Title

Exploring Methods of Faunal Analysis: Insights from California Archaeology

ISBN

978-1-931745-87-1

Publication Date

2012

EXPLORING METHODS OF FAUNAL ANALYSIS

Insights from California Archaeology

edited by Michael A. Glassow and Terry L. Joslin

Perspectives in California Archaeology
Volume 9
Series Editor: Jeanne E. Arnold

Cotsen Institute of Archaeology
University of California, Los Angeles

EXPLORING METHODS OF FAUNAL ANALYSIS:

INSIGHTS FROM CALIFORNIA ARCHAEOLOGY

UCLA COTSEN INSTITUTE OF ARCHAEOLOGY PRESS

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EDITED BY

MICHAEL A. GLASSOW AND TERRY L. JOSLIN

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COTSEN INSTITUTE OF ARCHAEOLOGY
UNIVERSITY OF CALIFORNIA, LOS ANGELES

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This book is set in 10.5-point Janson Text, with titles in 28-point Janson Text.
Designed by William Morosi
Edited by Carol Leyba

Library of Congress Cataloging-in-Publication Data
Exploring methods of faunal analysis : insights from California archaeology / edited by Michael A. Glassow and Terry L. Joslin.
p. cm. -- (Perspectives in California archaeology ; volume 9)
ISBN-13: 978-1-931745-87-1 (pbk.)
ISBN-10: 1-931745-87-0 (pbk.) ISBN: 978-1-938770-53-1 (eBook)
1. Animal remains (Archaeology)--California. 2. Archaeology--Research--California. 3. California--Antiquities. I. Glassow, Michael A. II. Joslin, Terry L.

CC79.5.A5E97 2011
979.4'01--dc23

2011037803

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Preface

This volume grew out of a session organized for the 2006 conference of the International Council for Archaeozoology (ICAZ), held in Mexico City and hosted by the Escuela Nacional de Conservación, Restauración y Museografía. Some of the papers in this volume were presented at this conference and subsequently expanded and in some cases extensively revised. After the conference, we solicited contributions to this volume from a number of colleagues who had not attended the conference but were involved in analysis of faunal remains. Five of the papers are the result of this invitation.

Our intent in organizing both the symposium and this volume was to bring attention to methodological issues of archaeozoology facing prehistoric archaeologists working in California. In recent years, we became increasingly aware of a variety of issues concerning the analysis of faunal remains, and we saw a need to bring them to the attention of our colleagues and stimulate discussion. Issues discussed in this volume concern the sources of sample bias and how to compensate for such bias, appropriate units of analysis and techniques of quantitative analysis, the importance not only of large and diverse reference collections but also of information on the natural history of the fauna represented in an assemblage, and, most importantly, how methods link to research issues of concern to California archaeology generally.

Although the ICAZ conference session was focused on coastal California, for this volume we felt that expanding the geographic scope to include interior regions made good sense. Nonetheless, the geographic bias remains on the coast, in large part the result of the greater amount of archaeological investigation that takes place in coastal and near-coastal areas of the state. This trend is due to the greater emphasis of cultural resource management projects, which generated many of the faunal collections considered in this volume, on the more densely occupied coastal zones of the state. At the same time, faunal assemblages from prehistoric sites in coastal settings typically are more diverse than those from interior areas because of their inclusion of remains of both terrestrial and marine fauna. Faunal remains are typically denser as well, due to greater prehistoric population density and relatively more sedentary settlement patterns. Also a contributing factor: assemblages in coastal sites often are better preserved due to the presence of substantial amounts of marine shells that lower the acidity of the soil matrix of archaeological deposits.

This volume would have never come to fruition without the hard work and dedication of many individuals. We express our sincere gratitude to our colleagues for contributing papers to this volume. We thank them for their patience, graciously responding to our comments, and meeting deadlines. We also thank those colleagues not represented among the chapter authors who have shared data, reviewed manuscripts, and inspired new ways of looking at our research. We appreciate all the help and advice we received from the staff at the Cotsen Institute of Archaeology with whom we interacted, including Shauna Mecartea, Eric Gardner, and Julie Nemer. In particular Julie's efforts were significant in the final push to complete this volume. We wish to recognize Series Editor Jeanne Arnold for her dedication to the Perspectives in California Archaeology series, and the Cotsen Institute of Archaeology's editorial board for their commitment to publishing significant California research. Two anonymous reviewers of the volume provided comments on the draft chapters that greatly improved the content of all chapters. Finally, we wish to recognize the role of prehistoric Native Californians for leaving us with a remarkable record of their use of animals.

CHAPTER 1

Introduction

MICHAEL A. GLASSOW AND TERRY L. JOSLIN

Faunal analysis as practiced today in California is a relatively recent development. Senior archaeologists working in the state can remember the days when only casual attention was devoted to faunal remains, reflecting the situation throughout much of the nation and beyond. Fifty-plus years ago, common practice was to save only complete or relatively large fragments of shells or bones, if any at all. Archaeologists of that time may have included in their publications lists of taxa of identified faunal remains, and some went so far as to indicate frequencies of remains pertaining to each taxon. The only analytical meaning attached to such lists would be that certain fauna were dietary constituents or that particular habitats were important in food resource acquisition. Despite this convention, a few studies stand out as significant exceptions. Howard's (1929) analysis of avifaunal remains from the Emeryville Shellmound on the perimeter of San Francisco Bay (discussed by Wake in this volume) and Lyon's (1937) analysis of sea mammal bones from a major village site at Point Mugu are noteworthy examples, although these two scholars were biologists not archaeologists. Nonetheless, archaeologists active 50 years ago were becoming aware of the potential of faunal analysis as a result of a few key publications, including Cornwall's (1956) *Bones for the Archaeologist* and various publications of T. E. White (1952, 1953a, 1953b, 1954, 1955a, 1955b).

Influential publications that highlighted the potential of zooarchaeology in California were Meighan and his colleagues' (1958) "Ecological Interpretation in Archaeology: Part I" and Meighan's (1959) "The Little Harbor Site, Catalina Island: An Example of Ecological Interpretation in Archaeology." The former publication set out a program for systematically collecting and processing faunal remains (and other subsistence remains) and interpreting data derived from them. The latter essentially implemented the program, and as Gifford-Gonzalez and Hildebrandt point out in this volume, it served as a model with various refinements for students of archaeology in the 1960s, who also gained inspiration from some earlier identification guides produced by Olsen (1964, 1968, 1972a, 1972b).

Since Meighan's seminal publications, California archaeologists have become increasingly more sophisticated in the analysis of faunal remains, a development paralleling that in archaeology generally. Beginning in the 1970s, guidance in taxonomic identification of bones and analysis of data derived from them became available in such works as Chaplin (1971), Casteel (1976b), Binford (1981), Klein and Cruz-Uribe (1984), Grayson

(1984), Hesse and Wapnish (1985), Gilbert (1990), Lyman (1994b, 2008), O'Connor (2000); and Reitz and Wing (1999). Much less attention has been devoted to analysis of shellfish remains, undoubtedly because shells require less effort and expertise in identification and generation of useful data. Nonetheless, Waselkov's (1987) treatment of the analysis of shellfish remains helped expand understanding of their research potential, and it served as an influential precursor to Claassen's (1998) more thorough coverage. Of particular interest to California archaeologists are issues revolving around generation of data from shellfish remains and the meaning of these data, topics that have generated some debate (Claassen 2000; Glassow 2000; Mason et al. 1998, 2000).

Over the last four decades, hundreds of analyses of faunal remains have taken place in the context of cultural resource management projects, and the results typically are presented in sections or chapters in technical reports. Although these analyses vary considerably in scope and quality, they reflect the potential of faunal remains to address important research issues in California archaeology, and the data they present have considerable potential for comparative analysis. Some of the faunal analyses are quite sophisticated and innovative, and they deserve to be seen by a wider audience than is typical of such reports. An example is Serena's analysis of shellfish remains obtained from a group of sites on northern Vandenberg Air Force Base. His analysis focused on "the intensity and diversity of shellfish exploitation at sites in different locations occupied during different chronological periods" (1984:9–100). Access to technical reports containing results of faunal analyses generally requires visiting one or more of the regional information centers scattered throughout the state. Some information centers are beginning to convert paper copies of the reports in their files into digital versions (generally searchable PDF files), and once this conversion is completed, access will be greatly improved.

The contributions to this volume exemplify the accomplishments of faunal analysis during the last few decades, and the different categories of faunal remains considered are generally representative of those encountered in California site deposits. Given the coastal focus of most of the contributions to this volume, a variety of marine resource remains are considered. These include bones of pinnipeds, sea otters, and marine fishes, and shells of both marine and estuarine shellfish. Nonetheless, coastal sites also contain remains of terrestrial mammals, deer and rabbit bones being the most commonly occurring, and of course these animals are also well represented among the remains from inland sites. The contributions dealing with faunal assemblages from central and northern California also consider other large game animals, such as antelope and elk, which also occasionally occur in southern California faunal assemblages. Despite the ubiquity of shellfish remains in coastal and near-coastal sites, they are given specific attention in only two of the contributions. This seeming neglect certainly is not purposeful, and we acknowledge that analysis of shellfish remains deserves a good deal more attention than what is represented in this volume. In fact, it is easy to imagine a volume similar this one devoted just to methods of analysis of shellfish remains.

Significantly, the contributors to this volume represent varying degrees of specialization in zooarchaeology. Some are widely recognized specialists in zooarchaeology, whereas others are generalists who focus a good deal of their attention to particular aspects of faunal analysis. The latter category is large within California, and in fact most California archaeologists have at least some competency in the taxonomic identification of faunal remains that commonly occur at the kinds of sites they typically investigate. Indeed, it makes sense that any archaeologist should be able to identify major taxonomic categories of faunal remains, simply because archaeologists are often faced with the task of sorting into categories faunal remains that will be handed over to zooarchaeological specialists for analysis, and archaeologists must be aware of the kinds of information that zooarchaeologists can contribute to meeting the general goals of an archaeological project.

The availability of training in zooarchaeology, however, is quite variable across the state. Most university-level undergraduate training programs in archaeology in California offer at least elementary training in basic taxonomic identification of faunal remains typically occurring in California prehistoric sites. Only a few programs, however, offer formal training in zooarchaeology; programs at California State University, Chico; University of California, Davis; University of California, Santa Barbara; University of California, Santa Cruz; and University of California, Los Angeles, are well known. A number of other academic programs in archaeology have faculty members with expertise in zooarchaeology, even if formal courses in the subject are not offered or are offered on an irregular basis.

We hope the contributions in this volume will stimulate a greater interest in zooarchaeology among both practicing and aspiring California archaeologists. Faunal remains of shellfish and/or vertebrates are abundant in many California site deposits, particularly at sites in the more arid portions of the state. Consequently, there is considerable potential to generate large and diverse assemblages that some sophisticated forms of analysis require. As well, significant collections of faunal remains from California sites exist in collections repositories. Many of these collections have been the subject of only superficial or narrowly focused analysis and are worthy of much more attention. In other words, California zooarchaeologists have the resources to become major contributors to the development of new methods for deriving useful information from faunal remains, and to the refinement of existing methods.

The methodological issues considered in this volume demonstrate the relevance of data from faunal remains to a wide variety of research domains prominent in California archaeology. The majority of the contributions exemplify how faunal remains may be used to elucidate subsistence and settlement systems, which is the most common application of faunal data. Other contributions demonstrate the value of faunal data to the investigation of technological systems, economic exchange systems, adaptation to geographic and temporal variability in resource distribution and abundance, social organization, and impacts of historic land use and development on fauna. The study of faunal remains truly is a fundamental source of information about California's prehistoric past.

CHAPTER 2

Interpreting New Samples from Famous Old Sites:

Mammal Remains from the 1999 Emeryville Shellmound Excavations (CA-ALA-309 and CA-ALA-310), with Comments on Fish and Birds

THOMAS A. WAKE

The San Francisco Bay was once ringed with a series of large shellmounds, some measuring up to 20 m in height. Nels Nelson had recorded 425 mounded bayshore archaeological sites by 1909, and more have been discovered since. Each of the excavated mounds contained human burials; various features including ovens; activity areas and surfaces; vertebrate, invertebrate, and plant food remains; and a plethora of stone, bone, and shell artifacts. Prior to urbanization, many of the bayshore mounds were surrounded by wet marshes during the winter months (e.g., see Nelson 1910:369).

Mound building began at least 4,500 years ago, based the earliest dates from East Bay mounds such as the West Berkeley Mound (ALA-307) and the Ellis Landing Shellmound (CCO-295) (Lightfoot 1997; Lightfoot and Luby 2002). While there is considerable variation in size, location, and period of occupation, most of the known bayshore mounds or mound clusters are interpreted as representing small to large villages. All the excavated bayshore shellmounds have produced complicated stratigraphic records indicating extensive depositional histories. It is generally assumed that each of these mounds represents more or less continuous, long-term occupation, in some cases (ALA-307, ALA-309, ALA-329, CCO-269) spanning several thousand years (Lightfoot 1997; Lightfoot and Luby 2002). Lightfoot (1997:139) states four reasons Bay Area inhabitants produced mounds as opposed to broadly dispersed middens: (1) mounds were constructed to keep villages above high tides; (2) mounds were constructed as optimal locations for exploiting local estuarine (and terrestrial) resources; (3) mounds were constructed as long-term repositories for the dead; and (4) mounds were constructed as territorial symbols for local communities. Bayshore villages may have justified their territorial rights to local land and resources by claiming descent relationships to their ancestors buried in respective mounds (Lightfoot 1997:139). Along the East Bay shore, many of these mounds were in sight of one another, and smoke rising from any fires tended on them might signal occupancy and could be seen from afar.

The Emeryville Shellmound (CA-ALA-309) was one of the most prominent prehistoric shellmounds ringing the late Holocene shores of San Francisco Bay before it was leveled in 1924 (Nelson 1909; Schenck 1926; Uhle 1907). Located close to the historic mouth of Temescal Creek, the mound itself was approximately 20 m high and roughly 120 m in diameter. ALA-309 was occupied for more than 3,000 years and has yielded radiocarbon dates ranging from approximately 2800 B.P. to nearly 700 B.P.

A smaller low mound, distinct in time and space from ALA-309 but clearly associated with the larger mound, is known simply as CA-ALA-310. This site is located to the southwest of the Emeryville Shellmound, a bit closer to the bay shore and Temescal Creek. The site occupation was relatively recent, dating to a roughly 200-year period from 300 to 550 B.P. Most of the radiocarbon dates range between 350 and 550 B.P.

Archaeological investigations of the Emeryville Shellmound by Max Uhle (1907), Nels Nelson (Broughton 1996), and Egbert Schenck (1926) demonstrated its complexity and considerable time depth. The site is historically important because it was one of the first large sites in the western United States to be excavated stratigraphically (Uhle 1907). In fact, Uhle and Nelson, both influenced by the work of Jens Worsaae, were instrumental in introducing stratigraphic excavation techniques to North American archaeology. Both Uhle (1907) and Schenck (1926) report and illustrate the wealth of late Holocene material culture recovered from the Emeryville Shellmound.

Investigators such as Hildegarde Howard (1929) demonstrated that a similar wealth of archaeological and environmental data could be derived from vertebrate faunal remains recovered from Uhle's and Schenk's excavations. She was able to reconstruct the shellmound's past avifauna and environment, and she showed, based on the presence of many juvenile cormorant remains, that information concerning season of occupation was available. Recently, Jack Broughton (1997, 1999) analyzed most of the available vertebrate faunal assemblage and showed that human exploitation of sturgeon (*Acipenser* spp.) probably led to size diminution and therefore resource depression. This and other mammalian resource depressions may have resulted in decreasing foraging efficiency, widening of inhabitants' diet breadth, and expansion of foraging areas (Broughton 1999).

Despite the leveling and apparent destruction of ALA-309 in 1924 by the Sherwin-Williams Paint Company, considerable intact archaeological deposits remained within the original footprint of the Emeryville Shellmound and at nearby ALA-310. Beginning in 1999, these intact deposits were examined by the URS Grenier Woodward-Clyde Corporation (URSGW-C) and several other archaeological entities as one of several stages of regulatory compliance prior to the sites' development into various commercial retail outlets and other businesses. Much of the archaeological fieldwork had to be undertaken by workers wearing haz-mat suits due to various contaminants, such as heavy metals, left in the soil as a by-product of paint manufacture. The 1999 field project clearly illustrated that much of the original shellmound remained beneath the earlier twentieth-century industrial edifices erected on the site. The skeletal remains of more than 120 individuals were recovered, identified, and eventually reinterred (City of Emeryville 2005). A wealth of stone and bone artifacts was recovered and analyzed. The use of fine-grained recovery techniques and fine-mesh screens resulted in the recovery of the large sample of vertebrate faunal remains discussed below. The original site of the Emeryville Shellmound and the contact-period East Bay shoreline now lie beneath the parking lot and associated structures in the Bay Street Shopping Center. Still, in 2011, hints of the past occupation of the Emeryville Shellmound, such as dark soil flecked with shell, can be glimpsed along the train tracks to the east of the Emeryville retail complex.

The addition of new samples of vertebrate faunal remains from the Emeryville Shellmound, acquired in 1999, allows some of the findings posed by Howard (1929) and Broughton (1997, 1999) to be tested and elaborated. The use of modern excavation techniques provides greater temporal and spatial control and allows for more accurate interpretation of temporal trends and activity areas. The finer control and recovery techniques employed also provide small remains missed by previous excavators and unavailable for study by Howard (1929), Cope (1985), and Broughton (1999). The new samples should provide a better representation of mammalian microfauna, which is relatively sensitive to environmental change, and both the terrestrial and marine mammals that Broughton contends were the focus of hunting activities at the Emeryville

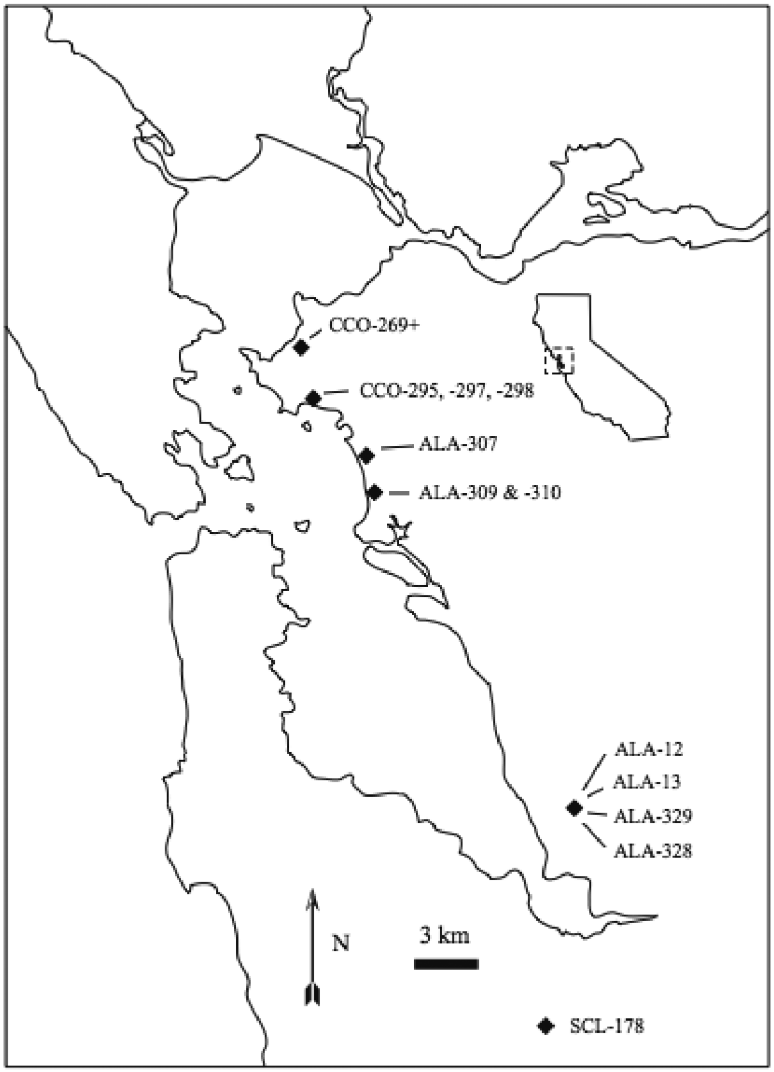


Figure 2.1. Map of the San Francisco Bay area showing locations of selected archaeological sites.

Shellmound—to such a degree that their population densities were affected. Analysis of the recently recovered mammal remains presented here will add new light to interpretations of resource depression and widening diet breadths at the Emeryville Shellmound. Comparison of the new and existing data from ALA-309 and ALA-310 with that from other Bay Area sites (Bickel 1981; Busby 1975; Simons 1979, 1981a, 1992) will also add to the picture of prehistoric mammal exploitation in the East Bay (Figure 2.1).

RESEARCH ISSUES

This chapter focuses primarily on the mammal remains recovered from ALA-309 and ALA-310 during the massive 1999 data recovery operation conducted by URSGW-C. Summaries of fish and bird remains recovered during the 1999 excavations are discussed later to examine how, and how much, past interpretations concerning these taxonomic groups are changed with access to modern samples collected with finer-mesh screens or screens at all for that matter.

Specific research issues focusing on mammal remains recovered during the 1999 excavations include comparison with Broughton's (1999) findings. For example, diet breadth should be relatively narrow earlier if resources are not yet depressed. Evaluation of the new data also allows for assessment of temporal efficiency of resource exploitation in comparison to Broughton's (1999) findings concerning whether similar exploitation patterns are evident in the newly recovered mammal remains. I briefly examine species diversity and representation in the recently excavated assemblages that resulted from finer recovery techniques in comparison to those used earlier. I follow with a brief comparison of the ALA-309 and ALA-310 faunas to those recovered from other roughly contemporaneous bayshore sites to see if general patterns observed at Emeryville are expressed elsewhere. I then offer a brief synopsis of the 1999 fish and bird faunas as compared to those reported by Broughton (1999) to emphasize the effects that modern recovery techniques and ever increasing sample sizes can have in the interpretation of vertebrate archaeofaunas.

METHODS

On arrival at the Cotsen Institute of Archaeology's Zooarchaeology Laboratory (CIOA-ZL) the vertebrate faunal remains made available by URSGW-C were washed when necessary and then sorted by vertebrate class. The respective classes were analyzed in the CIOA-ZL or sent to appropriate subcontractors for examination. Determination of specific units of analysis was difficult given the nature of shell middens, the depositional history, and the various modern impacts on the site. Data concerning cultural components, radiocarbon dates, temporal phases, and rough chronology were provided by and defined in consultation with Sally Morgan at URSGW-C, the lead archaeological contractor for the 1999 excavations (URS, Grenier, Woodward-Clyde 1999). Contextual integrity was maintained at all times by recording specific URSGW-C catalog numbers on tags for each specimen examined.

All mammal identifications were confirmed using the comparative osteological collection housed in the CIOA-ZL, and using the UCLA Department of Biology Dickey Natural History Collection. Visits were also made to and loans were received from the Los Angeles County Museum of Natural History (LACMNH), the UC Berkeley Museum of Vertebrate Zoology (UCBMVZ), and the UCLA Dickey Natural History Collection.

Each bone specimen was identified to the most discrete taxonomic level possible. More detailed taxonomic assignment (to species or genus) was usually limited to specimens with sufficient distinguishing features allowing rapid identification to the given level. The general identification and data recording methods used were as follows.

Bones lacking discrete identifiable features were sorted into broad mammal size categories by class. For mammals, size categories are defined as follows: *very large* represents elk size or larger, *large* represents deer size or larger, *medium* represents smaller than deer but larger than jackrabbit size, *small* represents jackrabbit to woodrat size, and *very small* represents mouse size or smaller.

For each discretely identifiable bone, a series of data were recorded, including catalog number, complete provenience and screen size information, skeletal element, part of element, side, age, and modification. Data recorded regarding modification of bone specimens included evidence of burning, cut marks, gnaw marks, and indications of tool or other artifact manufacture. The bone was counted and was weighed using electronic scales. Analysis addresses the research issues defined above and any other patterns that appear in the data. Taxonomy and scientific name usage primarily follow Wilson and Reeder (1993), as well as Broughton (1999). Habitat and range information follows Ingles (1965) and Jameson and Peeters (1988).

