indeterminate	12	116	82	19	3	24	8
Vertebral spine (unfused, salmon)	0	2	0	0	0	0	0
Vomer	0	1	4	0	1	0	0
Total	266	1452	601	216	76	264	126

Table 1b. NISP of elements for remaining rocky shoreline sites and MNT-1701. Elements are ordered alphabetically, sites geographically.

Element	MNT-831	MNT-125	MNT-170	MNT-834B	MNT-17	MNT-1701
3rd vertebra	0	0	0	0	0	0
3rd vertebra lateral process	0	0	0	0	0	0
4th vertebra	0	0	0	0	0	0
4th vertebra lateral process	0	0	0	0	0	0
Angular	7	1	3	11	5	9
Articular	0	0	0	1	0	0
Atlas vertebra	71	0	21	22	156	105
Atlas/Axis vertebra	0	0	0	0	0	6
Axial neural crest	0	0	0	0	0	0
Axis vertebra	7	0	0	2	3	106
Basioccipital	16	0	4	11	18	27
Basipterygium	2	0	0	3	0	6
Branchial indeterminate	7	0	2	8	11	0
Branchiostegal ray	7	0	2	11	2	0
Caudal vertebra	520	5	75	343	572	1906
Central tooth (bat ray)	0	0	0	0	0	0
Ceratohyal	1	0	0	8	2	0
Cleithrum	0	0	0	4	0	0
Coracoid	0	0	0	7	0	0
Dentary	5	0	3	21	14	6
Dentigerous bone	12	0	8	0	17	0
Ectopterygoid	1	0	0	1	2	0
Epibranchial	2	0	0	0	0	0
Epihyal	3	0	1	9	7	0
Epiotic	4	0	0	8	4	0
Ethmoid	2	0	0	0	1	0
Exoccipital	3	0	3	8	5	1
Fin ray	6	0	3	2	12	3
Fin spine	51	0	6	21	41	5
Frontal	2	0	0	2	1	2
Haemal spine (salmon)	0	0	0	0	0	0
Hyomandibular	6	0	1	28	7	3
Hypohyal	0	0	0	3	0	0
Hypural	8	0	2	7	4	1
Indeterminate element	265	9	150	251	354	196
Indeterminate ray/spine	0	0	0	2	0	0
Indeterminate ray/spine/rib	75	0	36	58	34	30
Interhaemal spine	0	0	0	0	0	0
Interopercle	0	0	0	0	1	0
Lateral tooth (bat ray)	0	0	0	0	0	0
Lower hypohyal	2	0	0	0	0	0
Lower pharyngeal	1	0	0	13	3	0
Maxilla	10	0	0	11	6	3
Metapterygoid	0	0	0	1	0	1
Neurocranium fragment	2	0	0	1	3	0

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Table 1b. (continued)

Element	MNT-831	MNT-125	MNT-170	MNT-834B	MNT-17	MNT-1701
Opercle	2	0	1	19	6	8
Orbitosphenoid	0	0	0	0	0	1
Otolith	0	0	0	1	2	0
Palatine	2	0	2	9	4	0
Parasphenoid	2	0	0	3	5	2
Parietal	3	0	0	1	2	0
Penultimate vertebra	14	0	3	14	8	0
Pharyngeal plate	0	0	0	0	1	0
Pharyngeal plate (lower/upper indet)	0	0	0	2	0	0
Pharyngeal tooth	9	0	5	28	15	1
Pharyngobranchial	0	0	0	5	3	0
Pharyngobranchial (upper pharyngeal)	0	0	0	4	0	0
Possibly identifiable	17	0	0	3	0	0
Postcleithrum	0	0	0	1	3	1
Postcleithrum (lower)	1	0	1	0	0	0
Postcleithrum (upper)	1	0	0	0	0	0
Posttemporal	11	0	0	12	4	9
Precaudal vertebra	606	5	114	374	724	2575
Prefrontal	0	0	0	3	0	0
Premaxilla	16	1	0	11	9	0
Preopercle	0	0	0	5	4	1
Prootic	2	0	0	2	4	10
Pterosphenoid	0	0	0	0	0	1
Pterotic	0	0	0	3	0	0
Pterygiophore	14	0	2	19	9	4
Quadrate	10	1	3	18	6	1
Radial	4	0	2	9	3	1
Retroarticular	1	0	0	3	0	0
Scale	22	0	0	4	29	944
Scapula	2	0	1	7	1	0
Scute	0	0	0	0	0	0
Sphenotic	0	0	0	3	3	0
Subopercle	0	0	0	2	2	3
Suborbital	1	0	0	1	6	0
Supracleithrum	2	0	1	11	6	10
Supramaxilla	0	0	0	0	0	3
Supraoccipital	1	0	0	1	0	1
Thoracic vertebra	98	0	3	23	92	1640
Tooth	3	0	0	3	11	0
Ultimate vertebra	15	0	3	12	27	31
Unidentifiable	0	0	0	2	0	0
Urohyal	2	0	1	19	6	8