Analysis

Besides site-specific species identifications (Tables 2.1 and 2.2), two broad types of analysis—spatial and chronological—are presented here. The spatial analysis simply attempts to identify, compare, and interpret any differences in frequencies of identified taxa within roughly contemporaneous units. The chronological analysis attempts to interpret broader

Table 2.1. Identified Mammal Remains from CA-ALA-309.

Scientific Name	Common Name	Frequency
Sorex sp.	Shrew	3
Scapanus latimanus	Broad-footed mole	17
Lepus californicus	Black-tailed jackrabbit	1
Lepus sp.	Hare	1
Sylvilagus audubonii	Audubon's cottontail	79
Sylvilagus bachmani	Brush rabbit	5
Sylvilagus sp.	Cottontail rabbit	1,676
Leporidae	Hare, rabbit family	60
Microtus californicus	California meadow vole	323
Microtus sp.	Vole	109
Neotoma fuscipes	Dusky-footed woodrat	13
Neotoma sp.	Wood rat	258
Peromyscus californicus	Parasitic mouse	2
Peromyscus sp.	Deer mouse	28
Thomomys bottae	Botta's pocket gopher	2,745
Thomomys sp.	Pocket gopher	351
Dipodomys heermani	Heerman's kangaroo rat	2
Perognathus californicus	California pocket mouse	4
Perognathus sp.	Pocket mouse	45
Rattus sp.	Rat	1
Sciuridae	Squirrel, chipmunk family	4
Spermophilus beecheyi	California ground squirrel	21
Spermophilus sp.	Squirrel	24
Rodentia	Rodent	1,031
Rodentia, sm.	Small rodent	142
Delphinidae	Dolphin, porpoise family	12
Delphinus delphis	Common dolphin	17
Odontoceti	Toothed whale	1
Cetacea	Whale, dolphin, porpoise order	128
Canis latrans	Coyote	21
Canis sp.	Dog, wolf, coyote genus	707
Urocyon cinereoargenteus	Gray fox	3
Canidae	Fox, dog, wolf, coyote family	1
Procyon lotor	Raccoon	98
Enhydra lutris	Sea otter	3,512
Mephitis mephitis	Striped skunk	202
Mustela frenata	Long-tailed weasel	6
Spilogale putorius	Spotted skunk	2
Taxidea taxus	Badger	24
Ursus arctos	Grizzly bear	2
Ursus sp.	Bear	3
Felis concolor	Mountain lion	7
Lynx rufus	Bobcat	30
Carnivora	Carnivore order	104
Callorhinus ursinus	Northern fur seal	2
Eumetopias jubatus	Steller's sea lion	1
Zalophus californianus	California sea lion	61
Otariidae	Eared seal family	19
Phoca vitulina	Harbor seal	439
Pinnipedia	Seal, sea lion order	89
Antilocapra americana	Pronghorn	20
Cervus elaphus	Elk	227
Odocoileus hemionus	Black-tailed deer	2,404
Cervidae	Deer, elk family	116
Artiodactyla	Even-toed ungulates	1,322
Artiodactyla, lg.	Large even-toed ungulates	16
Artiodactyla, sm.	Small even-toed ungulates	2
		16,543
Mammalia	Mammal	40,839
Mammalia (marine)	Sea mammal	68
Mammalia, v. lg.	Very large mammal	26
Mammalia, lg.	Large mammal	7,443
Mammalia, md.	Medium mammal	1,880
Mammalia, sm.	Small mammal	3,064
Mammalia, v. sm.	Very small mammal	8
		53,328
	Total	69,871

Table 2.2. Identified Mammal Remains from CA-ALA-310.

Scientific Name	**Common Name**	**Frequency**
Scapanus latimanus	Broad-footed mole	5
Lepus californicus	Black-tailed jackrabbit	2
Sylvilagus audubonii	Audubon's cottontail	32
Sylvilagus bachmani	Brush Rabbit	1
Sylvilagus sp.	Unidentified rabbit	403
Leporidae	Hare, rabbit family	5
Microtus californicus	California meadow vole	46
Microtus sp.	Vole	15
Neotoma sp.	Unidentified woodrat	44
Peromyscus boylii	Brush mouse	3
Peromyscus californicus	Parasitic mouse	1
Peromyscus sp.	Unidentified mouse	12
Thomomys bottae	Botta's pocket gopher	1,680
Thomomys sp.	Unidentified pocket gopher	4
Perognathus sp.	Unidentified pocket mouse	9
Spermophilus beecheyi	California ground squirrel	3
Spermophilus sp.	Squirrel	4
Sciuridae	Squirrel, chipmunk family	2
Rodentia	Unidentified rodent	204
Rodentia, sm.	Small rodent	45
Cetacea	Whale, dolphin, porpoise order	43
Delphinidae	Dolphin, porpoise family	5
Canis lupus	Gray wolf	1
Canis sp.	Unidentified dog, wolf, coyote	176
Urocyon cinereoargenteus	Gray fox,	4
Canidae	Fox, dog, wolf, coyote family	1
Procyon lotor	Raccoon	58
Enhydra lutris	Sea otter	837
Mephitis mephitis	Striped skunk	14
Mustela frenata	Long-tailed weasel	1
Taxidea taxus	Badger	9
Lynx rufus	Bobcat	2
Carnivora	Carnivore order	9
Zalophus californianus	California sea lion	5
Otariidae	Eared seal family	13
Phoca vitulina	Harbor seal	151
Pinnipedia	Seal, sea lion order	16
Antilocapra americana	Pronghorn	7
Cervus elaphus	Elk, wapiti	73
Odocoileus hemionus	Black-tailed deer	636
Cervidae	Unidentified deer family	32
Artiodactyla	Unidentified even-toed ungulates	169
Artiodactyla, lg.	Large Even-toed ungulates	2
Mammalia	Unidentified mammal	5,291
Mammalia (marine)	Unidentified sea mammal	10
Mammalia, lg.	Large mammal	1,446
Mammalia, md.	Medium mammal	497
Mammalia, sm.	Small mammal	529
Mammalia, v. lg.	Very large mammal	17
Mammalia, v. sm.	Very small mammal	1
	Total	12,575

subsistence patterns through time in terms similar to those used by Broughton (1999). Data generated from each individual excavation unit were first agglomerated by excavation area and gross chronological time frame. Sally Morgan (URSGW-C) provided the data used to formulate the chronometric analytical units (Table 2.3).

The gross chronology used is based on radiocarbon dates, stratigraphy, and extrapolation from dated units to adjacent undated units conducted by Morgan (City of Emeryville 2005). These respective groupings represent the primary units of analysis for the mammal remains. The goal of these groupings is to make analysis of the data more coherent and to provide a chronological framework for analysis. The units examined, their general location within the site, and respective gross chronological association are listed in Table 2.3, with corresponding excavation areas illustrated in Figure 2.2. The time span covered by the ALA-309 mammal remains ranges from 2800 B.P. to 800 B.P., roughly 2,000 years. The largest samples come from units dating within the 2700–1800 B.P. range. The time span covered at ALA-310 ranges from 550 to 300 B.P., with many units providing substantial sample sizes.

Table 2.3. Excavation Units, Areas, and Approximate Chronological Placement.

Unit	URS Area	Approximate Chronology	Data Source/comments
BB	W MGN 309	700-900 BP	Extrapolated from C14 on underlying U 58
50	DXS, MGN 309	800-1250 BP	3 C14 dates from unit
58	W MGN 309	900-1200 BP	1 C14 date at top of unit
65	E MGN 309	1100-1300 BP	Extrapolated from C14 from U 54 and relative elev.
77	DXS MGN 309	1300-1500 BP	Extrapolated from C14 in Trench X and U 72
23	DXS, MGN 309	1400-1600 BP	Possibly coeval with U 72
24	DXS, MGN 309	1400-1600 BP	Estimation, elevation higher than U 43
25	DXS, MGN 309	1400-1600 BP	Estimation, elevation higher than U 43
72	E MGN 309	1500-1800 BP	3 C14 dates in unit and adjacent to unit
43	DXS MGN 309	1600-1800 BP	Extrapolated from U 67 elevation and dates
67	DXS MGN 309	1600-1900 BP	1 C14 date and relative elevations
AA	C 309	1700-2200 BP	Highly variable: C14 on burials, units in area
37	AA SC 309	1750-2100 BP	Extrapolated from C14 in U 35 and relative elevation
44	AA SC 309	1750-2100 BP	Extrapolated from C14 in U 35 and relative elevation
27	AA SC 309	1800-2200 BP	Extrapolated from C14 date in Unit 35
28	AA C 309	1800-2200 BP	Extrapolated form other nearby units
36	AA C 309	1800-2200 BP	Extrapolated from AA C14 dates and elevation
38	AA SC 309	1800-2200 BP	Extrapolated from C14 in U 35 and relative elevation
39	AA SC 309	1800-2200 BP	Extrapolated from C14 in U 35 and relative elevation
41	AA C 309	1800-2200 BP	1 C14 date and extrapolated from nearby units
42	AA NC 309	1800-2200 BP	Extrapolated from C14 dates from burial AA-12
48	AA SC 309	1800-2200 BP	Extrapolated from C14 in U 35 and relative elevation
49	AA NC 309	1800-2200 BP	Extrapolated from C14 dates from burial AA-12
51	AA C 309	1800-2200 BP	Extrapolated from AA C14 dates and elevation
Trench V	C 309	1800-2200 BP	Extrapolated from C14 dates in vicinity
35	AA SC 309	1800-2200 BP?	1 C14 date at 1960 BP mid unit
53	DXS MGN 309	1800-2200 BP?	Extrapolated from U 67 elevation and dates
55	DXS MGN 309	1800-2200 BP?	Extrapolated from U 67 elevation and dates
57	AA C 309	1800-2200 BP?	Extrapolated from C14 dates in Unit 41
26	AA SC 309	1900-2000 BP	Extrapolated from C14 date in Unit 35
32	AA C 309	1900-2300 BP	3 C14 dates from unit
66	AA C 309	1900-2300 BP	1 C14 date at unit base
71	AA C 309	1900-2300 BP	Extrapolated from U. 66
Trench Z	C 309	1900-2300 BP	C14 on burials and extrapolated adjacent units
33/34/00	FF C 309	2000-2300 BP	Extrapolated from lower part of unit
33	FF C 309	2000-2300 BP?	Extrapolated from C14 lower in unit
33/34	FF C 309	2000-2300 BP?	Extrapolated from lower part of unit
34	FF C 309	2000-2300 BP?	Extrapolation from C14 lower in unit
61	W MGN 309	2000-2350 BP	Extrapolated from C14 at base of adjacent trench
69	ZZ C 309	2000-2400 BP	Extrapolated from 63
68	ZZ C 309	2000-2800 BP	Extrapolated from 63
63	ZZ C 309	2000-2800BP	3 C14 dates
33/34/35	FF C 309	2200-2700 BP	4 C14 dates
33/34/59	FF C 309	2200-2700 BP	4 C14 dates
60	FF C 309	2200-2700 BP	Extrapolated from C14 dates in 33/34/59
59	FF C 309	2300-2700 BP	C14 dates in 33/34/59

Table 2.3. (cont.)

Unit	**URS Area**	**Approximate Chronology**	**Data Source/comments**
75	N 310	300-500 BP	2 C14 dates
13	CC/DD/EE C310	350(?)-550 BP	C14 in adjacent units
45	CC/DD/EE C310	350(?)-550 BP	Extrapolated from C14 in adjacent units
46	CC/DD/EE C310	350(?)-550 BP	Extrapolated from C14 in adjacent units
52	CC/DD/EE C310	350(?)-550 BP	C14 at unit base
62	CC/DD/EE C310	350(?)-550 BP	Extrapolated from C14 in adjacent units
73	CC/DD/EE C310	350(?)-550 BP	Extrapolated from C14 in adjacent units
74	CC/DD/EE C310	350(?)-550 BP	Extrapolated from C14 in adjacent units
14	CC/DD/EE C310	350(?)-550 BP/ 2800 BP???	later date by C14 in adjacent units
CC	CC/DD/EE C310	350-550 BP	Extrapolated from C14 in adjacent units
DD	CC/DD/EE C310	350-550 BP	Extrapolated from C14 in adjacent units
EE	CC/DD/EE C310	350-550 BP	Extrapolated from C14 in adjacent units
Trench P	CC/DD/EE C310	350-600 BP/2900 BP	C14 dates
Trench T	N 310	Mixed?	Probably redeposited from 309

Notes: C=central, NC=north central, SC=south central, MGN=margin

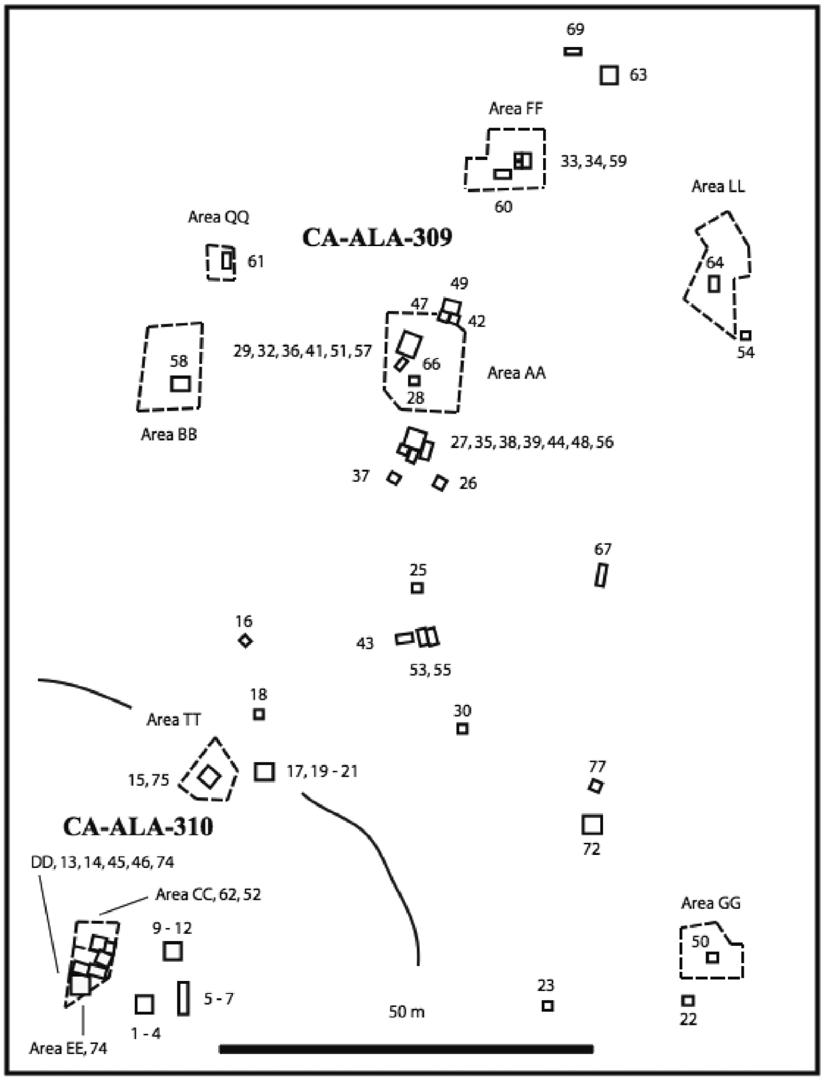


Figure 2.2. Schematic map of the 1999 ALA-309 and ALA-310 recovery units as excavated by URSGW-C field crews.

RESULTS

CA-ALA-309

The total number of specimens examined from ALA-309 is 69,869 (Table 2.1). Mammal remains from 60 separate ALA-309 excavation units were identified. These excavation units include trenches, areal exposures, and stratigraphic squares (Figure 2.2; Table 2.3). Of these, 16,541 were identified to at least the ordinal level. The remaining 53,328 were placed into relative size classes based on size and thickness of the given fragments. Thirty genera and 32 species of mammals representing 19 families and seven orders were identified in the ALA-309 material.

Insectivores (moles and shrews) are represented by two genera and one species in two families. Lagomorphs (rabbits, *n* = 1,822) are represented by two genera and three species (black-tailed jackrabbit, brush rabbit, and Audubon's cottontail). Rodents (*n* = 5,103) are represented by eight genera and seven species in six families, one of which is introduced (California vole, dusky-footed woodrat, parasitic mouse, Botta's pocket gopher, Heerman's kangaroo rat, California pocket mouse, introduced rat (*Rattus* sp.), and California ground squirrel). One genus and species and several fragments identifiable only to higher taxonomic levels represent the whales and dolphins (*n* = 158), both toothed and baleen. Carnivores (*n* = 4,720) are the most diverse mammal order, with 11 genera and species representing five families (coyote, gray fox, raccoon, sea otter, striped skunk, spotted skunk, long-tailed weasel, badger, mountain lion, bobcat, and grizzly bear). Pinnipeds (seals and sea lions, *n* = 611) are represented by four genera and four species in two families (northern fur seal, Steller's sea lion, California sea lion, and harbor seal). Artiodactyls (even-toed ungulates, *n* = 4,087) are represented by three genera and species in two families and various specimens identified only to the order (elk, black-tailed deer, and pronghorn).

Mammal remains classifiable only to relative size classes (*n* = 53,328) are the most numerous mammal specimens, with indeterminate mammals (*n* = 40,839) dominating. Unidentified large mammal remains (*n* = 7,443), small mammal remains (*n* = 3,064), medium mammal remains (*n* = 1,880), marine mammal remains (*n* = 68), very large mammal remains (*n* = 26), and very small mammal remains (*n* = 8) constitute the smaller of these less identifiable groups in the mammal assemblage.

The most numerous identified mammal taxa in order of relative abundance are sea otter (*n* = 3,512), followed by pocket gopher (*n* = 3,096), black-tailed deer (*n* = 2,404), cottontail rabbits (*n* = 1,760), dog (almost all probably coyote, *n* = 728), harbor seal (*n* = 439), California vole (*n* = 432), woodrat (probably all dusky-footed woodrat, *n* = 271), and elk (*n* = 227). The remaining identified mammals are all relatively poorly represented. The site's past occupants could have consumed many of the mammals identified in this assemblage. However, most of the rodents and insectivores are not considered economically important food items per se. It is possible that the pocket gophers, woodrats, and ground squirrels may have been consumed, as Costanoans and other indigenous Californian groups reportedly ate them (Heizer 1978; Levy 1978). Some of the bones are burned, possibly as a part of food preparation and disposal practices, although natural occurrences such as brush fires should not be ruled out.

The ALA-309 mammal assemblage as a whole consists primarily of fairly large terrestrial and marine mammals. The largest mammals represented in the collection are whales (*n* = 129). It is most likely that the large whale remains represent gray whales (*Eschrichtius robustus*), but species such as humpback and orca cannot be ruled out given the lack of specific characters on the specimens. The largest terrestrial mammals represented are elk (*n* = 227), bear (*n* = 4), mountain lion (*n* = 6), and deer (*n* = 2,404). These are followed by pinnipeds (primarily California sea lions, *n* = 61, and harbor seals, *n* = 439). Sea otters, coyotes, badgers, and bobcats constitute a smaller size class. The smaller carnivores and rabbits constitute the next size class, followed by rodents and insectivores.

Rabbit remains, especially cottontails, are abundant in many southern Californian archaeofaunas, but less so in northern California (Bickel 1981;

Broughton 1999; Simons 1979, 1981a, 1992). Broughton reported relatively few (*n* = 309, 1.9 percent) rabbits in his analysis of the previously extant Emeryville faunal collections. Rabbits, especially cottontails, are much more common in the 1999 collection than in collections previously reported. Fully 10.6 percent (*n* = 1,760) of the mammal remains are identified as cottontail. Rabbits dominate no Bay Area or coastal northern California mammal archaeofaunas, unlike southern and central California, where rabbit bones are typically the most common mammal remains encountered (Bickel 1981; Broughton 1999; Simons 1979, 1981a, 1992). In most coastal northern California vertebrate archaeofaunas where rabbits are represented, cottontails dominate. Farther inland, especially in more arid regions such as the Central Valley, the dominant species tends to be the black-tailed jackrabbit. The relatively low number of black-tailed jackrabbit specimens (*n* = 4; .69 g) is not surprising for a Bay Area locale such as this. The majority of reported Bay Area vertebrate archaeofaunas have correspondingly low jackrabbit frequencies (Bickel 1981; Broughton 1999; Cope 1985; Simons 1979, 1981a, 1992). Broughton reported none in his work on the Emeryville collections and expresses doubt about Cope's and other Bay Area sites with jackrabbits represented.

Rodents constitute a considerable portion (*n* = 5,103; 30.9 percent) of the identified mammal remains at ALA-309 (Table 2.1). Pocket gophers (*n* = 3,096) dominate the rodent remains. California voles (*n* = 432) and woodrats (*n* = 271) follow in order of abundance. Pocket mice (*n* = 49), ground squirrels (*n* = 45), and deer mice (*n* = 30) are the next most commonly identified rodents. Most if not all the rodents may be intrusive, either occurring naturally (living) on site or brought to the site in terrestrial carnivore scat. The ground squirrels and gophers are the most likely to be directly intrusive since they are the most vigorous burrowers identified. Deer mice and the Heteromyidae (kangaroo rats and pocket mice) are also burrowers, but in a much more superficial sense compared to gophers and ground squirrels. The woodrats are the only rodents present in this assemblage that are not habitual burrowers. They construct aboveground nests of sticks and twigs in overhangs or in bush and tree crotches. Unless the original Emeryville Shellmound had substantial brush and tree cover (which period photos published in Broughton 1996 and 1999 hint at), it is likely that the woodrat remains may represent animals brought to the site as potential food items.

Levy (1978:491) mentions the consumption of rodents by Costanoan peoples. He includes woodrats, tree squirrels, ground squirrels, and mice, stating that mice were captured with deadfall traps, woodrats by burning their nests, and ground squirrels by blowing smoke into their burrows. Therefore, it is quite possible that the various identifiable rodent specimens (Table 2.2) in the ALA-309 mammal collection represent dietary constituents.

Carnivores (*n* = 4,720) are the most diverse mammal order represented at ALA-309, with 11 genera identified. The most common carnivore is the sea otter (*n* = 3,512), while the largest is the grizzly bear (*n* = 1). Both of these carnivores were extirpated from the Bay Area during historic times. The second most common carnivore is dog/coyote (*n* = 728). The majority of the specimens identified as *Canis* sp. most likely represent coyote. However, identifications of these specimens were not taken beyond the generic level, either because they were too fragmentary or were deemed similar enough to domestic dog that they should be subjected to detailed morphometric examination for species identification. Domestic dogs have been reported in various California Indian groups (Heizer 1978), but little attention has been paid to them. One of the original research questions proposed for these collections involved a morphometric analysis of *Canis* remains. Unfortunately, the nature of the identification process and time available did not allow for measurements to be taken on the *Canis* remains, and the question of whether domestic dogs are represented in the Emeryville Shellmound fauna remains unresolved.

Artiodactyls (*n* = 4,107) are present at ALA-309 in relatively large numbers. Three genera and species are identified, two belonging to the family Cervidae and one belonging to the family Antilocapridae.

The most common artiodactyl is black-tailed deer (Cervidae, *n* = 2,404). The largest artiodactyl in the collection is elk (*n* = 227). Pronghorn (*n* = 20) are present but are relatively rare. Artiodactyls such as deer, elk, and pronghorn provide a great deal of meat and other resources for the amount of energy expended to procure them. Therefore, artiodactyls are typically considered a more highly ranked prey item, in cost-benefit terms, than are most other terrestrial species (e.g., Broughton 1994b, 1999). Various other artiodactyl specimens are identified to the family or order levels. The specimens identified as Cervidae include bits of antler and specimens that could not be distinguished between deer or elk. The specimens identified as artiodactyl are mostly long bone fragments that could not be differentiated beyond the ordinal level. These artiodactyl fragments may represent the opening of limb bones to extract marrow and perhaps grease to maximize caloric yield (Binford 1978, 1981).

ALA-309 Summary

The various mammal subsamples derived from different parts of ALA-309 tend to be dominated numerically either by rodents or by one of three economically important species, usually sea otter or deer and occasionally cottontail. The large numbers of rodents are clearly a reflection of a more fine-grained approach to data recovery at the site. In general, five mammal species—black-tailed deer, harbor seal, sea otter, *Canis* sp. (probably coyote but possibly domestic dog as well), and cottontail—occur most commonly in each of the subsamples reported above. Sea otter and black-tailed deer tend to be the two most commonly represented fairly large mammal species in most of the samples reported above. (Black-tailed deer stand roughly 122 cm at the shoulder, and sea otters are up to 152 cm in length in California waters.) Other important mammal species at ALA-309 include whales, the largest mammals represented at the site and likely contributors of considerable amounts of meat and bone raw material for tools. Elk, the largest and probably highest ranked in terms of available meat (and other useful raw materials) among the common terrestrial mammal species, were clearly important resources to the past inhabitants of ALA-309.

ALA-310

Mammal remains from 15 separate ALA-310 excavation units were identified. These excavation units include trenches, areal exposures, and stratigraphic squares. The total number of specimens examined from ALA-310 is 12,575 (Table 2.1). Of these, 4,784 were identified to at least the ordinal level (Table 2.2). The remaining 7,791 were placed into relative size classes based on size and thickness of the given fragments. Twenty-two genera and 21 species of mammals representing 16 families and six orders were identified in the ALA-310 material.

Insectivores (moles and shrews, *n* = 5) are represented by one genus and species. Lagomorphs (rabbits, *n* = 443) are represented by two genera and three species (black-tailed jackrabbit, brush rabbit, and Audubon's cottontail). Rodents (*n* = 2,072) are represented by seven genera and five species (California vole, a woodrat, parasitic mouse, brush mouse, Botta's pocket gopher, a pocket mouse, California ground squirrel) in five families. Whales (*n* = 48), both toothed and baleen, are represented by several fragments identifiable only to family or order. As they were at ALA-309, carnivores (*n* = 1,111) are diverse, including nine genera and eight species (gray wolf, *Canis* sp. [probably coyote], gray fox, raccoon, sea otter, striped skunk, long-tailed weasel, badger, and bobcat) representing four families. Pinnipeds (seals and sea lions, *n* = 185) are represented by two genera and species (California sea lion and harbor seal) in two families. Artiodactyls (*n* = 912) are represented by three genera and species (elk, black-tailed deer, and pronghorn) and various specimens identified only to the order.

Mammal remains classifiable only to relative size classes (*n* = 7,791) are the most numerous mammal specimens, with indeterminate mammals (*n* = 5,291) dominating. Unidentified large mammal remains (*n* = 1,446), small mammal remains (*n* = 529), medium mammal remains (*n* = 497), very large mammal remains (*n* = 17), marine mammal remains (*n* = 10), and very small mammal remains (*n* = 1) constitute the smaller of these less identifiable groups in the mammal assemblage.

The most numerous identified mammal taxa in order of relative abundance are pocket gopher (*n* = 1,684), followed by sea otters (*n* = 837), black-tailed deer (*n* = 636), cottontail rabbit (*n* = 426), dog (*Canis*, almost all probably coyote, *n* = 176), harbor seal (*n* = 151), elk (*n* = 73), California vole (*n* = 61), raccoon (*n* = 58), and woodrat (*n* = 44). The remaining identified mammals are all relatively poorly represented.

The ALA-310 mammal assemblage consists primarily of relatively large terrestrial and marine mammals, the largest being whales (*n* = 43). It is most likely that the large whale remains represent gray whales, but species such as humpback and orca cannot be ruled out given the lack of specific characters on the specimens. The largest terrestrial mammals represented are elk (*n* = 73) and deer (*n* = 636). These are followed by pinnipeds (primarily California sea lion, *n* = 5, and harbor seal, *n* = 151). Sea otters, coyotes, badgers, and bobcats constitute a smaller size class. The smaller carnivores and rabbits constitute the next size class, followed by rodents and insectivores. Nearly 9.3 percent (*n* = 443) of the ALA-310 mammal remains are identified as cottontail, with a low number of black-tailed jackrabbit (*n* = 2) specimens.

As was the case at ALA-309, rodents constitute a considerable portion (*n* = 5,103; 43.3 percent) of the identified mammal remains at ALA-310. Pocket gophers (*n* = 1,684) dominate the rodent remains. California voles (*n* = 61) and woodrats (*n* = 44) follow in order of abundance. Deer mice (*n* = 16), pocket mice (*n* = 9), and ground squirrels (*n* = 7) are the next most commonly identified rodents. As is the case at ALA-309, most if not all the rodents could be intrusive.

Carnivores (*n* = 2,072) are the most diverse mammal order represented at ALA-309, with 11 genera identified. The largest and most common carnivore is the sea otter (*n* = 837). The second most common carnivore is dog/coyote (*Canis* sp., *n* = 176). One other member of the genus *Canis*, the gray wolf (*Canis lupus*), is identified at ALA-310. A single burned proximal right mandible fragment bearing the last two molar alveoli was recovered from Area EE, Stratum II. This specimen was compared to five specimens from northern California or adjacent areas held in UCBMVZ. The archaeological specimen is as robust as and actually slightly larger than the museum specimens. Wolves once roamed the Sierra Nevada and Coast Ranges north of San Francisco Bay, but their presence in the Bay Area is debatable. Broughton identified four wolf specimens in his 1999 analysis of the ALA-309 fauna.

As they were at ALA-309, artiodactyls (*n* = 912) are present at ALA-310 in substantial numbers. In order of abundance, artiodactyls include black-tailed deer (*n* = 636), elk (*n* = 73), and pronghorn (*n* = 7). Various other artiodactyl specimens are identified to the family or order levels. These include bits of antler and specimens that could not be distinguished between deer or elk, and bone fragments that could not be differentiated beyond the ordinal level.

ALA-310 Summary

ALA-310 is really quite similar to ALA-309 in many respects, save chronological placement. The ALA-310 site dates almost to the protohistoric period—300 to 500 years ago. The various mammal subsamples derived from different parts of ALA-310 tend to be dominated numerically by one of three economically important species, usually sea otter or deer and occasionally cottontail. A variety of rodent species are present, their relatively high numbers being a reflection of a more fine-grained approach to data recovery at the site. In general, five mammal species occur most commonly in each of the subsamples reported above: black-tailed deer, harbor seal, sea otter, *Canis* sp. (probably coyote but possibly domestic dog as well), and cottontail. Sea otter and black-tailed deer tend to be the two most commonly represented fairly large mammal species in most of the samples reported above. Other important mammal species at ALA-310 include whales, the largest mammals represented at the site and likely contributors of considerable amounts of meat and bone raw material for tools. Elk, the largest common terrestrial mammal species and probably highest ranked in terms of available meat, were clearly important resources to the past inhabitants of ALA-310.

Species frequencies vary considerably between the selected subsamples at ALA-310. Such variability suggests that the different areas of the site reflect different hunting strategies and resource foci. As suggested for ALA-309, the observed differences in species frequencies at ALA-310 may be due to seasonal variability in resource availability and site occupation and perhaps fine-grained responses to local resource depression. The spatial differentiation of subassemblages at ALA-310 provides further support for the notion of periodic switching between productive and less productive resource patches over the short term. Once again, these questions could not even be raised in the previous investigations of the available ALA-309 archaeofauna because they were the result of focused stratigraphic investigation, and units were not dispersed across the site.

TEMPORAL PATTERNING AT ALA-309 AND ALA-310

To analyze temporal patterns of mammal exploitation at these two sites, I have combined roughly contemporaneous spatially distinct area and unit subassemblages into eight time periods (Table 2.4). These eight time periods average approximately 300 years in duration and are listed in Table 2.4. Each specific period has some temporal overlap with the previous and subsequent periods, but many temporal analyses of various artifact assemblages are forced to deal with temporal disparities and overlapping periods. I have attempted to provide as precisely combined groups as possible based on the radiocarbon dates and temporal assignments available.

Table 2.4. Time Period Numbers and Respective Date Ranges.

Time Period Number	Rough Date Range
1	2200–2700 B.P.
2	1900–2400 B.P.
3	1750–2200 B.P.
4	1500–1900 B.P.
5	1300–1600 B.P.
6	1100–1300 B.P.
7	800–1250 B.P.
8	300–550 B.P.

Once the temporal units of analysis were determined, I was able to produce a series of graphic illustrations of relative distributions of selected mammal groups through time. I began with the examination of relative distributions of the five most numerically common mammal species at these two sites through time. I selected black-tailed deer, harbor seal, sea otter, coyote, and cottontail for inclusion in this analysis. My approach here is simple. I wish to illustrate graphically the relative representation of these five species through the eight broad time categories represented in the collection, determine if any obvious patterns are present, and attempt to explain any evident trends in the data.

Figure 2.3 illustrates the relative frequencies of the five most common mammal species across the eight selected time periods. A number of patterns may be deduced from this figure. First of all, all five species are represented in every time period. Black-tailed deer and sea otter are clearly the most common mammal species. Sea otter is the most common species in six out of the eight time periods. Deer is the most common in only two time periods, those between 1,100 and 1,600 years ago. Cottontail is always the third most common of these five species and remains between 15 and 20 percent of these five species irrespective of time period. Dogs tend to be the fourth most common taxon, with the exception of 1,100 to 1,300 years ago, and tend to constitute less than 10 percent of these five species regardless of time period. Harbor seal tends to be the least common species represented in these periods, usually under 10 percent. The exception is a slight jump in harbor seal representation 1,100 to 1,300 years ago, when they overtake dogs in relative abundance.

The most intriguing patterns in Figure 2.3 have to do with the relationship between black-tailed deer and sea otters and the temporal patterning of this relationship. It is clear that these two species were important to the inhabitants of the Emeryville Shellmound. Two aspects of this relationship are evident in Figure 2.3. Deer appear to decrease in relative representation through time. As deer

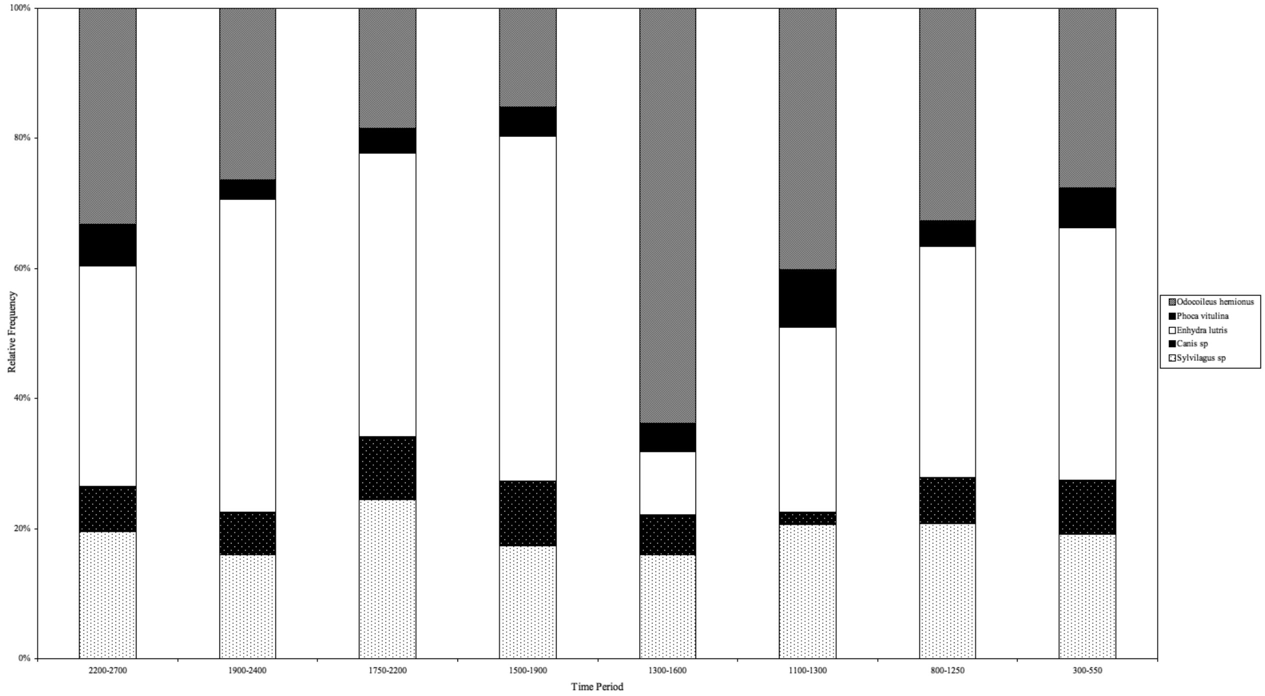


Figure 2.3. Selected economically important mammals at ALA-309 and ALA-310.

decrease in representation, sea otters increase concomitantly. However, this pattern appears twice in the sequence. From roughly 2,700 to nearly 1,500 years ago, a steady decrease in deer and increase in sea otter representation is witnessed. Then, in the period between 1,300 and 1,600 years ago, a radical resurgence in deer representation is evident. Subsequent to this resurgence, a steady decrease in relative representation of deer and a concomitant increase in sea otters occur once again.

Table 2.5. Mammal Indices and Respective Formulas.

Index	**Formula**
Pinniped-otter*	$\sum$ Pinnipeds$_i$ / $\sum$ (pinnipeds + sea otters$_i$)
Artiodactyl-carnivore*	$\sum$ Artiodactyls$_i$ / $\sum$ (artiodactyls + small carnivores$_i$)
Elk-deer*	$\sum$ Elk$_i$ / $\sum$ (elk + deer + artiodactyls$_i$)
Artiodactyl-otter*	$\sum$ Artiodactyls$_i$ / $\sum$ (artiodactyls + sea otters$_i$)
Artiodactyl-lagomorph	$\sum$ Artiodactyls$_i$ / $\sum$ (artiodactyls + lagomorphs$_i$)

*Broughton index (1999:52–53)

EXPLOITATION INDICES

To further examine temporal trends in the mammalian data, I decided to examine five indices of relative mammalian exploitation. Broughton (1999, see Table 2.5) first developed four of these. I have chosen Broughton's pinniped-otter, artiodactyl-carnivore, elk-deer, and artiodactyl-otter indices to examine the data presented here, as well as to afford direct comparison to previously published work on the Emeryville Shellmound. Broughton (1999:52–53) provides the formulas for these indices. I have derived an additional index, the artiodactyl-lagomorph index, to examine the relationship between artiodactyls and a small terrestrial mammal prey species, similar to Broughton's artiodactyl-carnivore index but perhaps a bit more specific in terms of patchiness, acquisition, and reproductive behaviors. The artiodactyl-lagomorph index is presented in Table 2.5 along with Broughton's indices.

Broughton's stated goals for these indices are "to derive taxonomic ratios that will measure changes through time in . . . relative abundances of different ranked mammalian prey taxa" (Broughton 1999:52).

Broughton (1999:52) states that declining mammalian prey choice efficiencies "would be signaled by decreasing frequencies of high-ranked prey types." To further clarify the point of these indices, Broughton states that "linear declines in high-ranked prey or declines followed by resurgences may each signal overall declines in efficiency, if resurgence is reflecting local resource depression and increasing use of distant less-depleted mammal patches." Broughton (1999:53) adds, "For each of these taxonomic ratios, higher values indicate proportionately higher frequencies of large sized or high ranked mammal prey in a stratum." He does not mention the possibility that resurgences in high-ranked prey types could be the result of reduced hunting pressure due to temporary abandonment of the local area or other factors that would allow impacted populations to rebound.

For the purpose of this report, following Broughton, high values for each index indicate relatively higher frequencies of high-ranked (larger) mammalian prey within a given temporal division. In terms of time, the temporal divisions presented above will have to suffice, since the units of analysis at this stage are not derived from distinct contiguous strata as were the samples recovered by Uhle and Nelson that Broughton analyzed. The time period numbers presented in the five various graphic presentations of each index (figures below) are correlated with the date ranges represented in Table 2.4.

Pinniped-Otter Index

The pinniped-otter index allows comparison of the most common marine mammal groups found in the CA-ALA-309 vertebrate archaeofauna. Broughton (1999:52) states that this index "summarizes the relative contribution of high-ranking pinnipeds . . . relative to sea otters." Pinnipeds rank higher than sea otters because they are larger, yield greater amounts of meat per individual (encounter), and have thick layers of calorie-rich blubber. He also states that these species are found in "the same general habitat," and therefore the fine-grained search assumption (no patchiness and random encounters of potential prey items) is approximated. While it is true that these species are found in broadly similar bayshore habitats, their similarities end there. They have divergent foraging strategies and general life histories, and the development of different specific hunting strategies would be required to obtain them in the numbers and implied relative consistency seen in the ALA-309 vertebrate archaeofauna. Within the pinnipeds, the two most common species at ALA-309, California sea lions and harbor seals, have considerably different life histories and habitat preferences. Harbor seals are resident and nonmigratory. California sea lions are migratory, resulting in seasonal reduction of prey availability. They simply do not haul out at the same sites and therefore are not found together. It is possible that encounters with these species were patchier than Broughton assumes.

Figure 2.4 shows the relationship between the pinniped-otter index and the time periods laid out in Table 2.5. A bimodal pattern is suggested by the distribution of the individual data points. During the first four time periods (2700–1500 B.P.), the index ranges between roughly .18 and .06. A dramatic increase in pinnipeds is seen from time period four to time period five. The subsequent decrease in pinnipeds (and increase in relative emphasis on sea otters) from time periods five through eight is equally dramatic. In general, sea otters are always far more common than all pinnipeds combined in the samples reported here. As with Broughton's findings, it is the magnitude of the difference that varies.

Based on the assemblages reported here, the marine mammal faunas at the early and late parts of the mound's occupational history appear dominated by sea otters. A dramatic increase in the presence of pinnipeds is seen from time period four to time period five, roughly in the middle of the occupational sequence. This relatively brief increase is followed by an equally dramatic decline from roughly 1600 to 300 B.P. This pattern differs considerably from that provided by Broughton (1999:53, Figure 8.1), who states that "the marine mammal faunas of the earliest and latest occupations are better represented by the high-ranked pinnipeds, while the middle period . . . is overwhelmingly dominated by sea otters." As with Broughton's findings, the general relationship between sea otters and pinnipeds is quite similar for the assemblages reported here. As sea otters

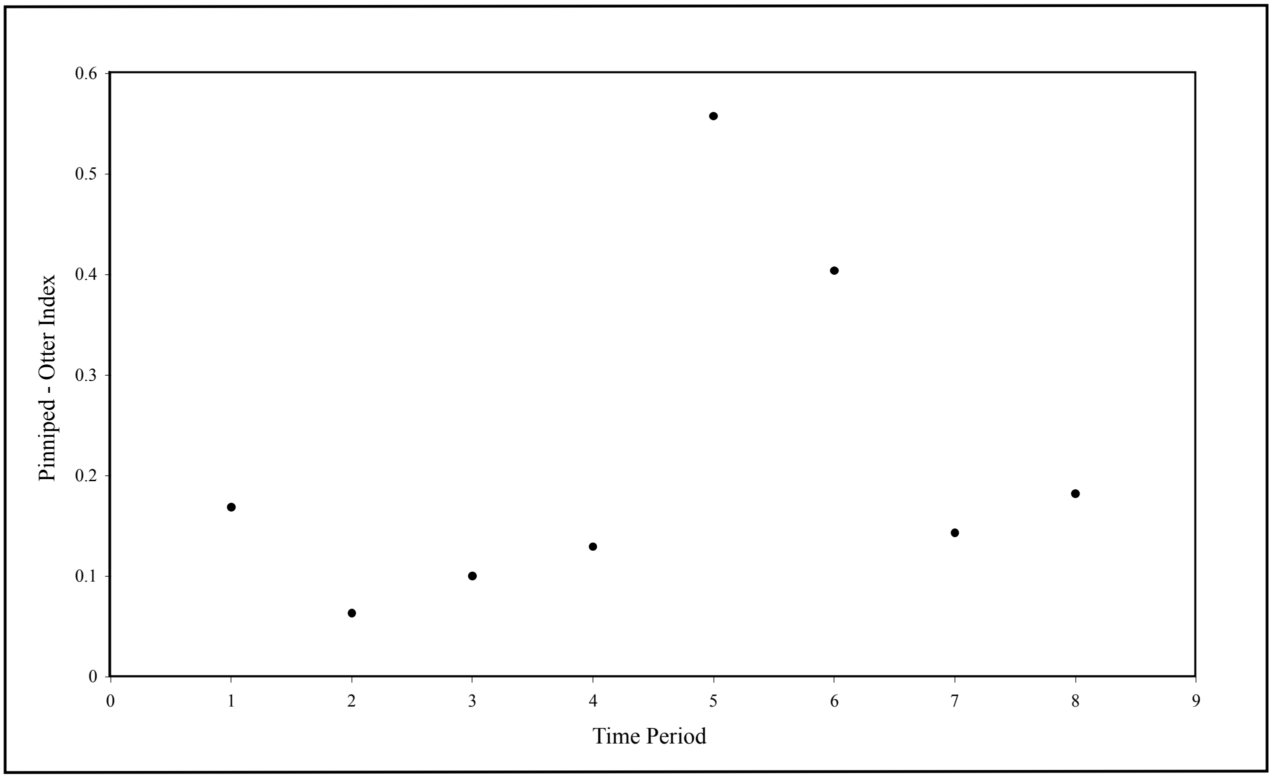


Figure 2.4. Pinniped-otter index.

increase, the pinniped index decreases and vice versa. In general, the recently recovered noncetacean marine mammal assemblage consists of a consistently numerous yet variable sea otter collection and a relatively small pinniped subassemblage that varied little through time.

Artiodactyl-Carnivore Index

The artiodactyl-carnivore index compares the two most common terrestrial mammal orders in Broughton's 1999 analysis of the available Emeryville mammalian fauna. Again, Broughton makes explicit a series of assumptions concerning this index. He states (1999:52) that terrestrial artiodactyls and carnivores occur in the same general habitats and that, as with the pinniped-otter index, "the fine-grained search assumption of the prey model is . . . roughly approximated for this set of resources." Essentially, the artiodactyl-carnivore index is a measure of terrestrial hunting efficiency, whereas the pinniped-otter index serves as a measure of marine/estuarine hunting efficiency. One assumption implicit in this index is that all the carnivores in this assemblage, including skunks, badgers, and other small mustelids, represent food resources. This certainly cannot be ruled out, but the naturally occurring patchiness in microhabitat preferences of terrestrial carnivores and artiodactyls is not considered, and cannot be for the index to be valid.

Figure 2.5 illustrates the distribution of the artiodactyl-carnivore index across time for the recently recovered Emeryville collection. The general pattern is similar to that seen in the pinniped-otter index in that representation of high-ranked terrestrial prey—artiodactyls—decreases across the first four time periods, increases fairly dramatically across time periods four to five, and decreases once again across the last four time periods. One important difference is that the artiodactyl (high-ranked terrestrial prey) index is relatively much higher than the pinniped (high-ranked marine/estuarine prey) index. Artiodactyls are generally the most common high-ranked prey at Emeryville.