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Table 1b. (continued)

Element	MNT-831	MNT-125	MNT-170	MNT-834B	MNT-17	MNT-1701
Uroneural	1	0	1	1	0	0
Ventral hypural	0	0	0	0	0	18
Ventral hypural (sardine)	0	0	0	0	0	13
Vertebra 2 and 3	0	0	0	0	0	0
Vertebra 3 or 4	0	0	0	0	0	0
Vertebra indeterminate	341	2	72	114	664	54
Vertebral spine (unfused, salmon)	0	0	0	0	0	0
Vomer	6	1	1	6	2	0
Total	2305	25	535	1617	2940	7748

Table 2. NISP of portion categories by site. Sites are ordered geographically. CO = complete, FR = fragment.

Site number	CO	FR	NA
CA-MNT-228	213	32	21
CA-MNT-229	1248	146	58
CA-MNT-234	391	89	121
CA-MNT-112	179	25	12
CA-MNT-113A	36	16	24
CA-MNT-113B	202	47	15
CA-MNT-113D	79	35	12
CA-MNT-831	1456	444	405
CA-MNT-125	12	4	9
CA-MNT-170	244	93	198
CA-MNT-834B	1017	262	338
CA-MNT-17	1813	673	454
CA-MNT-1701	6337	238	1173
Total	13227	2104	2840

Table 3. NISP of landmark presence/absence by site. Sites are ordered geographically.

Site number	Y	N	0
CA-MNT-228	237	8	21
CA-MNT-229	1299	98	55
CA-MNT-234	421	61	119
CA-MNT-112	193	12	11
CA-MNT-113A	46	6	24
CA-MNT-113B	224	25	15
CA-MNT-113D	104	12	10
CA-MNT-831	1614	294	397
CA-MNT-125	12	4	9
CA-MNT-170	272	67	196
CA-MNT-834B	1161	174	282
CA-MNT-17	1906	588	446
CA-MNT-1701	6399	182	1167
Total	13888	1531	2752

Table 4. NISP of specimen colors by site. Colors are ordered alphabetically, sites geographically.

Bone Color	CA-MNT-228	CA-MNT-229	CA-MNT-234	CA-MNT-112	CA-MNT-113A	CA-MNT-113B	CA-MNT-113D	CA-MNT-831	CA-MNT-125	CA-MNT-170	CA-MNT-834B	CA-MNT-17	CA-MNT-1701
Black	1	38	19	6	0	6	5	68	2	18	43	57	90
Bluish gray (gley chart)	1	3	0	0	0	4	0	17	0	4	11	10	0
Brown	8	104	2	12	1	11	6	263	0	26	38	106	157
Brownish yellow	27	175	222	29	7	17	5	193	1	54	326	507	261
Dark bluish gray (gley chart)	0	1	0	1	0	0	0	8	0	1	1	0	0
Dark brown	1	23	0	6	0	2	2	55	1	8	10	15	53
Dark gray	1	15	0	0	0	3	0	12	0	0	30	32	55
Dark gray (gley chart)	0	0	0	0	0	0	0	0	0	0	1	0	0
Dark grayish brown	1	19	0	4	0	1	3	40	0	6	15	59	106
Dark yellowish brown	9	50	5	23	10	11	4	176	4	32	17	35	528
Gray	0	1	0	0	0	0	1	12	0	0	7	18	9
Grayish brown	0	1	0	0	0	1	0	3	0	1	16	28	8
Light bluish gray (gley chart)	0	0	0	0	0	7	0	4	0	2	2	12	0
Light brown	0	24	0	2	0	5	2	59	0	0	5	0	0
Light brownish gray	0	0	0	0	0	0	0	1	0	0	0	10	60
Light gray	0	3	0	0	0	1	0	6	0	1	15	3	5
Light gray (gley chart)	0	0	0	0	0	0	0	0	0	0	0	1	0
Light yellowish brown	34	148	60	12	3	31	4	122	1	29	173	184	191
N/A	1	2	0	0	0	0	0	0	0	0	0	0	0
Pale brown	0	4	1	0	0	0	0	5	0	4	61	43	10
Pale yellow	0	1	0	0	0	0	0	0	0	0	0	0	0
Pink	0	11	0	0	0	4	2	11	0	0	1	0	0
Pinkish gray	0	0	0	0	0	0	0	1	0	0	0	0	0
Reddish yellow	1	64	0	20	2	23	25	99	0	0	20	0	0
Strong brown	0	33	1	19	13	22	46	132	0	14	17	1	0