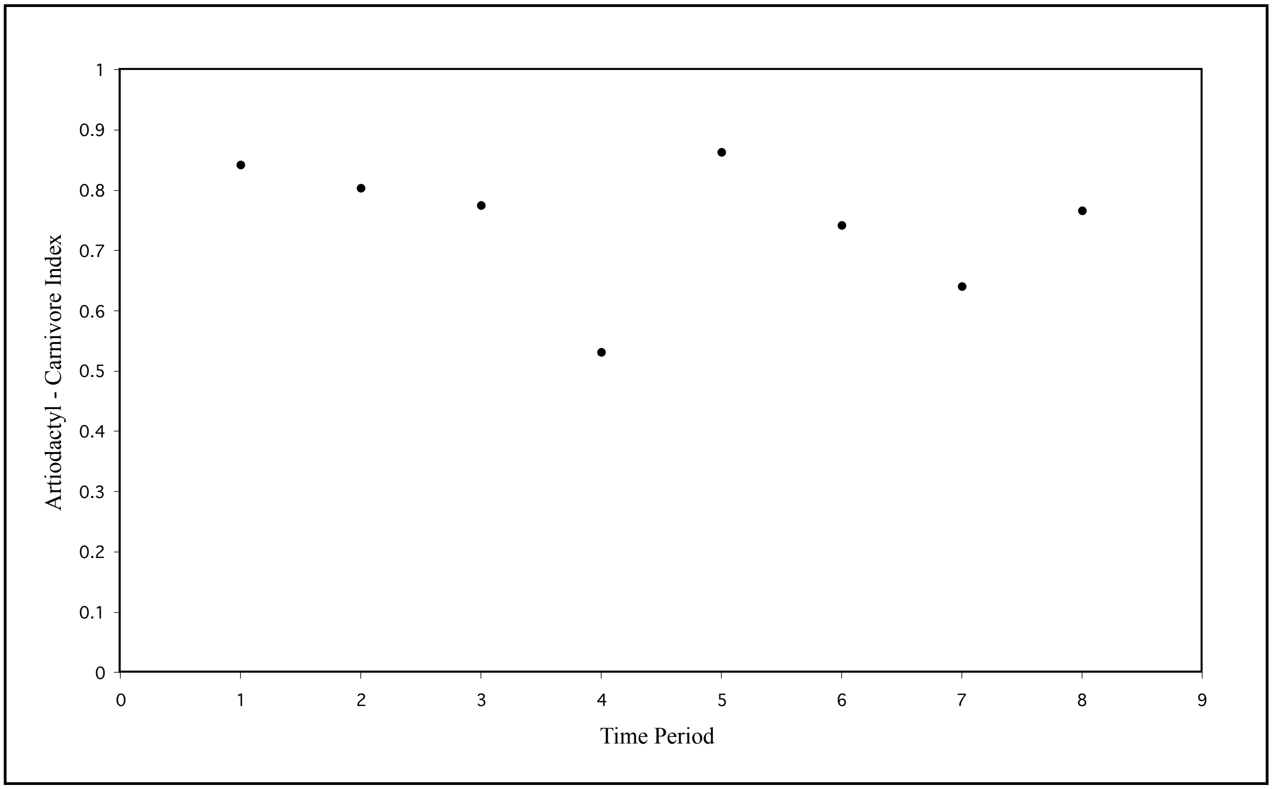


Figure 2.5. Artiodactyl-carnivore index.

Artiodactyl-Lagomorph Index

The artiodactyl-lagomorph index compares the two most common terrestrial mammal orders in the recently recovered Emeryville mammalian fauna reported here. Broughton (1999, personal communication 2002) was not confident that the lagomorph remains he identified represented human food refuse, since few specimens were burned or cut. However, the recently recovered lagomorph subassemblage reported here includes a considerable number of burned specimens and a few cut-marked ones as well, suggesting inclusion in the overall human diet at the sites. This independently derived index follows along the lines of Broughton's artiodactyl-carnivore index, but the underlying assumptions are generally more reliable. First, there is considerably less species diversity to be compared between East Bay artiodactyls (3 species) and East Bay lagomorphs (2 species) than there is between East Bay artiodactyls (3 species) and East Bay carnivores (potentially 14 species)—and concomitantly less microhabitat preference diversity to be factored in. These two orders (artiodactyls and lagomorphs) include species cited as ethnographically and archaeologically important food resources throughout California. In none of the available California ethnographies was I able to find reference to general food restrictions concerning any artiodactyls or lagomorphs, whereas various specific carnivore species are cited as being taboo.

The assumptions Broughton makes concerning the use of his artiodactyl-carnivore index are equal to and actually much more valid for those concerning the artiodactyl-lagomorph index. Terrestrial artiodactyls and lagomorphs occur in much more similar habitats than do artiodactyls and carnivores (which, being at higher trophic levels, tend to have much wider home ranges that cover a wide variety of habitat types). Elk and pronghorn are generally grazers and tend to occur in grassy or savanna habitats (Jameson and Peeters 1988; McCullough 1969). Black-tailed deer are browsers and tend to occur more commonly in ecotonal zones around

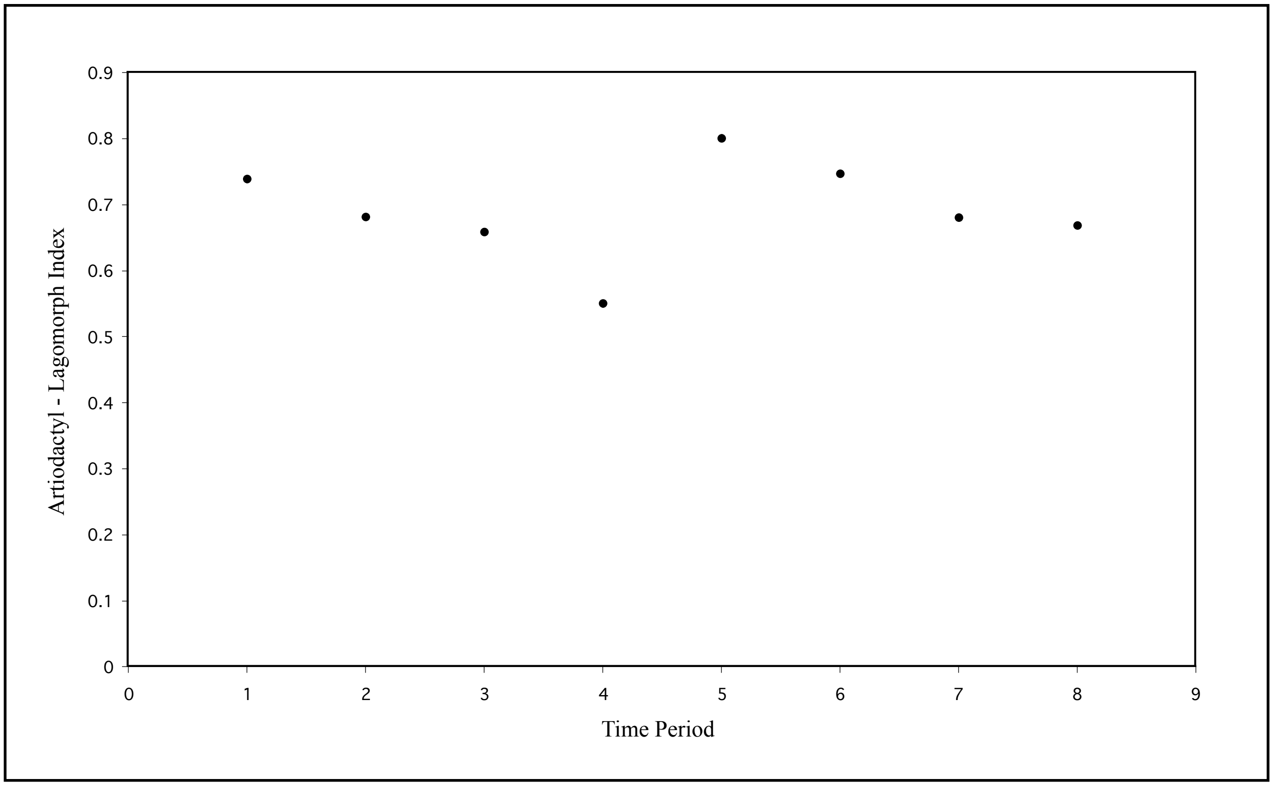


Figure 2.6. Artiodactyl-lagomorph index.

riparian, woodland, and chaparral habitats (Jameson and Peeters 1988). Likewise, black-tailed jackrabbits, relatively rare in the East Bay in general, tend to occur in more open, grassy areas, and cottontails (*Sylvilagus* species) tend to occur in ecotonal zones around riparian, woodland, and chaparral habitats (Jameson and Peeters 1988). The fine-grained search assumption of the prey model is more closely approximated by the artiodactyl-lagomorph index. Essentially, the artiodactyl-lagomorph index may be a better measure of terrestrial hunting efficiency as a comparison to the pinniped-otter index than the artiodactyl-carnivore index.

Figure 2.6 illustrates the distribution of the artiodactyl-lagomorph index across time for the recently recovered Emeryville collection. The general pattern is similar to that seen in the pinniped-otter and artiodactyl-carnivore indices in that representation of high-ranked terrestrial prey—artiodactyls—decreases steadily across the first four time periods, increases fairly dramatically across time periods four and five, and decreases once again across the last four time periods. The artiodactyl-lagomorph index shows less variability than the artiodactyl-carnivore index. This most likely has to do with more consistently large sample sizes for lagomorphs compared to carnivores. As with the artiodactyl-carnivore index, the artiodactyl (high-ranked terrestrial prey) index is relatively much larger than the pinniped (high-ranked marine/estuarine prey) index. The artiodactyl-lagomorph index provides further support to the contention that artiodactyls are generally the most common high-ranked prey at Emeryville.

Elk-Deer Index

The elk-deer index as derived by Broughton (1999:52) illustrates the relationship of the region's largest terrestrial herbivore, elk, relative to deer. Elk and deer generally prefer different habitats. Black-tailed deer prefer woodlands and ecotonal habitats with abundant browse, whereas elk prefer more open, grassy grazing habitat. Such predictable patchiness reduces the likelihood of absolutely

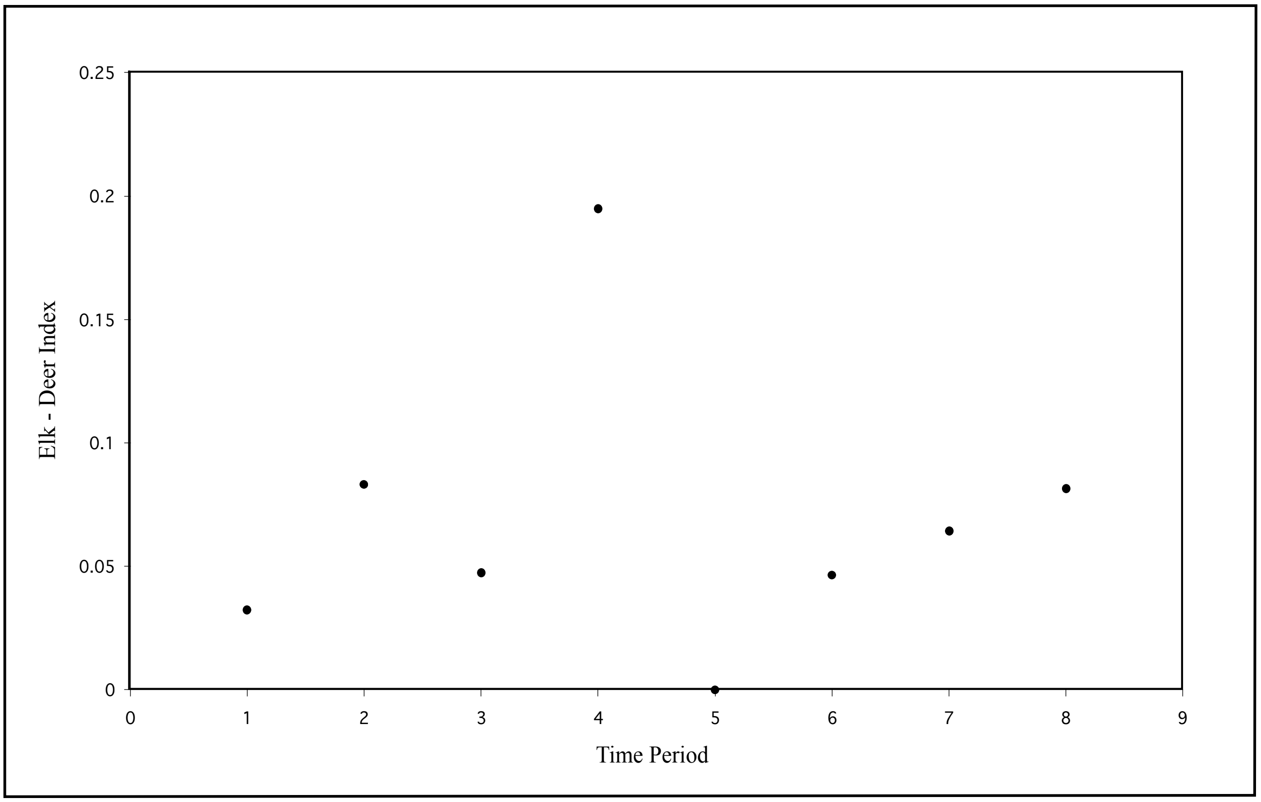


Figure 2.7. Elk-deer index.

random encounters, thus potentially violating the fine-grained encounter assumption necessary for this index to be valid within an optimal foraging framework. While the fine-grained encounter assumption may be violated, Broughton attempts to validate this index by stating that both elk and deer can often be found outside their "preferred" habitats.

Figure 2.7 represents the distribution of the elk-deer index across time within the recently recovered Emeryville mammal assemblage. The actual index values are low compared to the other indices calculated here. These low index values and the relatively low NISP values for elk suggest that, while ranking perhaps the highest in terms of meat value among the terrestrial mammal prey, they were not acquired in any great number during any given time period. The elk index varies considerably across the first four time periods, with a trend toward increasing values. A distinct reduction in overall elk index values is observed between time periods four and five. Elk index values show a steadily increasing trend across time periods five through eight. The pattern illustrated in Figure 2.7 suggests slight increases in the elk index at times when the general artiodactyls indices tend to decrease and lower ranked prey appear to increase their representation. In general, elk are poorly represented in all time periods but do appear to exhibit a trend opposite that of the artiodactyls in general.

Artiodactyl-Otter Index

The artiodactyl-otter index compares the two most common mammal species in the ALA-309 and ALA-310 vertebrate archaeofaunas. This index essentially compares the marine/estuarine and terrestrial ecotonal resource acquisition patches. Broughton (1999) declares that this index compares high-ranking and low-ranking prey types that occur in distinctly different habitats. Since these two prey types are "patchy" compared to one another, the fine-grained search assumption of the prey model may be violated more seriously than any previously discussed index. Broughton (1999:54) argues that

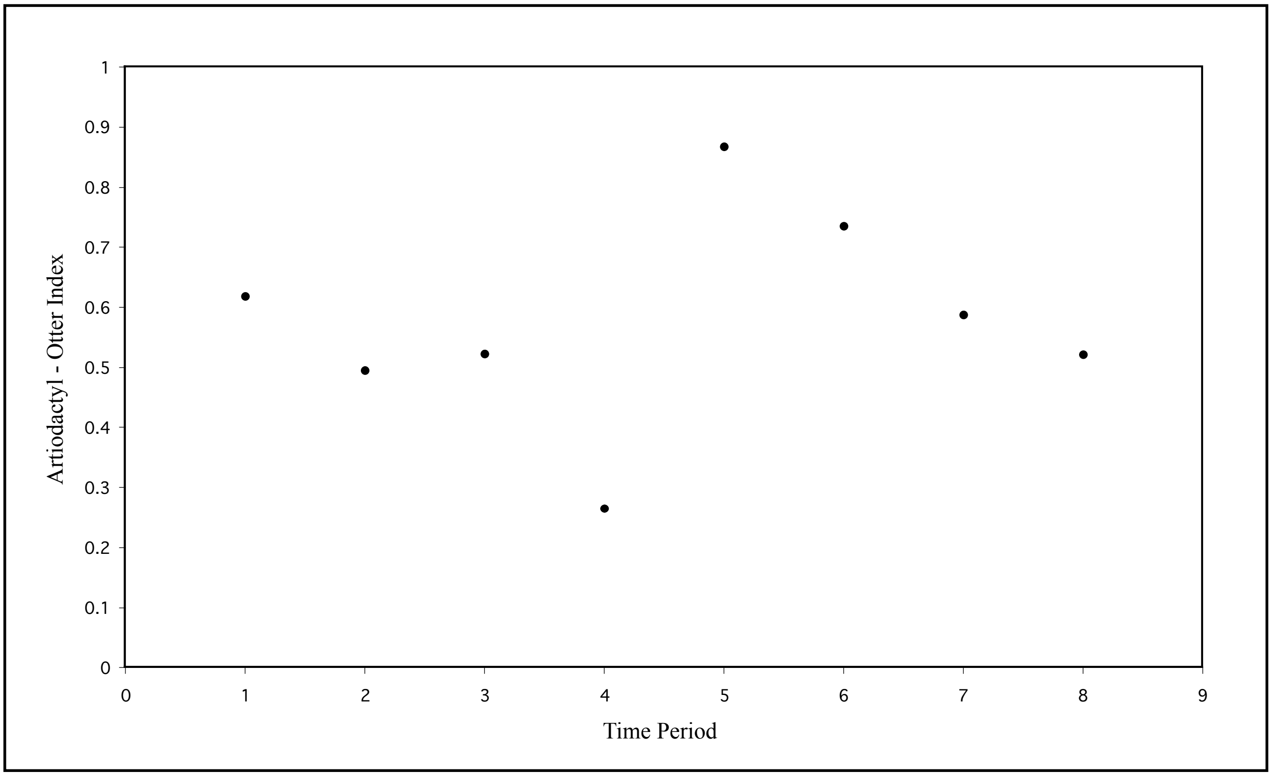


Figure 2.8. Artiodactyl-otter index.

in the early period of the Emeryville Shellmound's occupation "prior to . . . local depression and disturbance . . . sea otters, deer, and elk may have been . . . randomly encountered . . . especially at the interface of the terrestrial and estuarine habitat types."

I find this argument spurious, since the ecological niches of these three mammals, especially those filled by terrestrial artiodactyls versus marine sea otters, are so distinct and since each taxon has evolved distinct suites of morphological (tooth morphology, digestive tracts, and pelage) and behavioral (sexual display, elk trumpeting, scent marking) adaptations to its respective habitat. It would be highly unusual to randomly encounter these taxa while searching for the other. Artiodactyls do not swim in the Bay, nor do sea otters browse in grassy meadows. In this respect, I believe the fine-grained search assumption is indeed seriously violated. However, as Broughton points out, this index certainly does "reflect the relative profitability of the estuarine and terrestrial resource patches," whether or not they are distant.

Figure 2.8 illustrates the distribution of the artiodactyl-otter index across time for the recently recovered Emeryville collection. The general pattern is similar to that seen in the pinniped-otter, artiodactyl-carnivore, and artiodactyl-lagomorph indices. The representation of high-ranked terrestrial prey—artiodactyls—decreases steadily across the first four time periods, increases fairly dramatically across time periods four and five, and decreases once again across the last four time periods.

The artiodactyl-otter index shows somewhat greater variability than the artiodactyl-carnivore and artiodactyl-lagomorph indices. This most likely has to do with more consistently large sample sizes of sea otters compared to terrestrial carnivores. As with the artiodactyl-carnivore and artiodactyl-lagomorph indices, the magnitude of the artiodactyl (high-ranked terrestrial prey) index is relatively much larger than the pinniped (high-ranked marine/estuarine prey) index. Following on the assumption that the artiodactyl-otter index reflects relative productivity of the estuarine versus terrestrial resource patches (in terms of mammals), one pattern seems clear. The index suggests that while artiodactyls, especially black-tailed deer, are generally the most common high-ranked prey at ALA-309, sea otters were an important part of the mammal protein diet at ALA-309, and they increase in relative importance across the first four and last four time periods. Artiodactyls again exhibit a radical increase in representation between time periods four and five.

SUMMARY

In general terms, a fairly consistent pattern may be seen in the relative abundances of the mammal species selected for more detailed analysis in the recently recovered ALA-309 mammal collection. High-ranked prey types, black-tailed deer and harbor seals, decline in relative abundance through time. However, they decline in two distinct phases. Across the first four time periods, high-ranked terrestrial and marine species (artiodactyls and pinnipeds, respectively) decrease in relative abundance. In contrast, the contribution of lower ranked terrestrial and marine species such as canids, rabbits, and sea otters increases. A marked increase in relative abundances of the high-ranked marine and terrestrial species, at times higher than seen in the earliest occupational periods of the sites, occurs between time periods four and five in four out of the five indices presented above. The pattern of a clear decrease in relative abundances of high-ranked terrestrial and marine species is then repeated across the last four time periods. Interestingly, elk, arguably the highest ranked terrestrial prey item, do not follow this general pattern. Although consistently but poorly represented in general, elk (with respect to the elk-deer index) appear to increase in relative abundance when artiodactyls in general decrease dramatically in representation.

A Brief Comparison to Other Bay Area Faunal Assemblages

Comparing the Emeryville Shellmound mammal collection to other Bay Area archaeological mammal faunas illustrates a number of similarities and differences (Table 2.6). I compare the findings reported here to those from 13 other East Bay shore archaeological site assemblages (ALA-309 [Broughton 1999], ALA-12, ALA-13, ALA-307, ALA-328, ALA-329, CCO-268, CCO-269 [a and b], CCO-270 [a and b], CCO-271, CCO-295, CCO-297, CCO-298) and one South Bay inland site (SCL-178). These data were extracted from Bickel (1981), Broughton (1999), Busby (1975), Holson et al. (2000), Simons (1979, 1981a, 1992), and Wilson (1993).

This comparison is only general at this point and does not account for temporal placement of these late Holocene sites. For a more detailed discussion of temporal trends in Bay Area mammal consumption, see Broughton (1994b) and Simons (1992). Both authors observe a general increase in sea otter consumption across the later Holocene but suggest slightly different causes—resource depression and expanding diet breadth for Broughton (1994b) and resource depression and coharvesting for Simons (1992).

In general, East Bay shore sites appear similar in terms of species diversity and resource focus. The five most common economically important mammal species at ALA-309 and ALA-310 appear to be ranked similarly at the other bayshore sites, with some difference in actual precedence. Other carnivores, such as raccoon, badger, and bobcat, appear to be more common in central East Bay (Alameda County) sites than in northern East Bay (Contra Costa County) sites. Cetaceans are extremely rare except at Emeryville. Cottontails are common in most bayshore sites, whereas jackrabbits are common only at the more inland South Bay site (SCL-178).

In general, sea otters are the single most common identified species in these sites, followed by deer, dogs, cottontails, elk, and harbor seals, respectively. Other fairly common species include raccoon, striped skunk, badger, and pronghorn. The most common rodents are pocket gophers, followed by voles and ground squirrels. Most of the rodent remains probably represent intrusive individuals but could be potential food items (Heizer 1978; Levy 1978).

Table 2.6. Emeryville Shellmound Mammals Compared to Other Bay Area Sites.

		Site																
Scientific Name	**Common Name**	**ALA-309**	**ALA-310**	**ALA-310***	**ALA-12**	**ALA-13**	**ALA-307**	**ALA-328**	**ALA-329**	**SCL-178**	**CCO-268**	**CCO-269**	**CCO-270**	**CCO-271**	**CCO-295**	**CCO-297**	**CCO-298**	**All Sites**
Sorex sp.	Shrew	3																3
Scapanus latimanus	Broad-footed mole	17	5							4	1	12	2			2	2	45
Lepus californicus	Black-tailed jackrabbit	1	2						2	86								91
Lepus sp.	Hare	1					2	1										4
Sylvilagus audubonii	Audubon's cottontail	79	32							6								117
Sylvilagus bachmani	Brush rabbit	5	1	1						4								11
Sylvilagus sp.	Cottontail rabbit	1,676	403	309	9	47	1	257	6	204	6	31	20	2		8	3	2,982
Leporidae	Hare, rabbit family	60	5															65
Microtus californicus	California vole	323	46	1						13	95	321	546	49		57	16	1,467
Microtus sp.	Vole	109	15	1														125
Neotoma fuscipes	Dusky-footed wood rat	13		1						11								25
Neotoma sp.	Wood rat	258	44	8	1	13	1	51				4	5					385
Onychomys torridus	Grasshopper mouse									3								3
Reithrodontomys megalotis	Harvest mouse									5								5
Peromyscus sp.	Deer mouse	2	3															5
Thomomys bottae	Botta's pocket gopher	2,745	1,680	2,060	21	310	25	919		783	248	452	137	67		244	234	9,925
Thomomys sp.	Pocket gopher	351	4															355
Dipodomys heermani	Heerman's kangaroo rat	2								13						2		17
Dipodomys sp.	Kangaroo rat											8	3					11
Perognathus californicus	California pocket mouse	4	9							2								15
Perognathus sp.	Pocket mouse	45																45
Rattus sp.	Rat (introduced)	1											2			5		8
Castor canadensis	Beaver			1														1
Sciuridae	Squirrel family	24	4															28

Table 2.6. (cont.)