(continued on next page)

Table 4. (continued)

Bone Color	CA-MNT-228	CA-MNT-229	CA-MNT-234	CA-MNT-112	CA-MNT-113A	CA-MNT-113B	CA-MNT-113D	CA-MNT-831	CA-MNT-125	CA-MNT-170	CA-MNT-834B	CA-MNT-17	CA-MNT-1701
Very dark brown	1	2	4	0	0	0	0	13	0	11	4	3	2
Very dark gray	0	30	1	2	0	6	1	42	0	4	18	25	42
Very dark gray (gley chart)	0	0	0	0	0	1	0	0	0	0	0	0	0
Very dark grayish brown	0	22	1	7	0	6	2	131	0	14	13	37	167
Very pale brown	73	154	88	10	3	16	3	169	0	25	186	689	3237
White	1	57	1	4	0	19	0	197	0	21	57	62	11
Yellow	14	139	125	8	2	3	0	47	1	7	159	665	1532
Yellowish brown	92	328	71	51	35	64	15	419	15	253	371	338	1224
Total	266	1452	601	216	76	264	126	2305	25	535	1617	2940	7748

Table 5. NISP of pitting intensity by site. Sites are ordered geographically.

Site Number	None	Light	Medium	Heavy	NA	Total
CA-MNT-228	233	2	0	0	31	266
CA-MNT-229	1197	25	5	0	225	1452
CA-MNT-234	449	4	0	0	148	601
CA-MNT-112	159	23	2	0	32	216
CA-MNT-113A	34	7	2	2	31	76
CA-MNT-113B	186	8	0	0	70	264
CA-MNT-113D	82	16	2	0	26	126
CA-MNT-831	1381	86	3	1	834	2305
CA-MNT-125	13	2	0	0	10	25
CA-MNT-170	250	38	1	0	246	535
CA-MNT-834B	972	69	3	0	573	1617
CA-MNT-17	1581	554	45	4	756	2940
CA-MNT-1701	6109	77	0	0	1562	7748
Total	12646	911	63	7	4544	18171

Table 6. NISP of rounding intensity by site. Sites are ordered geographically.

Site Number	None	Light	Medium	Heavy	NA	Total
CA-MNT-228	207	14	10	4	31	266
CA-MNT-229	1059	90	37	41	225	1452
CA-MNT-234	347	61	32	13	148	601
CA-MNT-112	137	21	9	17	32	216
CA-MNT-113A	45	0	0	0	31	76
CA-MNT-113B	129	29	17	19	70	264
CA-MNT-113D	67	23	2	8	26	126
CA-MNT-831	777	285	248	161	834	2305
CA-MNT-125	15	0	0	0	10	25
CA-MNT-170	234	37	18	0	246	535
CA-MNT-834B	822	123	56	43	573	1617
CA-MNT-17	1321	385	328	146	760	2940
CA-MNT-1701	5841	272	55	18	1562	7748
Total	11001	1340	812	470	4548	18171

Table 7. NISP of deformation intensity by site. Sites are ordered geographically.

Site Number	None	Light	Medium	Heavy	NA	Total
CA-MNT-228	224	5	5	1	31	266
CA-MNT-229	1189	30	7	1	225	1452
CA-MNT-234	439	11	3	0	148	601
CA-MNT-112	183	1	0	0	32	216
CA-MNT-113A	43	2	0	0	31	76
CA-MNT-113B	193	1	0	0	70	264
CA-MNT-113D	98	2	0	0	26	126
CA-MNT-831	1452	18	1	0	834	2305
CA-MNT-125	14	0	1	0	10	25
CA-MNT-170	287	1	1	0	246	535
CA-MNT-834B	1021	17	6	0	573	1617
CA-MNT-17	2143	28	9	0	760	2940
CA-MNT-1701	6149	23	13	1	1562	7748
Total	13435	139	46	3	4548	18171

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