		Site																
Scientific Name	**Common Name**	**ALA-309**	**ALA-310**	**ALA-310***	**ALA-12**	**ALA-13**	**ALA-307**	**ALA-328**	**ALA-329**	**SCL-178**	**CCO-268**	**CCO-269**	**CCO-270**	**CCO-271**	**CCO-295**	**CCO-297**	**CCO-298**	**All Sites**
Spermophilus beecheyi	California ground squirrel	21	3	1	2	45				335	1	3	6			44	12	473
Spermophilus sp.	Ground squirrel	4	2															6
Rodentia	Rodent, unid	1,031	204															1,235
Rodentia, sm.	Rodent, small	142	45															187
Delphinidae	Dolphin family	12	5	62				2										81
Tursiops gilli	Bottlenose dolphin			54			1											55
Grampus griseus	Grampus			1														1
Phocoena phocoena	Harbor porpoise			26														26
Delphinus delphis	Common dolphin	17																17
Odontoceti	Toothed whale	1																1
Mysticeti	Baleen whale			1														1
Cetacea	Whale order	128	43	5											20			196
Canis cf. *lupus*	Gray wolf		1	4														5
Canis cf. *latrans*	Coyote			594														594
Canis latrans	Coyote	21		49					17	15								102
Canis familiaris	Dog								6	2								8
Canis sp.	Dog, wolf, coyote	707	176		61	265	40	955		4	4	30	1	2			1	2,246
Urocyon cinereoargenteus	Gray fox	3	4	1					2									10
Canidae	Dog family	1	1	3					18									23
Procyon lotor	Raccoon	98	58	88	1	24	2	88	2			4	1		12			378
Lutra canadensis	River otter			1														1
Enhydra lutris	Sea otter	3,512	837	4,768	28	313	29	1,290	146	1	3	27	2	2	232	44	5	11,239
Mephitis mephitis	Striped skunk	202	14	53	1	32		44	5		7	1			8	5		372
Mustela frenata	Long-tailed weasel	6	1	1						1		1						10
Spilogale putorius	Spotted skunk	2		1				2										5
Taxidea taxus	Badger	24	9	22	4	31	1	98	10	5		1			12			217
Ursus americanus	Black bear			1					1									2

Table 2.6. (cont.)

		Site																
Scientific Name	**Common Name**	**ALA-309**	**ALA-310**	**ALA-310***	**ALA-12**	**ALA-13**	**ALA-307**	**ALA-328**	**ALA-329**	**SCL-178**	**CCO-268**	**CCO-269**	**CCO-270**	**CCO-271**	**CCO-295**	**CCO-297**	**CCO-298**	**All Sites**
Ursus arctos	Grizzly bear	2		2						4								8
Ursus sp.	Bear	3																3
Felis concolor	Mountain lion	7		1					1									9
Lynx rufus	Bobcat	30	2	34		1		9	2	4		1			1			84
Carnivora	Carnivore order	104	9															113
Callorhinus ursinus	Northern fur seal	2																2
Arctocephalinae	Fur seal subfamily			19														19
Eumetopias jubatus	Steller's sea lion	1		5									3					9
Zalophus californianus	California sea lion	61	5	12				1	5			2						86
Otariidae	Eared seal family	19	13	69			10								31			142
Phoca vitulina	Harbor seal	439	151	258	1	1	13	25	25			10			64	2		989
Pinnipedia	Seal, sea lion order	89	16									2						107
Antilocapra americana	Pronghorn	20	7	32	5	17	2	27	29				2					141
Cervus elaphus	Elk	227	73	808	80	50	4	109	29	3			3		13	19	1	1,419
Odocoileus hemionus	Black-tailed deer	2,404	636	2,044	54	547	73	459	126	107	3	41	2	4	86			6,586
Cervidae	Deer family	116	32	209														357
Artiodactyla	Ungulates	1,322	169	1,870								10						3,371
Artiodactyla, lg.	Ungulates, large	16	2															18
Artiodactyla, md.	Ungulates, medium			2,291														2,291
Artiodactyla, sm.	Ungulates, small	2																2
	Totals	16,515	4,771	15,772	268	1,696	204	4,337	432	1,615	368	961	735	126	479	432	274	48,985

Fish and Birds at ALA-309

A large sample of fish remains recovered from 1999 excavations at ALA-309 (Gobalet and Hardin 2002:Table 2.7) provides an excellent example of recovery bias. The identified fish specimens alone number 49,920 (versus 2,004 in the early twentieth-century samples) and exhibit greater overall species richness than was evident in prior analyses. A total of 28 genera and 27 species representing 21 fish families are identified in the 1999 sample, compared to the 4 genera and 2 species representing 8 families that Broughton (1999) identified.

Small fish such as jacksmelt (*Atherinopsis californiensis*: Atherinopsidae), Pacific sardine (*Sardinops sagax*: Clupeidae), northern anchovy (*Engraulis mordax*: Engrualidae), and similar species were caught in recently excavated samples primarily sieved through 3-mm mesh . Broughton (1999) reports few atherinopsid and clupeiform fish (Table 2.7). Their presence in relatively large numbers raises these families of small fish to a much greater level of importance in the past subsistence regime at the site. Their underrepresentation is due to a lack of finer screening in his samples from 1903, 1909, and 1924 excavations. Virtually all the 1999 sampled bones of these smaller species passed through 6-mm mesh as opposed to 3-mm mesh.

The more numerous 1999 fish sample also includes many of the dominant species reported by Broughton (1999), but in much greater numbers. In terms of NISP, California bat rays dominate the 1999 collection, whereas they are a distant second in the assemblage reported by Broughton (1999). Likewise, salmon appear more than twice as numerous in the recently analyzed sample. Sturgeon are well represented in the 1999 collection, but come nowhere near to constituting the nearly 60% percent of the collection they do in the earlier samples (Table 2.7).

Of course, a single large sturgeon could provide more meat than 1,000 sardines, resulting in a high relative rank as a prey item in the ecological terms of the prey model. The greater relative numbers of small-bodied fish, most easily harvested in bulk with small-gauge nets, indicate a wider diet breadth for the past inhabitants of the site than previously documented. Gobalet's (2002) data suggest limited exploitation of freshwater fish species (five genera and species) other than salmonids (Table 2.7). Broughton (1999) identified no freshwater fish species. Further research may be able to determine if the ALA-309 archaeological fish fauna became more diverse through time and if more microenvironments were exploited. Both patterns could represent possible indicators of dietary stress resulting from either overexploitation of highly ranked resources or a growing hungry population.

The bird remains recovered during the 1999 project exhibit similar but less profound differences in number and species richness when compared to the previously identified samples (Broughton 1999; Howard 1929:Table 2.8). The recent (1999) collection is much more numerous (10,922 versus 2,302) and includes 10 genera not previously reported (Table 2.8). Ducks and geese (Anseriformes), followed by cormorants (Pelecaniformes), dominate both collections. As Howard (1929) found, juvenile cormorant remains are abundant. The abundance of juvenile cormorant remains at ALA-309 illustrates two important points: (1) occupation at the site during hatching season; and (2) the presence of cormorant rookeries relatively close to the site, probably on Yerba Buena Island. Eight cormorant breeding colonies are currently located in San Francisco Bay (Stenzel et al. 1995), the closest to ALA-309 being on the Bay Bridge.

The use of finer-mesh screens is clearly evident in the numbers and diversity of rodents, birds, and especially fish recovered from the recent ALA-309 and ALA-310 investigations. Few of the other, earlier excavated bayshore sites yielded such diverse rodent, bird, and fish archaeofaunas. This increased diversity can be attributed to sampling and recovery differences. Various authors have discussed sample size effects, one of which is increased species diversity with greater relative sample sizes (e.g., Baxter 2001; Grayson 1978, 1984; James 1997; Leonard and Jones 1989; Plog and Hegmon 1993).

Table 2.7. Identified Fish Remains from ALA-309 and ALA-310.

Scientific Name	**Habitat**	**Common Name**	**ALA-309 (2002)**	**ALA-309 (1999)**
Notorynchus cepedianus	M	Sevengill Shark	7	
Carcharodon carcharias	M	White Shark	1	
Carcharhinidae	M	Requiem Sharks	2010	281
Raja sp.	M	Ray	1	
Rajiformes	M	Rays	9237	
Platyrhinoidis triseriata	M	Thornback	1	
Myliobatis californica	M	California Bat Ray	11561	403
Elasmobranchiomorphi	M	Cartilaginous Fish	414	
Acipenser medirostris	A	Green Sturgeon	72	
Acipenser transmontanus	A	White Sturgeon	883	
Acipenser sp.	A	Sturgeon	6802	1193
Archoplites interruptus	F	Sacramento Perch	11	
Atherinopsis californiensis	M	Jacksmelt	1	
Atherinopsidae	M	Smelt	4782	2
Atractoscion nobilis	M	White Seabass	5	2
Ptychocheilus grandis	F	Sacramento Pikeminnow	1	
Orthodon microlepidotus	F	Sacramento Splittail	1	
Gila crassicauda	F	Thick-tailed Chub	3	
Lavinia exilicauda	F	Hitch	1	
Cyprinidae	F	Minnows	20	
Catostomus occidentalis	F	Sacramento Sucker	4	
Engraulis mordax	M	California Anchovy	111	
Sardinops sagax	M	South American Pilchard	18	
Clupea pallasi	M	Pacific Herring	137	
Clupeidae	M	Sardines	5985	7
Cymatogaster aggregata	F, M	Shiner Perch	3	
Rhacochilus vacca	M	Pile Perch	3	
Amphisticus sp.	M	Surfperch	55	
Embiotoca sp.	M	Seaperch	3	
Embiotocidae	M	Surfperch	457	1
Gasterosteus aculeatus	F, M	3-spined Stickleback	4	
Gillichthys mirabilis	M	Long-jawed Mudsucker	322	
Leptocottus armatus	M	Pacific Staghorn Sculpin	16	
Cottidae	F, M	Sculpins	1	
Oncorhynchus kisutch	A	Silver Salmon	6	
Oncorhynchus mykiss	A	Steelhead	15	
Oncorhynchus sp.	A	Salmon	4722	113
Oncorhynchus tshawytscha	A	King Salmon	2090	2
Pleuronectiformes	F, M	Flounders	87	
Porichthys notatus	M	Plainfin Midshipman	34	
Porichthys sp.	M	Midshipman	6	
Sebastes sp.	M	Rockfish	26	
Thunnus alalunga	M	Albacore	1	
Total NISP			49920	2004
Actinopterygii		Ray-finned Fish	17119	
Grand Total			67039	2004

A = anadromous, F = fresh water, M = marine.

Table 2.8. Identified Bird Remains from ALA-309 and ALA-310.

Bird Taxa	**ALA-309**	**ALA-310**	**ALA-309**[1]
Loon (*Gavia* sp.)	41	2	36
Grebe (*Podiceps* sp.)	70	9	3
Grebe (*Aechmophorus* sp.)	16	2	7
Grebe (*Podilymbus* sp.)	8		
Grebe (Podicipedidae)			5
Fulmar (*Fulmarus glacialis*)	1		
Pelican (*Pelecanus* sp.)	6	9	21
Cormorant (*Phalacrocorax* sp.)	2,341	70	486
Great blue heron (*Ardea herodias*)	13	4	5
Goose (*Anser/Branta/Chen* sp.)	1,776	153	327
Duck (*Anas/Aythya/Bucephala/Melanitta/Oxyura* sp.)	2,496	1,628	76
Ducks and geese (Anatidae)			1,027
Turkey vulture (*Cathartes aura*)	2		2
California condor (*Gymnogyps californianus*)	1		
Hawk (*Accipiter* sp.)	6	5	
Hawk (*Buteo* sp.)	19	2	18
Hawk (*Circus* sp.)	9	15	2
Black-shouldered kite (*Elanus caeruleus*)			2
Bald eagle (*Haliaeetus leucocephalus*)	1		4
Golden eagle (*Aquila chrysaetos*)	3		
Falcon (*Falco* sp.)	11	13	8
Quail (*Callipepla californica*)	28	2	5
Chicken (*Gallus gallus*)	2	10	
Crane (*Grus canadensis*)	21		22
Clapper rail (*Rallus longirostris*)	7		3
Coot (*Fulica americana*)	35	3	4
Shorebird (*Numenius* sp.)	158	136	20
Shorebird (*Limosa fedoa*)	86	89	3
Shorebird (*Tringa* sp.)	2	6	1
Shorebird (*Catoptrophorus* sp.)	29	15	2
Shorebird (*Limnodromus* sp.)	12	135	1
Shorebird (*Calidris* sp.)	9	103	
Shorebirds (Scolopacii)			22
Gull (*Larus* sp.)	40	12	15
Kittiwake (*Rissa tridactyla*)	2		
Murre (*Uria aalge*)	313	241	72
Pigeon guillemot (*Cepphus columba*)	1		
Cassin's auklet (*Ptychoranphus aleuticus*)	1		
Barn owl (*Tyto alba*)	140	23	20
Owl (*Otus* sp.)	3		
Owl (*Bubo* sp.)	7	2	6
Owl (*Asio* sp.)	1		1
Raven (*Corvus corax*)	27	43	10
Crow (*Corvus brachyrhynchos*)	267	122	40
Crow/raven (*Corvus* sp.)			19
Passeriform bird	20	37	
Totals	8,031	2,891	2,302

Note: Data from Broughton 1999; Simons et al. 2002.

[1] Broughton 1999.

CONCLUSIONS

Analysis of the recently recovered Emeryville Shellmound mammal remains has shown that this collection is a rich resource for zooarchaeological study and for developing a better understanding of past hunting strategies and human–environment interactions in the East Bay. Many of the findings compare favorably with previous work on earlier Emeryville vertebrate archaeofaunas. However, modern recovery techniques and much larger sample sizes have added many more species to the known diversity of the Emeryville Shellmound and provide even more fine-grained information concerning the vertebrate resource exploitation patterns of the site's past inhabitants and for use in paleoenvironmental reconstruction. The current and previous studies illustrate the rich diversity of vertebrates available to the past inhabitants of the mound.

Rodent remains are numerous in the samples reported here. The specimens may represent either human or carnivore prey items. Broughton (1999) did not find convincing evidence that humans were responsible for their appearance in the Emeryville fauna and suggested that most of the rodents represented carnivore meals. However, Levy (1978) states clearly that rodents were captured in a variety of ways and consumed by Costanoans.

At least six economically important mammal species occur fairly commonly throughout the ALA-309 and ALA-310 time continuum. These species include sea otter, black-tailed deer, elk, *Canis* (probably coyote but maybe some domestic dogs), harbor seal, and cottontail rabbit. However, within a given time period, the presumed dietary contribution of a given species varies greatly from unit to unit. A number of other smaller carnivores, pinnipeds, cetaceans, and pronghorn supplemented the mammalian diet at these two sites.

The most interesting patterns are those seen in mammalian exploitation indices originally developed by Broughton (1999). Broughton (1999) indicates a steady decrease in high-ranked mammalian species through time and a concomitant shift to lower ranked sea otters and carnivores, with a strong resurgence in high-ranked species late in his sequence. He suggests that the resurgence in highly ranked mammal species late in the Emeryville Shellmound sequence is due to hunters accessing more distant, undepleted patches (Broughton 1999:64–65). The primary assumption here is that patches more distant from ALA-309 were available—that is, not claimed by anyone else. Given the potential population density of the East Bay during the Late period (Lightfoot and Luby 2002), this may not be a safe assumption.

The data from this analysis when evaluated with respect to Broughton's indices (and an additional one) over similar time intervals do not exactly match his findings. The indices show a steep decrease in high-ranked prey early in the occupation, with a radical resurgence around 1,500 years ago and another fairly steep decrease in high-ranked species near the end of the sequence (deer, elk, and harbor seals as opposed to sea otters, small carnivores, and rabbits). If Broughton (1999:64–65) is correct, then the more distant resource patches accessed at the end of the Emeryville Shellmound sequence that Uhle (1906) and Schenck (1926) produced were rapidly depleted. An alternative explanation is technological. It is possible that the resurgences of highly ranked mammalian prey species illustrated here and by Broughton (1999) are due to the introduction of more efficient hunting technology—the bow and arrow. Broughton (1999:65–66) does briefly address this alternative explanation but quickly discards it as a possibility, stating that the bow and arrow was introduced into the Bay Area just after the resurgence he illustrates, around 950 B.P. Milliken et al. (2007:117) state that the first arrow-sized projectile points appear in the Bay Area after A.D. 1250 (750 B.P.). Clearly, the dating of the initial introduction of the bow and arrow into the San Francisco Bay area remains unresolved.

The introduction of new hunting technology into a relatively depleted environment could produce a similar resurgence of highly ranked mammalian species, especially if showing off or costly signaling (Bird et al. 2001; Broughton and Bayham 2003; Hildebrandt and McGuire 2002; McGuire and Hildebrandt 2005) was important. Intensification of hunting in an already depleted environment could produce a rapid resurgence, with an equally dramatic decline when no other underutilized patches remain available to exploit.

Finally, this analysis sadly attests to the profound environmental degradation the East Bay has witnessed over the past 200 years. Animals once common, such as tule elk, pronghorn, sea otter, grizzly bear, and vast flocks of resident and migratory waterfowl, have been completely extirpated from the entire Bay Area. The various habitats once available to the inhabitants of ALA-309 and ALA-310 have been completely replaced by urban sprawl, houses, roadways, and a fully anthropogenic landscape. Like the mounds themselves, Temescal Creek, and its potential to support all kinds of vertebrates, has been destroyed. The last vestiges of native habitat close to the bay shore are found only on Brooks Island, on the north side of Albany Hill (El Cerrito), and in Coyote Hills Regional Park, and even those are only remotely similar the East Bay of 1,000 years ago.

ACKNOWLEDGMENTS

I wish to extend thanks to Sally Morgan of URSGW-C for the opportunity to analyze the vertebrate remains from ALA-309 and ALA-310. Specimens not still undergoing analysis at UCLA are curated by the Phoebe A. Hearst Museum of Anthropology at UC Berkeley. Identification of the mammal remains from the Emeryville sites was facilitated by Carla Cicero, James Patton, and David Wake, who provided access to comparative osteological materials in the UCBMVZ; Christine Thacker, Jeffrey Seigel, Richard Feeney, John Heyning, and David Janiger, who provided access to and loaned specimens from the LACMNH; and Kathy Molina, who provided access to and loaned specimens from the UCLA Dickey Natural History Collection. Thanks also to Ken Gobalet and Kalie Hardin, Department of Biology, CSU, Bakersfield, who analyzed the 1999 fish remains; Dwight Simons, Archaeological Research Center, CSU, Sacramento, who analyzed the 1999 bird remains; and Jack Broughton, Department of Anthropology, University of Utah, for various insightful discussions regarding this project and its findings.

The staff of the CIOA-ZL identified the mammal remains recovered from the 1999 excavations at ALA-309 and ALA-310. The lab staff included Mercedes Duque, Ana Gonzalez, Lady Harrington, Kay Hullett, Judy Porcasi, John Schroeder, and Thanos Webb. I supervised the overall identification process, identified as many specimens as possible, and confirmed most identifications made. Marillyn Holmes and Sue Verity volunteered considerable amounts of time on this project. I thank Sally Donohue and Wendy Teeter for their valuable assistance as the project wound its way to completion. I am indebted to Michael Glassow and Terry Joslin for their invitation to participate in this volume, their editorial comments, and those of two anonymous reviewers. Of course, the conclusions presented here and any potential errors are mine and mine alone.

CHAPTER 3

Contradictions and Complements:

The Use of Geochemistry and Body Part Utility Analysis to Detect Nonlocal Procurement Strategies In Late Holocene Northern California

DEANNA N. GRIMSTEAD

The procurement, consumption, and discard of animals often serve several sociopolitical and socioeconomic functions (Potter 1997; Reitz and Wing 1999). Revealing these functions and underlying human behaviors often requires application of several different approaches, including ethnozooarchaeology, experimental zooarchaeology, and quantitative zooarchaeology. These methods are robust and diverse (Lyman 1994b; Reitz and Wing 1999; Stiner 2005), such that a wide array of questions related to human behavior may be addressed. In this paper, a traditional method, body part representation, and a method relatively new to zooarchaeology, geochemical sourcing, will be used to reconstruct the procurement and discard behavior of prehistoric northern California foragers. The analysis of the procurement and discard of large game inferred from archaeofaunal remains collected from a midden mound site in northern California (CA-COL-267) will provide an opportunity to ask: Did prehistoric human hunters travel greater distances to obtain large-bodied prey items following hypothesized resource depression? To answer this question, an evaluation of resource depression will be based upon proportions of large-bodied prey items (artiodactyls: the order including deer, pronghorn, and sheep) relative to small-bodied prey items (lagomorphs: the taxonomic order including jackrabbits and cottontails), while relative procurement distances will be evaluated via body part representation and geochemical sourcing techniques.

THEORETICAL BACKGROUND AND EXPECTATIONS

Throughout California, research has demonstrated that as human population density and aggregation increased, evidence of resource depression and intensification also increased (Basgall 1987; Broughton 1994a, 1994b, 1995, 1999, 2002; Broughton and Grayson 1993; Hildebrandt and Jones 1992; Porcasi et al. 2000; Raab and Jones 2004). The concept of resource depression stems largely from the observation that as a predator comes into a region and/or inhabits an area, resource depression of prey populations takes three forms: overhunting (exploitation depression), movement of prey items out of the area (habitat depression), and changes in individual or population prey behavior that serve to reduce rates of encounter with the predator (behavioral depression), all of which serve to reduce the availability of and/or rates of encounter with prey (Charnov et al. 1976). Research among agricultural societies has revealed that as productivity per unit time invested decreases, people invest increasingly more energy simply to maintain the same amount of productivity. This behavior is termed resource intensification, and it applies to all levels of society (Boserup 1966). Similarly, resource extensification is the increased investment in the procurement of resources from nonlocal sources (Beaton 1991). Resource depression, intensification, and extensification blend well into expectations derived from the central place foraging model (Cannon 2003; Orians and Pearson 1976), which assumes that foragers leave the central place—in this case the archaeological site—to forage, then return to the central place with food to store, consume, or share (Schoener 1979). The longer a group of foragers inhabits the central place and the more its population increases, the greater the extent of resource depression in the area surrounding the central place. As a result, more energy is invested to obtain the same quantity of returns locally (resource intensification) and nonlocally (resource extensification) (see Hamilton and Watt's 1970 concept of refuging systems). Increasing energy investments may be observed in the distance traveled to procure fauna that was once locally available and/or in a broadening of diet breadth, as predicted under the prey choice model (Pulliam 1974).

The site investigated in this research, CA-COL-267, was a year-round habitation site, or central place, with an approximate occupation span between 1200 and 800 B.P.[1] Resource depression can occur rather quickly, certainly within the time span being investigated here (Charnov et al. 1976; Grayson 2001); therefore, it is hypothesized that the availability of artiodactyls near this central place declined through time, such that foragers traveled greater distances to obtain deer, a high-economic-return prey item. As artiodactyls (high-ranked in terms of economic efficiency; see Bayham 1979) became less available locally, the forager spent more time and energy to obtain the same prey item farther from the habitation site. Here, a high-ranked prey item is defined in its classic sense within behavioral ecology (Krebs and Davies 1981), which ranks a set of prey items based upon each one's overall caloric returns after the cost of procurement has been deducted. Previous archaeological applications of optimal foraging theory have argued a prey's body weight to be highly correlated with its prey rank (Bayham 1979; Broughton 1994a, 1994b; Smith 1991), such that when a forager is confronted with three prey items—a deer, jackrabbit, and pocket gopher—the deer would be ranked one (meaning more preferred), the jackrabbit ranked two, and the pocket gopher ranked three (meaning least preferred). As local deer were hunted and became less available, CA-COL-267 hunters should have broadened their diet breadth and procured high-ranked prey from farther afield. Changes of diet breadth are not evaluated in this paper; rather, resource depression is evaluated by investigating the presence and proportions of nonlocal large game. Increases in nonlocal prey through time would be considered evidence of local habitat resource depression.

Body part profiles and utility analysis are both well-established concepts in zooarchaeology (Binford 1978; Lyman 1994b; Perkins and Daly 1968; White 1952, 1953b, 1954, 1955) and are considered standard methods (Lupo 2001; Metcalfe and Jones 1988). Ethnoarchaeological research has shown that field processing and transport decisions about prey body parts obtained at some distance from the central place often result in only body parts with the most and highest-quality meat being returned (O'Connell and Hawkes 1988; O'Connell et al. 1990), an observation that fits with theoretical predictions of optimal foraging behavior (Metcalfe and Barlow 1992). If increased travel distances were endured later in time, then body part profiles and utility analyses should reflect higher proportions of high-utility elements later in time.

An inherent problem with using utility indices and/or body part profiles to assess whether field processing occurred as a result of distance traveled is that a zooarchaeologist is unable to distinguish between forager decisions based upon caloric and noncaloric currencies. For example, it is possible that low-utility parts would be transported for tools or that the entire carcass would be transported as a symbol of prestige, despite the prediction of an economic efficiency model that lower utility parts would be discarded. In this example, three potentially confounding variables are at work: value as a raw material for tools, value as a prestige item, and value as a source of calories. Because these potential variables can all be acting to produce observed body part patterns, this paper seeks to use geochemical sourcing techniques in tandem with utility indices to assess the relative distance of procurement. The expectation for this tandem use is: the relative abundance of large game specimens having nonlocal geochemical signatures should increase through time, reflecting the decreasing local availability of high-ranked prey.

The geochemical sourcing aspect of the paper requires a brief proof of concept utilizing a sample of modern black-tailed deer (*Odocoileus hemionus*) from a cross section of northern California. Discriminant functions are derived from modern samples of known origin, then applied to the archaeological black-tailed deer specimens from CA-COL-267. Ultimately, the tandem use of geochemical sourcing and body part utility analyses reveals aspects of human behavior that neither alone could expose.

THE FAUNAL DATA SET

CA-COL-267 is situated within the Cache Creek watershed, Colusa County, California (Figure 3.1). The site lies along Thompson Creek, a tributary to Cache Creek. Today Thompson Canyon is a large meadow system lying at the base of several steep topographic peaks. Much of the basin can be characterized as meadow and grassland surrounded by oak woodland (*Quercus* sp.), gray pine (*Pinus sabiniana*), and chamise (tree taxonomy from Little 2001). Taber (1956) found that the deer of

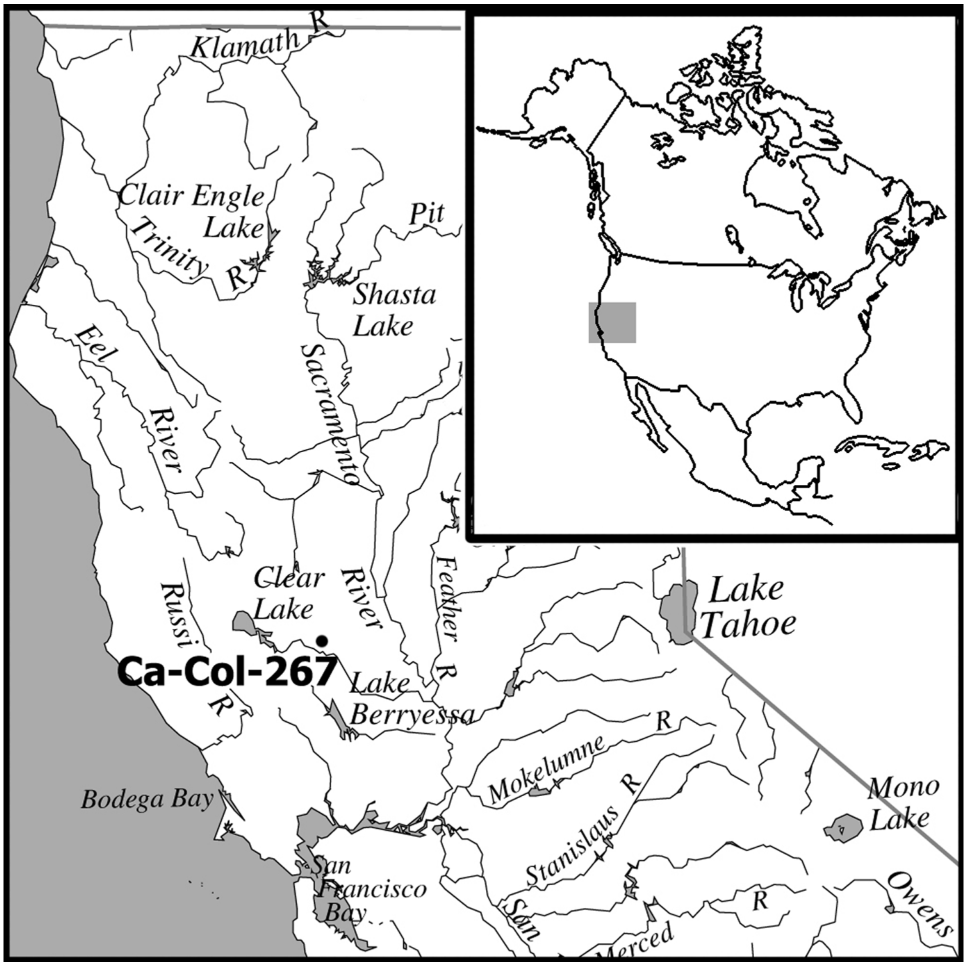


Figure 3.1. Location of CA-COL-267, nearly due east of Clear Lake near Cache Creek.

this area consumed several herbaceous annual and perennial grasses, including bedstraw (*Galium* sp.), American vetch (*Vicia americana*), and soap root (*Chlorogallum* sp.), while Longhurst et al. (1979) found the deer of the region to preferentially consume mistletoe (*Phoradendron villosum*), lichen (*Ramalina reticulata*), poison oak (*Rhus diversiloba*), mountain mahogany (*Cercocarpus betuloides*), and several oak species (*Quercus lobata*, *Q. kelloggii*, and *Q. douglasii*). Climate within the region has been characterized as Mediterranean, with hot, dry summers and cool, moist winters (Longhurst et al. 1979). Precipitation generally comes from October through May and may manifest as light snowfall in the upper elevations.

Important to the geochemical aspects of this paper is the geology of the region. Geology of the coastal range is derived from a history of marine sedimentation, subduction, thrusting, and a small amount of marine volcanism (Norris and Webb 1976). Mesozoic sandstones, shales, conglomerates, and ultramafic plutonic rocks, as well as Pliocene/Pleistocene continental sedimentary rocks and Quaternary volcanic rocks, represent the geology surrounding CA-COL-267. The Great Valley, to the east of the site, has been formed by several sedimentary, thrusting, and sinking processes. Deep stratigraphy of the Great Valley has much in common with the Klamath and Peninsular ranges and the proto–Sierra Nevada (also known as the Nevadan Mountain Range), but more recent deposits are composed almost entirely of alluvial sedimentation derived from both the Sierra Nevada and Coast Ranges (Norris and Webb 1976). The Sierra Nevada derives most of its geology from Mesozoic volcanism, but Cenozoic volcanism also contributes, especially in the northeastern regions, while the Coast Ranges resulted from slippage and subduction of the North American and Pacific plates, resulting in a sedimentary geology composed primarily of shale and sandstone.

The Archaeology

The archaeofaunal sample is derived from test excavations conducted at CA-COL-267 during the field season of 2001. Dr. Greg White supervised the excavations under the authority of the U.S. Bureau of Land Management. The site consists of a large midden deposit with surface lithics visible across an area measuring approximately 240 × 80 m, but fluvial impacts have likely removed an estimated 60 percent of the original deposit. Units were excavated by arbitrary 10-cm levels, and only two units reached the bottom of the deposit (N27, 100 cm total depth, and N15, 120 cm total depth). Throughout the investigation, these two units were excavated using .25-inch screens. The density of artifacts within the midden, the volume and spatial extent of the midden, the presence of lithic artifacts characteristic of a central place (Patterson 2007), and the presence of taxa that may be obtained only during discrete periods of the year (Grimstead 2005) suggest that CA-COL-267 was a long-term and persistent habitation site that functioned as a central place. The presence of hibernating taxa such as the western pond turtle (*Clemmys marmorata*), black bear (*Ursus americana*), and squirrels (Sciuridae) all point toward a nonwinter habitation of the site. The presence of fish (Osteichthys) points toward a fall or spring habitation, and the presence of ducks (Anatidae) within the site points toward a winter habitation (Grimstead 2005).

The chronology of occupation at CA-COL-267 is based upon bead typologies, projectile point typologies, and obsidian hydration analysis utilizing a calibration curve developed for the region (DeGeorgey 2003). Projectile point and shell bead typologies from Fredrickson (1994) and White (2002) correlate well with the terminal Upper Archaic period and the proximal Lower Emergent period, or between approximately 1200 and 800 B.P. (Grimstead 2005). Fredrickson (1994) suggests that these periods were characterized by the introduction of the bow and arrow, increased sociopolitical complexity, complex trade and exchange networks, intensified status competition, and well-defined territorial boundaries, all of which generally characterize resource intensification within northern California during this period. Results of obsidian hydration analysis[2] suggest that the two units have undergone some degree of depositional mixing, but when the two units are divided into two arbitrary strata (stratum 1, 0–50 cm, and stratum 2, 50–120 cm), an independent samples t-test comparing mean rim values of stratum 1 and 2 shows a statistically significant difference between the mean rim values of the two strata ($p = .023$; Grimstead 2005:Chapter 3, Appendix C). Notably, when converting the rim values and their standard deviations to dates using a regional calibration curve (DeGeorgey 2003), the standard deviation of mean rim values and the error margin associated with the calibration curve produced some degree of temporal overlap between the two strata: stratum 1 = 881 ± 620 B.P. and stratum 2 = 1234 ± 711 B.P. Due to the significant overlap, any conclusion regarding changes through time will be approached cautiously.

The Zooarchaeology

The original zooarchaeological identifications of the CA-COL 267 archaeofauna were conducted by Carolyn Orban, formerly a graduate student at California State University, Chico; subsequently, the assemblage was reanalyzed by the author. Both analysts followed the same zooarchaeological identification methods, in which any specimen identified to the taxonomic level of order or below was considered identifiable, and anything above the order level was considered unidentifiable. Taxonomies follow Stebbins (1972) for reptiles and amphibians, the National Geographic Society (2002) for birds, and Whittaker (1996) for mammals. The assemblage is currently curated by the California State University, Chico, curation facility under accession number 345.

Unit N15 had a total of 846 specimens, 75 of which were identifiable to the order level or lower (Table 3.1). Unit N27 had nearly double the quantity of specimens, with a total of 1,430 specimens, 92 of which were identifiable (Table 3.1). Both units had very low percentages of identifiable specimens: 6.4 percent for unit 27 and 8.9 percent for unit N15, and the medium- to large-mammal-sized unidentifiable category included a significant quantity of unidentifiable specimens from both units: 53 percent from N15 and 20 percent from N27.

N27 has a total of 47 specimens identified to the Cervidae family, or black-tailed deer species, while N15 has 36. For this analysis, the category medium artiodactyls refers exclusively to either black-tailed deer or pronghorn (*Antilocapra americana*). This distinction is made in part because of the difficulty in distinguishing between members of these species and also because other artiodactyls present in the region, such as elk (*Cervus elaphus*), and others not present in the region, such as bighorn sheep (*Ovis canadensis*), could be excluded. Although no antelope specimens were identified within the assemblage, historical populations ranged within the San Francisco Bay region and the Sacramento Valley (McLean 1943), making this taxon a potential contributor to the assemblage.

FOOD UTILITY ANALYSES

A fundamental question in zooarchaeological inquiry is: Why are some elements found at certain sites while others are not? One way to address this question is through body part and utility analysis. T. E. White (1952, 1953b, 1954, and 1955) was one of the earliest analysts to use body part representation to interpret human behavior. Research conducted by Perkins and Daly (1968), resulting in the term *schlep effect*, is a classic early application of body part representation used to reconstruct human behavior. In short, the schlep effect refers to the observation that fewer low-utility portions of a large animal were brought back to the central place when transport distances were significant, although low-utility lower limb elements may have been used as "handles" during transport. The study of differential transport decisions and animal body part representation became commonplace in zooarchaeological research during the 1960s and 1970s (Thomas 1996), with Binford's (1978) ethnoarchaeological research characterizing the era. Binford's (1978) research resulted in the modified general utility index (MGUI), which spawned later work by Metcalfe and Jones (1988), ultimately resulting in the food utility index—FUI. The FUI provides a method for assessing the degree to which an assemblage represents high food utility, such as an assemblage dominated by femurs, innominates, and vertebrae, or relatively low utility, such as an

Table 3.1. Identifiable and Nonidentifiable Remains from Units N27 and N15.

	North 27, West 0 & 1			North 15, West 0 & 1		
	Stratum 1	Stratum 2		Stratum 1	Stratum 2	
Identifiable	0-50cm	50-120cm	**Total**	0-50cm	50-120cm	**Total**
Osteichthys	0	0	**0**	1	0	**1**
Reptilia	0	0	**0**	0	0	**0**
Clemmys marmorata	6	1	**7**	1	0	**1**
Anguidae	0	1	**1**	2	0	**2**
Aves	0	0	**0**	0	0	**0**
Accipitridae	1	0	**1**	0	0	**0**
Mammalia	0	0	**0**	0	0	**0**
Lagamorpha	0	0	**0**	0	0	**0**
Leporidae	1	1	**2**	2	0	**2**
Lepus californicus	1	0	**1**	0	0	**0**
Rodentia	4	2	**6**	7	0	**7**
Sciuridae	6	0	**6**	18	2	**20**
Spermophilus beecheyi	15	1	**16**	3	1	**4**
Thomomys bottae	3	0	**3**	1	0	**1**
Carnivora	0	0	**0**	0	0	**0**
Felis concolor	1	1	**2**	1	0	**1**
Artiodactyla	0	0	**0**	0	0	**0**
Medium artiodactyl*	20	7	**27**	30	4	**34**
Odocoileus hemionus	15	5	**20**	1	1	**2**
Ursus americanus	1	0	**1**	0	0	**0**
Subtotal	74	18	**92**	67	8	**75**
Nonidentifiable	0-50cm	50-120cm	**Total**	0-50cm	50-120cm	**Total**
Aves	2	0	**2**	2	0	**2**
Mammal/indet	104	0	**104**	53	52	**105**
Small mammal	7	1	**8**	7	4	**13**
Medium mammal	2	0	**2**	17	0	**17**
Medium/large mammal	270	0	**270**	312	97	**409**
Indet/unid	692	260	**952**	177	48	**225**
Subtotal	1,077	260	**1338**	568	201	**771**
Total	1,151	278	**1430**	635	209	**846**

*Refers to the inability to further distinguish between black-tailed deer and pronghorn, but other artiodactyls could be excluded based upon size, morphology, and range.

assemblage dominated by phalanges, metapodials, tarsals, and carpals.

Body part representation variability has continued to be of interest, with some zooarchaeologists studying butchery, discard, and transport decisions among modern hunters (Bartram and Marean 1999; Borrero 1990; Bunn et al. 1988; Egeland and Byerly 2005; Lupo 2001, 2006; O'Connell and Hawkes 1988; O'Connell et al. 1990). Others continue to analyze the utility of elements from various taxa (Blumschine and Madrigal 1993; Borrero 1990; Brink 1997; Metcalfe and Jones 1988; O'Connell and Marshall 1989; Outram and Rowley-Conway 1998). Researchers also have used nonhuman predators to model transport decisions (Stiner 1991), while others investigate taphonomic processes that produce differential survivorship (Grayson 1988, 1989; Lyman 1994b; Marean and Cleghorn 2003; Marean and Spencer 1991; Stiner 2002).

Ethnoarchaeological research among the Hadza provides an excellent example of element transportation patterns characteristic of long-distance travel. This research has documented the butchery and transport decisions of central place foragers when they are confronted with a variety of taxa spanning several different size classes (Friesen 2001; Lupo 2001, 2006; Marshall and Pilgram 1991; Monahan 1998; O'Connell and Hawkes 1988; O'Connell et al. 1990). While these studies have revealed that social, ecological, and economic factors all contribute to the set of potential solutions available to central place hunters, it is apparent that carcass size, anatomy, and distance from the central place have particular importance when processing decisions are made (Lupo 2006).

O'Connell and Hawkes (1988) and O'Connell et al. (1990) found that the depositional patterns at butchering sites and central places tend to complement each other. Hadza more frequently deposited vertebrae, scapulae, innominates, and humerii at the central place, while ribs, skulls, mandibles, metapodials, and tibias were less often deposited at the central place (O'Connell and Hawkes 1988:140). This pattern is consistent with a model of field butchering and transport proposed by Metcalfe and Barlow (1992). This model predicts that as distance from the central place increases, there should be a concomitant increase in field processing aimed at removing portions with lower caloric yields, resulting in a net increase in the efficiency of the load (Metcalfe and Barlow 1992). The reasoning of Metcalfe and Barlow (1992), as well as observations made by others (Lupo 2001, 2006; O'Connell and Hawkes 1988; O'Connell et al. 1990), strongly aligns with tenets of the central place foraging model (Cannon 2003; Lupo 2006; Rands et al. 2000; Schoener 1979). Many zooarchaeologists, such as Bayham (1982) at Ventana Cave, Arizona, and Jackson and Scott (1995) at Summerville village, a Late Mississippian site, have used implications from the ethnoarchaeological research discussed above to understand the function of sites and to interpret associated human behavior.

CA-COL-267 should show evidence of resource depression via declining representation of high-utility elements and decreasing food utility through time. To assess the utility of the assemblage, zooarchaeological specimens identified to the level of Artiodactyla or below were assigned an FUI value scaled to 1.0, derived from Metcalfe and Jones (1988) (Table 3.2). These results were then averaged for each stratum, resulting in a mean FUI value of .18 (sd = .074) for stratum 1 and .15 (sd = .157) for stratum 2. These two stratum means are not significantly different (p = .423), suggesting no meaningful changes through time. What is apparent, however, is the very low utility of artiodactyl specimens in both assemblages.

Figures 3.2 and 3.3 also display a pattern of low utility. These figures compare the percentage of NISPs from each stratum to percentages from a complete modern deer. Mandibles, ulnae, astragali, metapodials, and phalanges are all overrepresented in stratum 2, while high-utility elements are absent (Figure 3.2). Antlers, craniums, ribs, tibias, femurs, tarsals, metapodials, and phalanges are represented in stratum 1, while the remaining elements that compose a complete deer are absent (Figure 3.3). Given observations of Hadza hunters made by O'Connell and Hawkes (1988), this body part representation most clearly resembles a butchering site from which high-utility parts were being transported back to a central place. Both the body part profiles and utility results are inconsistent with the assignment of CA-COL-267 as a central place and are contrary to expectations.

The degree to which density-mediated attrition affected the artiodactyl body part profiles was assessed following Lyman (1994b:234–258). Lyman categorized an assemblage into one of nine utility-attrition categories based upon the results of correlation coefficients between the MAU percentage of a bone assemblage and bone density and the MGUI percentage. Lyman (1994b:234–258) used minimum number of elements (MNEs), but this study used NISPs (number of identified species), following Grayson and Frey's (2004) observation

Table 3.2. Number of Identified Artiodactyl Specimens from Both Strata Categorized by Body Part and FUI Values.

	Stratum I (0-50 cm)	Stratum II (50-120 cm)	Food Utility Index Standardized to 1.0
Axial			
Antler	1	0	0.010
Cranium	3	0	0.091
Mandible (including teeth)	4	1	0.331
Ribs	1	0	0.516
Appendicular			
Scapula	2	0	0.440
Proximal ulna	0	1	0.086
Carpals	2	1	0.127
Proximal metacarpal	0	1	0.090
Femur shaft	1	0	1.000
Tibia shaft	1	0	0.628
Distal tibia	1	0	0.441
Tarsals	1	1	0.227
Proximal metapodial	1	1	0.143
Metapodial shaft	9	4	0.212
Distal metapodial	24	1	0.113
Phalanx	15	6	0.086
Total	**66**	**17**	

Note: Following Classification of Metcalfe and Jones (1988).

that NISPs produce the same results and simplify the analytical process. FUIs were used in substitution for MGUIs (see Grimstead 2005, chapter 4, for a thorough description of methods). Density measurements were derived from Lyman (1994b).

The results for stratum 2 show a statistically significant, strong correlation between NISP and the FUI percentage (p = .005; Spearman's rho = .649). When comparing bone density to NISP, however, there is no correlation (p = .447; Spearman's rho = .198). Following Lyman's method, these results show a strong correlation with food utility in stratum 2 that is not affected by density-mediated attrition. Lyman classifies these results as a class 8 faunal assemblage, meaning it represents an assemblage with bulk or gourmet utility that has not been affected by attritional processes (Lyman 1994b:264). These results do not agree with common sense, however. The mean FUI value from stratum 2 is .15 (standard deviation of .0741), and no FUI value exceeded 33 percent, reflecting the exceptionally low utility of this assemblage. Despite the lack of support for density-mediated attrition being the cause of the utility curve, clearly there is a lack of high-utility elements.

Stratum 1 shows a similar pattern, except that the bone density and FUI percentage correlation was positive and significant (Spearman's rho = .366; p = .004). Again, there was a statistically significant and strong correlation between FUI percentage and NISP (r = .780; p < .001). In this case, Lyman classifies the assemblage pattern as having a bulk or utility pattern that has been ravaged by carnivores and/or rodents or has been affected by fluvial processes—class 7 (1994:264). In this stratum, the FUI value was slightly higher (.18; standard deviation of .157) but still not a pattern that should be considered bulk or gourmet utility.

The results from applying Lyman's (1994b) methods are not overly compelling, and it is not

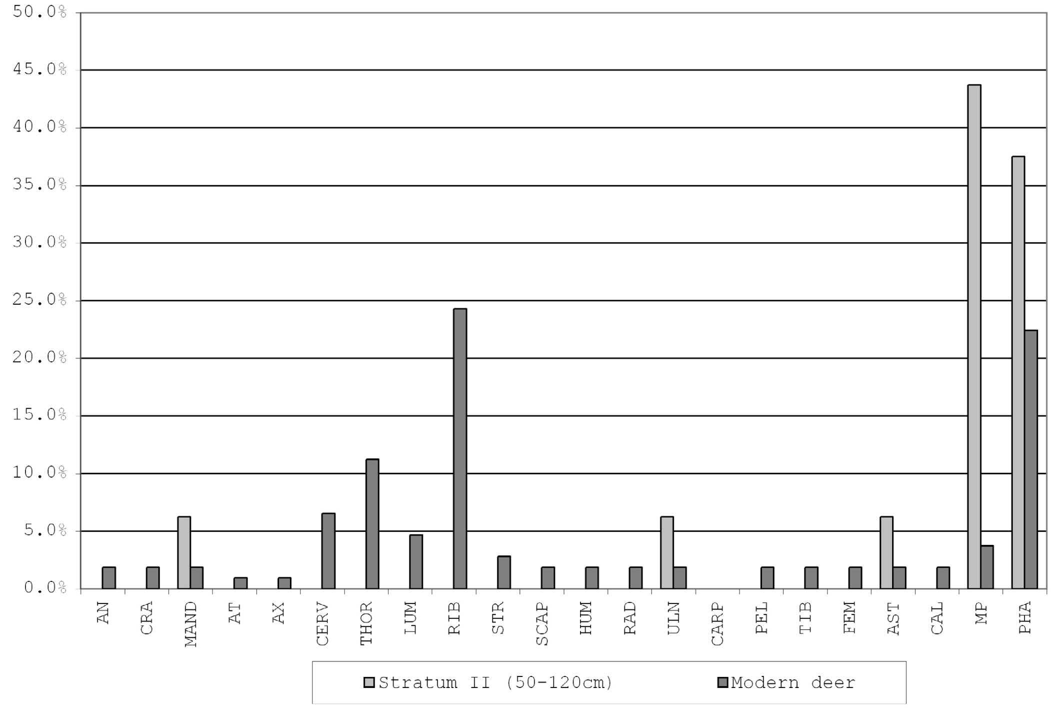


Figure 3.2. Percentages of NISPs from stratum 2 categorized into elements (gray foreground) compared to percentages from a complete modern deer (white background).
Note: AN = antler, CRA = cranium, MAND = mandible, AT = atlas, AX = axis, CERV = cervical vertebrae, THOR = thoracic vertebrae, LUM = lumbar vertebrae, RIB = ribs, STR = sternum, SCAP = scapula, HUM = humerus, RAD = radius, ULN = ulna, CARP = carpals, PEL = innominate, TIB = tibia, FEM = femur, AST = astragalus, CAL = calcaneous, MP = metapodials, PHA = phalanges.

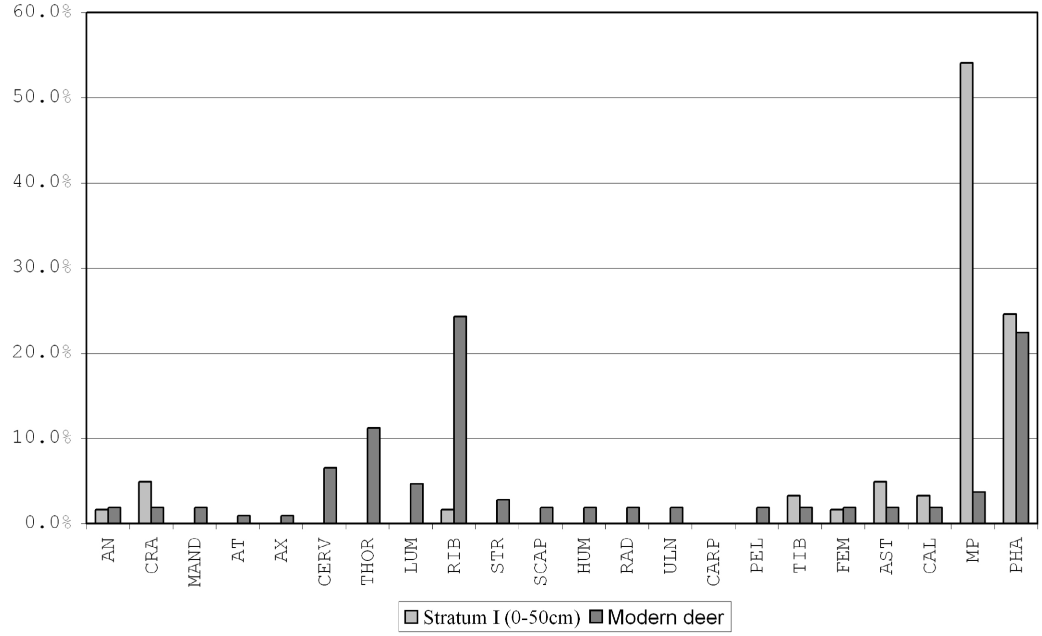


Figure 3.3. Percentages of the number of identified specimens from both strata.
Note: Percentages of the number of identified specimens from stratum 1 categorized into elements (gray foreground) compared to percentages from a complete modern deer (white background). Acronyms are the same as in Figure 2.

the author's position that the quantitative results should be taken at face value. A portion of the results suggested that density-mediated attrition was affecting the body part representation. The presence of carnivore gnawing within the assemblage and the proximity to Thompson Creek (a perennial stream) support this conclusion. The body part representation does not support the conclusion that the utility profile represents a gourmet profile. In fact, it more closely resembles the opposite of a gourmet utility curve—that is, a profile in which high-utility elements have been removed. The presence of low-utility elements, regardless of why they are overrepresented, suggests that these medium-sized artiodactyls were not butchered in the field to increase the utility of the load, as the models and ethnoarchaeological research would suggest. Because these low-utility elements do not appear to have been removed prior to transport, one would be inclined to conclude that these artiodactyls were procured from distances relatively close to the central place. The geochemical sourcing results will shed light on whether this inclination is in error or an accurate reflection of human butchery and transport decisions among these prehistoric foragers.

BACKGROUND TO THE TRACE ELEMENT ANALYSIS

Trace element analysis has been exceptionally productive for researchers attempting to locate geographically isolated obsidian sources (Hughes 1982, 1989, 1998; Jack 1976), raw materials necessary for the production of ceramics (Kosakowsky et al. 1999; Mills 1997; Neff 1993; Triadan 1998), and prehistoric subsistence resources (Benson et al. 2003). Stable isotope sourcing of biological materials also has been productive (Chamberlain et al. 1996; Eerkens et al. 2005; Fry 1983; Hall-Martin et al. 1993; Hobson and Wassenaar 1997; Hoppe et al. 2003; Koch et al. 1992, 1994, 1995; Porder et al. 2003; Reynolds et al. 2005; Schell et al. 1989; Sillen et al. 1998; van der Merwe et al. 1990), and researchers show improved reliability and reproducibility when trace elements and stable isotopes are used in tandem (Benson et al. 2003). For example, Thorrold and colleagues (1998) used trace elements derived from modern fish otoliths to determine the natal river of origin of American shad (*Alosa sapidissima*). They studied fish originating in the Connecticut, Hudson, and Delaware rivers. Osteological samples derived from juvenile portions of fish otoliths were sampled for relative proportions of potassium, manganese, strontium, and barium, resulting in discriminant functions that were between 80 and 90 percent accurate as indicators of a fish's natal river of origin (Thorrold et al. 1998).

Bioarchaeological applications of trace element and stable isotope sourcing have also shown promise (Burton et al. 2003; Ericson 1985; Price et al. 1994, 2000, 2002; Szostek and Glab 2001). Perhaps most relevant for this study is the research conducted by Burton et al. (2003). In this case study, the trace elements strontium and barium were shown to be reliable indicators of geographic origins, as determined from 173 modern white-tailed deer (*Odocoileus virginianus*) metapodials derived from five Wisconsin counties. This proof-of-concept study was then used to argue that the trace elements strontium and barium should be reliable indicators of nonlocal humans in Maya and Tarascan archaeological contexts. Human teeth trace element ratios from both archaeological contexts showed evidence of local and nonlocal individuals within a burial population (Burton et al. 2003).

The reason trace elements may be indicative of the geographic origin of food resources is based on the fact that trace elements found in plants, animals, soil, and groundwater reflect the geology of an area. Trace elements vary based upon the rock type and mineralogical history of the formation. For example, volcanic formations derived from magmatic flows generally have high concentrations of calcium-depleted minerals such as olivine ($[Mg, Fe]_2SiO_4$). Because strontium and barium readily substitute for calcium in minerals, volcanic formations have low relative concentrations of strontium and barium, particularly when compared to limestone ($CaCO_3$). Other minerals, such as plagioclase ($CaAl_2Si_2O_8$), have higher concentrations of calcium and, through elemental substitution, higher concentrations of strontium and barium. This geological variability across a landscape provides an opportunity to identify unique trace element signatures of a region, where animals such as deer consume the plants that reflect the unique geological history of the soil. In summation, it is the geological variation present across a landscape that produces variations in trace elements and isotopic compositions (Odum 1951), and these variations are reflected within the flora and fauna of that particular region.

Research over the years has demonstrated that trace elements and isotopes flow through all trophic levels (Sillen and Kavanagh 1982). Plants absorb the trace elements and isotopes from the soil and groundwater in which they live (Burd 1919; Eckert and Blincoe 1970; Hart et al. 1932; Hurst and Davis 1981; Reynolds et al. 2005), whereas animals obtain trace elements and isotopes from plants, soils, meteroic water, and other animals; these elements are then reflected in animal products such as bone, horn, blood, and feathers (Comar et al. 1957; Hoppe et al. 2003). The geochemical composition of these materials will reflect the proportional availability of each respective element or isotope within the environment, which is unequally distributed throughout the lithosphere (Odum 1951). Therefore, the trace element composition of animal bone will look similar to the relative abundance of trace elements in the geological region where the animal subsisted. It should be noted, however, that more consistent geochemical compositions are obtainable from cortical bone compared to cancellous bone (Brätter et al. 1977), and enamel is always preferable to bone due to its greater resistance to diagenesis resulting from decreased porosity (Passey and Cerling 2002).

As with all mammals, deer require minerals for basic biochemical processes. Some of these minerals include calcium, manganese, and phosphorus for bone and teeth construction, sodium for nervous system function and pH regulation, potassium for muscle functions and enzyme systems enhancements, and iron for oxygen transportation within the hemoglobin (Short 1981). Deer also require selenium to prevent muscular dystrophy (Short 1981:111–113). Not only do these minerals find their way into the skeletal structure because they are necessary for bone function, but many elements are stored in the crystalline structure of hydroxyapatite for later use (Short 1981). Thus metabolism of major and minor (trace) elements for a variety of biochemical functions is the process that provides the opportunity for deer osteology to reflect the geological variability of a home range. Notable exceptions would be unweaned fawns that derive most of their mineral and vitamin requirements from their lactating mothers (Jenkins et al. 2001; Wallmo 1981:110). Bone of unweaned fawns does display decreased trace element abundances when compared to environmental availability (Maynard and Loosli 1956). Similarly, bucks may show decreases during antler development (Cowan et al. 1968).

The question then becomes: To how much geological variability was the animal exposed? This variability results from several factors, including the degree of variability in the geological environment, the size of the home range, and an animal's degree of philopatry. The home range habits and philopatric tendencies of deer play a pivotal role in their potential to be sourced. For the purposes of this paper, home range will be defined as "the area, usually around a home site, over which the animal normally travels in search of food" (Burt 1943:351).

Key to understanding potential sources of home range variability is the dispersal tendency of the animal; the greater the dispersal distance, the more likely the individual is exposed to forage of a distinctly different geochemical composition. Dispersal can occur under three broad categories: natal dispersal, breeding dispersal, and gross dispersal (Greenwood 1980:1141). In fact, some ecologists have used geochemistry to identify the temporary dispersal behavior of animals (Fry 1983; Hobson and Wassenaar 1997; Koch et al. 1995).

Most individuals from the taxonomic order Artiodactyla, including moose (*Alces alces*; Sweanor and Sandgruen 1988), bighorn sheep (*Ovis canadensis*; Geist 1971), white-tailed deer (*Odocoileus virginianus*; Tierson et al. 1985), and black-tailed deer (Dasmann and Taber 1956; Longhurst et al. 1952; Rue 1988; Zwickel et al. 1953), are extremely philopatric or have low dispersing tendencies. Deer tend to establish a home range by the age of one or two years, and they generally stay within that range the rest of their lives (Dasmann and Taber 1956:151; Longhurst et al. 1979:196). Bucks tend to have larger home ranges than does, estimated at 2.85 km^2 and 2.07 km^2, respectively (Longhurst et al. 1979:196). Research on the southern Clear Lake deer population in Lake County, California (the deer herd that lives within our site boundaries today), found the average home range of does to be less than .8 km in diameter, while the bucks had a mean of 1.2 km (Dasmann and Taber 1956; Taber and Dasman 1958:41). Some bucks traveled up to 1.6 km outside their home ranges during the rut and returned to their original home ranges after breeding dispersal (Dasmann and Taber 1956:155), but females do not display breeding dispersals (Dasmann and Taber 1956). Deer from the region will make seasonal migrations in search of better forage, but these migrations rarely exceed 1.6 km (Longhurst et al. 1979), supporting the observation that deer populations from the region surrounding CA-COL-267 lack a distinct seasonal migration (Dasmann and Taber 1956). Deer from this region lack high degrees of breeding, seasonal, and natal dispersals, suggesting their trace element composition should be closely aligned with local geological trace element ratios.

On the west slope of the Sierra Nevada (a potential source for our zooarchaeological assemblage), seasonal deer migrations occur biannually. Seasonal migrations from winter habitation sites in the lower valley to the higher elevations of the Sierra Nevada entail movement from 46 to 160 km every year (Longhurst et al. 1952:37), but deer on the eastern side of the Sierra Nevada do not display a high degree of seasonal dispersals (Longhurst et al. 1952:40). Seasonal movements take the animals from between 4,000 and 9,000 feet of elevation in the mountain range to between 0 and 3,500 feet of elevation on and near the valley floor (Leach and Hiehle 1956). Fortunately, in this population, philopatry is visible in the migrational paths, as well as [in?] the ultimate location of seasonal home ranges (Longhurst et al. 1952:37). The movements of Sierra Nevada deer populations are not indiscriminant; rather, they follow the same paths to the same home ranges every season. Therefore, while these deer are exposed to greater geochemical variability than those surrounding CA-COL-267, the exposure is consistently the same, making the averaged trace element ratios reflective of their distinct migrational pathways and home ranges. This paper will assume that prehistoric deer populations were similarly philopatric to their modern counterparts.

METHODS

The sample of modern deer sample was derived from opportunistic scavenging of fatalities resulting from vehicular trauma[3] or deer poachers.[4] (For details on collection locations, see Grimstead 2005.) Each of the 49 modern deer in the sample was assigned to one of three deer collection target regions (Figure 3.4; the Near Cache Creek region [NCC], the Valley region [V], and the Sierra Nevada region [SN]), ultimately resulting in an eight-county sample crosscutting northern California (Butte, Colusa, Glenn, Lake, Lassen, Mendocino, Plumas, and Shasta counties). The NCC group was acquired from a 48 ± 8-km radius surrounding CA-COL-267, while the V and SN groups were classified based upon the underlying geology of the region: alluvium and volcanics, respectively. The modern specimens were recovered in various states of decomposition, some completely skeletonized and others completely fleshed. Flesh was manually removed, and the specimens were allowed to skeletonize using either the hydro-decomposition or the burial method.

Thirty-one archaeological specimens from units N15 and N27 of CA-COL-267 were sampled. Table 3.3 provides a detailed summary of each selected archaeological specimen, including provenience, element or feature identification, and the region of origin as determined by the modern discriminant function analysis (method for sourcing discussed below).

The archaeological bone had already been cleaned via warm tap water and toothbrush prior to faunal identification. Both modern and archaeological samples underwent the same inductively

Figure 3.4. Modern deer sample target regions and rough geological source assignment.
Note: Three regions of deer targeted sampling, categorized into rough geological and geographic boundaries, are circled in gray and labeled as follows: Near Cache Creek region, NCC; Great Valley region, V; Sierra Nevada region, SN. The highlighted counties represent regions where deer were actually collected. Some counties within the target region failed to produce deer carcasses during the sampling phase.

coupled plasma mass spectrometry (ICP-MS) preparation from this point forward following Djinggova et al. (2004), Price et al. (2000), and suggestions from the ICP-MS lab technician at UC Davis (Gras, personal communication 2004).

Many archaeologists have labored over questions of diagenesis: Are samples diagenetically altered (Buikstra et al. 1989; Kryzysztof and Glab 2001; Nelson and Sauer 1984; Nelson et al. 1986; Pate et al. 1989; Price 1989a, 1989b; Sealy and Sealy 1995; Stuart-Williams et al. 1996; Trueman et al. 2004)? If so, what is the degree of alteration (Gilbert 1975; Hoppe et al. 2003; Lambert et al. 1984; Pate et al. 1989)? And how can we address this issue (Koch et al. 1997; Lambert et al. 1991; Nielsen-Marsh and Hedges 2000a, 2000b; Price et al. 2000; Sillen and Sealy 1995)? To evaluate the possibility that the archaeological material had been diagenetically altered, acetic acid pretreatment was conducted on roughly half the archaeological and modern specimens following Price et al. (2000). No statistically significant difference in the trace element quantities was detected when comparing pretreated to nonpretreated samples from the same specimen (Grimstead 2005:Chapter 6), suggesting that diagenesis had not occurred or that the pretreatment failed to remove the alterations. The pretreated specimens were excluded from further analyses. The fact that several specimens source to outside the NCC trace element signature further suggests that diagenesis was not a significant factor, as diagenesis tends toward chemical equilibrium between soil and artifact.

Small portions (1–3 g) of the specimens were cut from the modern and archaeological osteological

Table 3.3. Detailed Description of Each Archaeological Specimen Selected for ICP-MS.

Unit	Level	Part	Source
N15-W0	1-10cm	Distal metapodial	SN
	10-20cm	Distal metapodial	SN
	20-30cm	Shaft metapodial	SN
		Shaft metapodial	SN
		proximal phalanx	SN
		glenoid scapula	SN
	30-40cm	Distal metapodial	SN
		Distal metapodial	SN
		Navicular-cuboid	NCC
	40-50cm	Fragment, scapula	SN
		Distal tibia, left	SN
N15-W1	60-70cm	mandible with tooth	SN
	70-80cm	distal second phalanx	SN
	90-100cm	metapodial shaft fragment	NCC
N27-W0	0-10cm	distal second phalanx	SN
		rib	NCC
	10-20cm	distal second phalanx	SN
	20-30cm	Navicular-cuboid, rt. **[right?]**	SN
		metapodial shaft	SN
		Distal metapodial	SN
	30-40cm	petrosal portion	SN
		proximal metapodial	SN
	40-50cm	tibia shaft	SN
		molar	SN
		mandible, right, juvenile	SN
N27-W1	50-70cm	proximal ulna	SN
	70-80cm	astragalus	SN
	80-90cm	Unidentified long bone	SN
		metapodial fragment	NCC
	90-100cm	metapodial fragment	NCC
	110-120cm	distal metapodial fragment	SN

Note: Data provided includes unit, level, anatomical part, and most likely source group.

material using a Dremel tool with a diamond disk blade. Specimens were ultrasonically cleaned with Nanopure water three times for three minutes. After air drying, the specimens were placed in a 105°C oven for approximately 12 hours to remove any residual moisture. After this low-temperature firing, specimens were placed into a Coors Crucible and fired at 725°C for approximately seven hours. After this high-temperature firing, the ashen bone was pulverized with an agate mortar and pestle. After pulverization, approximately 100 mg were selected from each sample. Each 100-mg sample was placed into a glass Pyrex beaker under a fume hood for dissolution. The dissolution process included adding 3 ml of redistilled nitric acid (HNO_3) and evaporating the liquid over a hot plate without boiling the liquid. After the liquid had evaporated, another 3 ml of redistilled nitric acid (HNO_3) was added to the sample, and some heat was applied to assist in redissolving the residue. The solution was then placed into an acid-resistant syringe and forced through a .2-micron Teflon filter. A solution of 3 percent redistilled nitric acid was added to the sample until the final weight of the redissolved nitric acid and the 3 percent solution reached 100 g. All internal and calibration standards were added by the UC Davis ICP-MS laboratory, and SRM-1486 was used as a standard. The Interdisciplinary Center for Plasma Mass Spectrometry at UC Davis used an inductively coupled plasma mass spectrometer to derive quantities of 18 trace elements (strontium, barium, calcium, magnesium, manganese, iron, potassium, arsenic, cobalt, lead, uranium, selenium, zinc, nickel, chromium, vanadium, aluminum, and sodium) from the analyte.

SOURCING RESULTS

Analysis initially followed that of Burton et al. (2003) in hopes of yielding large-scale geographic differences within the modern sample. The results are very encouraging, as demonstrated when each region is compared via box plots of strontium, barium, potassium, and sodium displayed as a ratio of calcium (Figures 3.5–3.8). These figures show individual trace element variation that is not able to distinguish between large-scale geographic regions alone, but when combined into discriminant functions, the variation becomes relatively predictable. One specimen from New York was included in the box plots to emphasize the point that caution is needed during sourcing studies. This inclusion shows how a sample that is clearly from a nonlocal region can fall within ranges for the local habitat. The implication for archaeology is that specimens can be sourced to the local habitat when in fact the item is nonlocal. This sample was removed from further discriminant function analyses.

To support these visually observable trends, a stepwise discriminant function analysis using Wilks's Lambda was conducted. Two canonical discriminant functions were created using SPSS 12.0, and these functions were 83.3 percent accurate when reapplied to the already known modern sample ($p < .001$). Figure 3.9 shows the results of the modern discriminant functions with the CA-COL-267 archaeological specimens included. Admittedly, a reclassification value of 90 percent or better would be preferable, but these results are consistent with

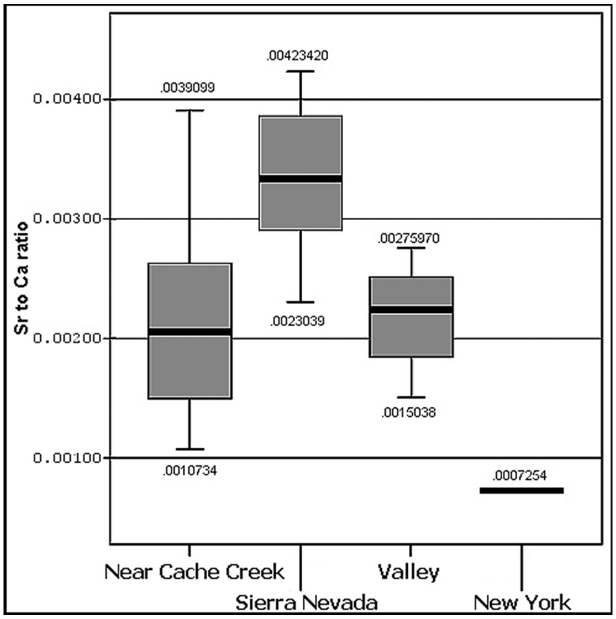


Figure 3.5. Box plots from each of the four subjectively assigned geographic regions showing the variations of Sr:Ca. *Note:* Near Cache Creek: mean = 0.002042; Sierra Nevada: mean = 0.003363; Valley: mean = 0.002175, and New York. Minimum and maximum values displayed.

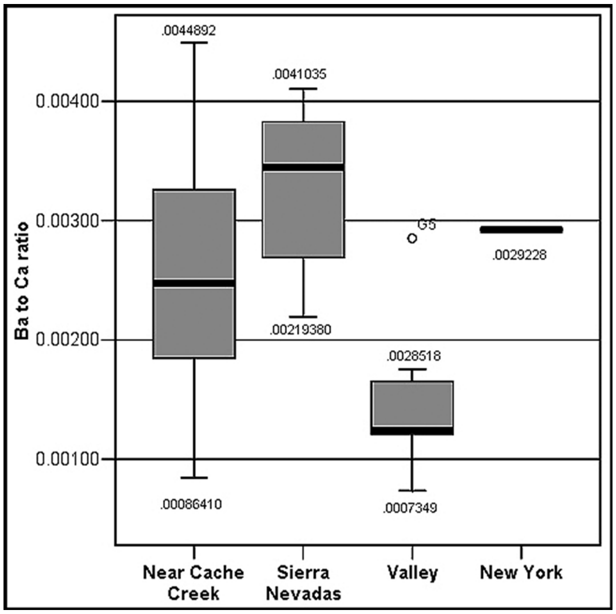


Figure 3.6. Box plots from each of the four subjectively assigned geographic regions showing the variations of Ba:Ca. *Note:* Near Cache Creek: mean = 0.0025509; Sierra Nevada: mean = 0.003268; Valley: mean = 0.001508, and New York. Minimum and maximum values displayed.

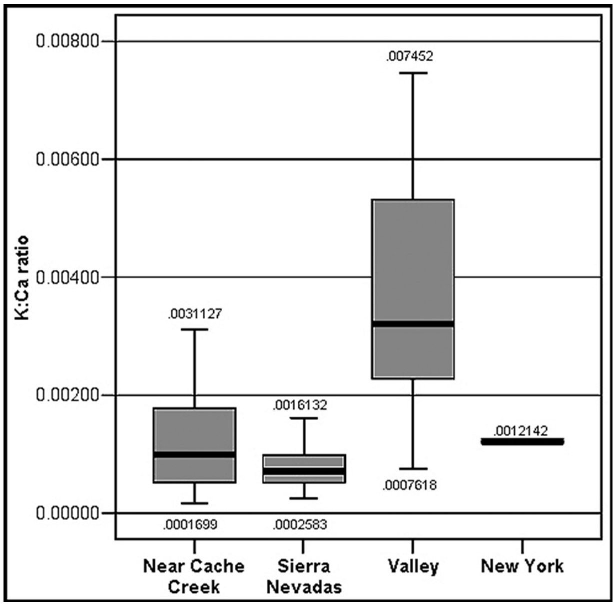


Figure 3.7. Box plots from each of the four subjectively assigned geographic regions showing the variations of K:Ca . *Note:* Near Cache Creek: mean = 0.001214; Sierra Nevada: mean = 0.000812; Valley: mean = 0.003801, and New York. Minimum and maximum values displayed.

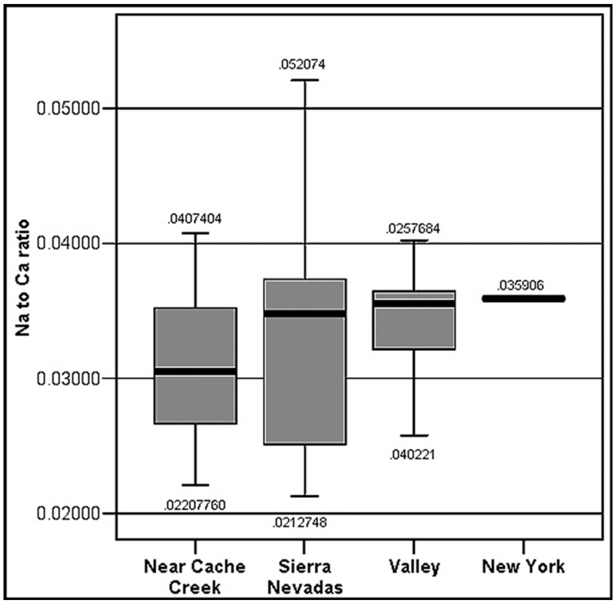


Figure 3.8. Box plots from each of the four subjectively assigned geographic regions showing the variations of Na:Ca. *Note:* Near Cache Creek: mean = 0.031096; Sierra Nevada: mean = 0.033541; Valley: mean = 0.034107, and New York. Minimum and maximum values displayed.

other trace element sourcing studies of biological materials (Burton et al. 2003; Thorrold et al. 1998).

Reassignment of the archaeological specimens was conducted using the discriminant functions derived from the modern samples (Figure 3.9 and Table 3.4). It is clear from both Figure 3.9 and Table 3.4 that a relatively small proportion of specimens is sourced to the central place (the Near Cache Creek group). In fact 10.5 percent of the stratum 1 sample contained deer from the local group, while the stratum 2 sample contained 42.9 percent from the local group. Visually, these proportions appear to support the hypothesis of declining proportions of locally procured deer through time (Figure 3.10), but the Cochran statistic (Cannon 2001) did not identify this difference as being statistically significant at a p = .05 value (p = .137).

GENERAL DISCUSSION

The original hypothesis suggested that resource depression should be evident in a relatively high frequency of specimens having a nonlocal trace element ratio—nonlocal here meaning not from the Near Cache Creek central patch. In fact, only 5 of the 31 specimens analyzed were sourced to the central patch, upholding the expectation and supporting the hypothesis. No statistically significant increase through time of nonlocal signatures occurred, which does not support the hypothesis of a temporal intensification of this hunting behavior.

Twenty-six specimens were sourced to the Sierra Nevada patch, which is intriguing but requires some cautionary statements. Discriminant functions, despite their name, act rather indiscriminately when assigning group membership to a specimen that does not have modern representatives within the sample (Baxter 2003). That is, if the specimen came from Florida, the discriminant function would assign it to one of the three northern California groups. The implication for this study is that all or a portion of the specimens sourcing to a Sierra Nevada patch may in fact be from regions that were not a part of the modern sample, such as to the north and south of the Near Cache Creek patch. Thus the author is reluctant to say with certainty that these specimens came from the Sierra Nevada deer herds, but it is clear that these specimens did

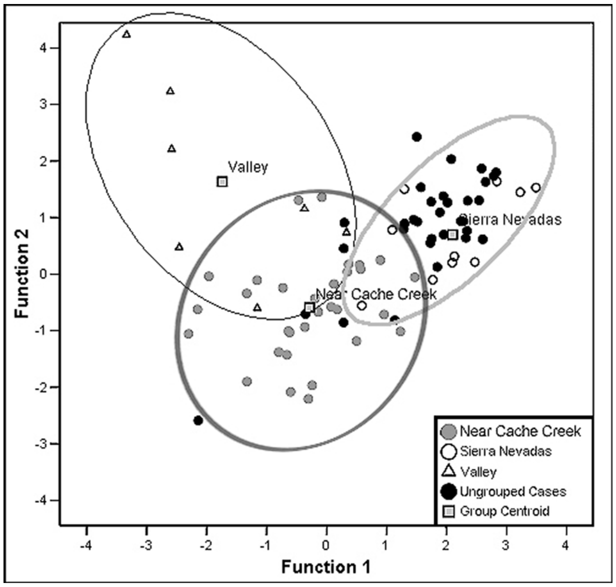


Figure 3.9. A scatter plot of the discriminant functions showing the large geographic groups and the archaeological specimens.

Note: NCC = gray-filled circles, with 100 percent of samples circled in thick dark gray ellipse; SN = black unfilled circles, with 100 percent of samples circled in light gray ellipse; V = unfilled triangles, with 100 percent of samples encircled in thin black ellipse; archaeological (ungrouped) = filled black circles.

Table 3.4. Distributions of Geographically Sourced Artiodactyl Remains.

Location	Stratum 1	Stratum 2
Near Cache Creek	2	3
Sierra Nevada	19	7
Valley	0	0
Total	21	10
Proportion of Near Cache Creek artiodactyls	0.095	0.3

Note: Based upon the results of the modern discriminant function analysis, the distribution of archaeological specimens that likely derived from the Near Cache Creek, Valley, or Sierra Nevada geographic regions [Recast as full sentence—unclear what is being said here]. The proportion of specimens that likely derived from the Near Cache Creek group is also displayed.

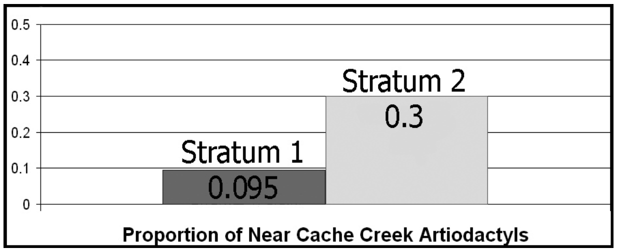


Figure 3.10. Bar graph of the relative proportion of archaeological samples assigned to the Near Cache Creek group (p = 0.137).

not subsist within the central patch (Near Cache Creek). It is apparent that 26 of 31 specimens did not come from the central patch and must have come from a geologically distinct region more than 48 km away.

Most intriguing is the lack of deer represented from the Valley source group, given that the Valley lies approximately 30 km from CA-COL-267. The first possible explanation for this observation assumes that there are indeed no Valley deer represented within the archaeological sampling and suggests a behavioral ecological solution. Expectations of the prey choice model say that a high-ranked prey item such as a deer should always be taken upon encounter (Pulliam 1974; Pyke et al. 1977; Schoener 1971). Consistent with this theoretically derived prediction, it may be assumed that encounter rates with deer within the 48 ± 8-km radius of the central patch were low, because 84 percent of the geochemically sourced specimens show a trace element ratio that is not consistent with the central place source. The lack of local procurement could be the result of prey choices made by hunters once the decision to travel to the Valley had been made. Once the decision had been made to travel to the Valley, hunters would operate under the expectation to always take the highest-ranked prey item (Rands 2000). The Sierra Nevada deer are much larger than the Valley deer herds (Longhurst et al. 1952) and would be preferentially taken over the Valley deer when available (winter range).

It is also possible that Valley deer were unavailable to the CA-COL-267 hunters. This may have resulted from habitat depression caused by the human presence within the Valley, or due to social relationships that prevented the CA-COL-267 hunters from being able to hunt within this territory. Resource depression during this period in northern California appears to be the norm (Basgall 1987; Broughton 1994a, 1994b; Broughton and Grayson 1993; Hildebrandt and Jones 1992; Raab et al. 2004 [2002?]). Thus it is possible that local deer herds within the Valley were unavailable due to depression. It is also possible that the inhabitants of CA-COL-267 did not have good relations with their neighbors to the east and were not able to hunt within these territories. Conducting extensive sourcing studies on deer remains from Valley and Sierra Nevada sites would shed light on whether the lack of Valley deer within the CA-COL-267 assemblage is due to ecological depression or socially prescribed restrictions.

Also informative from these results is the lack of agreement between how far body parts were being transported relative to their respective economic utilities. Table 3.4 reveals that 21 of the 31 specimens are nonlocal and from low-utility "rider" elements, including metapodials, tarsals, and carpals. If field processing of the nonlocal artiodactyls had occurred, there should be an absence of low-utility elements with nonlocal trace element ratios. The pattern revealed here is suggestive of a lack of field processing that removed these low-utility elements and the transport of the entire carcass. This idea is both exciting and problematic to zooarchaeologists. On the one hand, tandem use of utility analyses and geochemical sourcing has revealed prehistoric human behavior contrary to our models of field butchery and transport. Indeed, showing human behavior contrary to our expectations is where we learn the most. On the other hand, this potentially means a rethinking of butchery and transport models as regional and temporal trends of these contradictions become more and more available. The question now becomes: Why does the body part profile of this assemblage not adhere to ethnoarchaeological observations and theoretical predictions? Two answers are offered below.

The first potential answer suggests that the cost of transportation of low-utility elements may have been less than the cost of field processing, as viewed through the currency of calories; consequently, the conclusions of Metcalfe and Barlow (1992) may not be accurate in this instance. This answer is a possibility, given the number of variables required to accurately calculate the cost of transport, such as weight of the prey before and after processing, difficulty of processing, weight of the forager, distance of transport, and difficulty of terrain (Rands et al. 2000). These variables are at best difficult to assess prehistorically and at worse not visible, but the trace element sourcing results may have revealed the end results of a prehistoric assessment of these factors. The decision made by prehistoric foragers was to transport low-utility elements over 40 km despite their low utility, and a reasonable conclusion would be that the cost of transporting low-utility elements was insignificant from the perspective of the forager. This conclusion is supported by modeling conducted by the author (Grimstead 2010).

The second answer entails the possibility that multiple currencies were being evaluated by the forager, resulting in a body part pattern that contradicted expectations (see Lupo 2006). The methodology of utility analyses assumes optimal decisions based upon the currency of calories. That is, food utility and body parts with high food value were assumed to be more likely candidates for preferred transport given an agent whose decisions were aimed at optimizing caloric returns to the central place. This answer highlights the difficulty in using utility and body part patterns to characterize the function of a site or to interpret human behavior. Hunters likely made decisions of transport based upon several currencies, including caloric returns, fat content, tool utility, prestige, and many more (Lupo 2006). Transport decisions based upon multiple currencies will likely alter body part patterns beyond what one would expect if caloric returns were the sole currency. In cases where the removal of low-utility elements is expected but is not supported by geochemical sourcing data, it can be assumed that the cost of transporting the low-utility elements is less than the sum of returns expected from all currencies. Simply stated in terms of cost versus benefit, when considering all potential currencies, the low-utility elements were worth transporting and contributed some value to the overall value of the carcass.

Both potential answers are equally plausible and both may be contributing to the observed pattern. Further analyses and refinement of geochemical methods are required to further extricate human choice relative to pertinent currencies, but for now it seems clear that geochemical sourcing provides zooarchaeologists a method for removing one of the numerous layers of factors affecting the tradeoffs between field butchery and transportation that produce human-caused body part representation. Knowing whether a food item was procured locally or at a distant location allows zooarchaeologists to assess the degree to which the body part profile agrees or disagrees with food utility expectations.

CONCLUSIONS

This paper hypothesizes that as time spent in the central place, CA-COL-267, increased, resource depression of large-bodied prey items within the central patch occurred. To address this hypothesis, utility and body part representation and geochemical sourcing were used.

The results of applying these methods are as follows:

1. The body part profile shows small quantities of high-value elements, such as femurs, innominates, humerii, and vertebrae, and large quantities of low-return elements, such as metapodials, tarsals, carpals, and phalanges. This pattern is characteristic of a distant patch or kill/butchery site, where field butchery removed high-value parts, or a central place, where procurement distances were insufficient to require the removal of low-value elements.
2. The food utility analysis also reflects the preponderance of low-utility elements within the assemblage.
3. The results of the geochemical analysis showed that modern deer display trace element ratio variations that reflect the geologically distinct home range, or origin, of black-tailed deer in northern California, allowing trace element ratios to be used as a sourcing technique for the prehistoric artiodactyl remains from CA-COL-267.
4. When modern trace element ratios were used to source black-tailed deer from CA-COL-267, a pattern of nonlocal procurement was revealed. Eighty-four percent of the analyzed specimens were obtained from distances greater than 48 km.
5. The results of the trace element sourcing support the hypothesis of resource depression and intensification in the area surrounding CA-COL-267, while the body part representation and food utility of the assemblage, combined with the sourcing study, point toward a rejection of caloric currencies as the primary factor driving the prehistoric transport decisions represented by the archaeofaunal assemblage of CA-COL-267.
6. It appears that a significant proportion of the black-tailed deer deposited at CA-COL-267 were obtained from distances greater than 48 km, and the elements of low food value on these animals were transported despite their economic cost.

The results of this study show contradictions between body part and utility analyses directed at assessing nonlocal procurement and geochemical sourcing, which are useful for understanding human behavior. Geochemical sourcing methods in zooarchaeology will help provide a multidimensional picture of human behavior by revealing procurement behavior that may be masked by assemblage-altering processes such as nonhuman taphonomic processes or variations in human behavior. Future research should look to multiproxy sourcing methods that include both trace element and stable isotopes. This should improve the ability of these methods to correctly classify known geological regions. As with most archaeological research, larger sample sizes, both in the modern and zooarchaeological samples, should be sought.

This paper has shown the utility of geochemical sourcing techniques, specifically trace element sourcing, in zooarchaeology while emphasizing the importance of multimethod approaches. Theory-driven inquiries and predictions used in tandem with multiple methods have made significant contributions toward extricating human behavior from the archaeological record. In this case study, geochemical sourcing methods used in tandem with tried-and-true zooarchaeological methods and evolutionary theory were shown to have utility in understanding human behavior. This case study leads one to be hopeful about the potential of further applications and advancements in this methodology in the understanding of past human behavior.

ACKNOWLEDGMENTS

I would like to thank Laynette Davis and Brett Gomes of the California Department of Fish and Game, Paul of the California Department of Transportation, Michelle A. Gras of the UC Davis ICP-MS laboratory, and Jelmer Eerkens, Frank Bayham, Greg White, Tom Origer, and Richard Hughes for assisting with this research. I am grateful for early comments on the manuscript made by Mary Stiner and Barnet Pavao-Zuckerman. Additional suggestions from two anonymous reviewers aided in clarifying and improving the manuscript.

NOTES

1. B.P. in this paper refers to a blend of artifact seration dates (Fredrickson 1994; White 2002) and obsidian hydration dates based upon a paired, uncalibrated radiocarbon-obsidian hydration calibration curve (DeGeorgey 2003).

2. Tom Origer of Origer and Associates conducted the rim measurements, while Richard Hughes of the Geochemical Research Laboratory conducted the sourcing studies. Both analyses were donated as a portion of the James A. Bennyhoff Memorial Award, granted to myself and Brandon A. Patterson by the Society for California Archaeology.

3. The California Department of Transportation assisted in this endeavor, as did the zooarchaeology laboratory at California State University, Chico, by donating specimens.

4. The collection of poached deer was aided by Laynette Davis and Brett Gomes, Department of Fish and Game wardens.

CHAPTER 4

Mass Capture in Prehistoric Northwestern California, Energy-Maximizing Behaviors, and the Tyranny of the Ethnographic Record

ADRIAN R. WHITAKER

Salmon and acorns have traditionally been identified as the hallmark resources in late-period northwestern California (Gibbs and Heizer 1973; Kroeber 1925, 1960; Kroeber and Barrett 1960). In coastal settings, the addition of sea mammals was thought to have completed a triumvirate of staple resources (Heizer 1951; Kroeber 1960). The perceived importance of these resources is based almost exclusively on the long history of ethnographic research with groups of the area, especially the Yurok (Curtis 1924; Gibbs and Heizer 1973; Kroeber 1925; Kroeber and Barrett 1960). Due to a paucity of archaeological studies and poor preservation in the forested environs of northwestern California, little archaeological evidence is available to help us evaluate the ethnographic record. Small samples from mainly coastal sites, excavated prior to the advent of modern screening techniques, have substantiated the importance of pinnipeds in the diet (Gould 1966; Heizer and Elsasser 1966; Milburn et al. 1979). In these studies, bone was collected using shovel broadcasting techniques (Gould 1966) or was field identified and thrown back into the ocean (Heizer and Elsasser 1966).

The fine-grained analysis of a large (more than 35,000 specimens) faunal assemblage from *Tsahpek*, an ethnographic Coast Yurok village, indicates a broad-spectrum subsistence economy on the Humboldt County coast. Rather than a dominance of salmonids and pinnipeds in the coastal assemblage, it appears that waterfowl and smaller, near-shore and freshwater fish were staple foods for the duration of site occupation.

The most abundant taxa in the zooarchaeological record from *Tsahpek* are gregarious species that could have been easily captured en masse using nets. These species, however, often require high processing costs, which in many cases would preclude them from the diet of a forager seeking optimal returns. Since species offering lower return rates are abundant in the faunal record at the site, it is obvious that site inhabitants deviated from this expectation. This paradox is discussed in light of the benefits of mass capture techniques (Ugan 2005b) and the trade-offs engendered in energy-maximizing and time-minimizing strategies (Bettinger 2001).

ETHNOGRAPHIC RECORD

This section provides a brief introduction to the Yurok, the ethnographic inhabitants of *Tsahpek*. The broader ethnographic record of bird procurement techniques throughout the state of California is addressed separately below. The Yurok tribe inhabited the coastal region of northwestern California between modern Trinidad and Crescent City and along the lower 45 miles of the Klamath River

(Pilling 1978). Yurok is one of two Algic languages (the other is the neighboring Wiyot) and belongs to the broader Algonquin language family (Golla 2007). In addition to this distant linguistic tie, the Yurok are considered by many to be the southernmost representative of the sedentary Northwest Coast cultures (Kroeber 1925; Pilling 1978). Similar to these more northerly cultures (for example, the Haida), Yurok society was highly structured, with tiered social obligations to individuals, families, villages, and districts. The household was the fundamental social and economic unit of Yurok society, but between three and seven households might form a "sweat house group," with men sharing a common sweat house and the wives and children of each man occupying a separate house (Tushingham 2009).

Although considered part of the Northwest Coast culture area, Yurok villages were smaller than the large corporate villages of British Columbia and Alaska, and their houses were smaller as well. Kroeber recorded villages of between 2 and 24 houses and estimated populations between 15 and 165 people (Kroeber 1925:16). Based on this information, Kroeber estimates that the average Yurok village was home to 45 people. While villages generally were occupied year-round, some may have been occupied only seasonally.

The Yurok were hunter-gatherer-fishers who practiced intensive food gathering regimes and storage to maximize yields on local resources. The ethnographic record emphasizes the seasonal abundances of two resources—acorns and salmon—in particular. Salmon required a great deal of upfront costs, to build nets, weirs, and dams and then to prepare fish for storage. Acorns required a similar effort but were "back loaded," with most of the labor entailed in processing rather than initial procurement. Though of secondary importance, sea lions were obtained at offshore rocks using dugout redwood canoes and were harpooned at the entrances to lagoons and rivers (Kroeber and Barrett 1960). Other resources noted in the Yurok ethnography include surf fish, mussels, and deer (Kroeber 1925). Curtis (1924) and Powers (1925) both provide brief descriptions of bird hunting, but most Yurok ethnography does not report that birds were an important subsistence resource.

ARCHAEOLOGICAL RECORD

The prehistoric record in northern California is relatively shallow. Synthesized by Hildebrandt and Hayes (1993) and later refined by Hildebrandt and Levulett (1997, 2002; Hildebrandt 2007), the culture history of northwestern California is divided into three periods: the Borax pattern (5000–1500 B.C.), the Mendocino pattern (1500 B.C.–A.D. 500), and the Gunther pattern (A.D. 500–contact). With two exceptions (Angeloff 2007; Schwaderer 1992), no northern Californian sites dating to the Borax pattern have been found in coastal settings. Similarly, few coastal sites dating to the Mendocino pattern have been found (Jones 1991). Both the Borax and Mendocino patterns are thought to represent a reliance on interior resources with occasional procurement of marine shellfish (Hildebrandt 2007; Hildebrandt and Levulett 1997; Levulett 1985). Ephemeral deposits at coastal sites indicate a highly mobile settlement and subsistence pattern.

The Gunther pattern marks the emergence of intensive littoral and riverine resource use. Diagnostic artifacts from this pattern include Gunther barbed points (presumably arrowheads), net sinkers, ground stone, and nonsubsistence-related artifacts such as shell beads, steatite pipes, and ceremonial obsidian blades. Woodworking materials are thought to signal the use of redwood dugouts along the rivers (Hildebrandt and Levulett 1997). The fluorescence of material culture at approximately A.D. 500 accompanies a rapid increase in the number of coastal sites (Jones 1991).

Linguistic data indicate that the shift in settlement patterns was likely accompanied by the arrival of Algic- and Athabaskan-speaking peoples in the region. As mentioned, the Algic stock consists of two languages in northwestern California, Wiyot and Yurok. Golla (2007) speculates that the Wiyot had arrived around Humboldt Bay by A.D. 100, followed by the arrival of the Yurok on the Klamath River drainage around A.D. 700–800. Athabaskan groups followed soon thereafter, occupying areas of the coast to the north and south of Humboldt Bay and the mouth of the Klamath River (Figure 4.1).

Tsahpek (CA-HUM-129), the focus of this study, is located in Coast Yurok traditional territory on

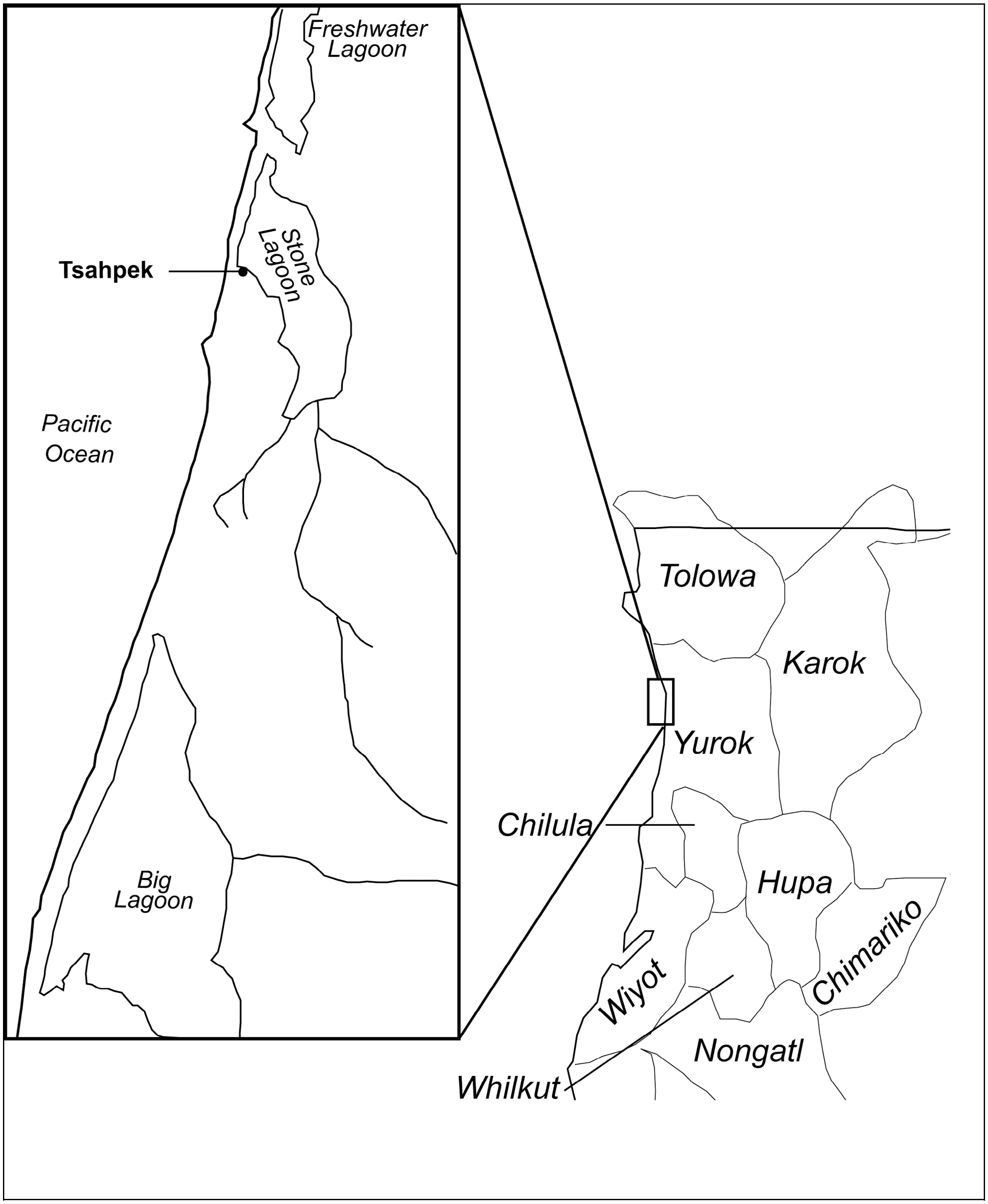


Figure 4.1. Map of study area.

Table 4.1. Radiocarbon Dates from Tsahpek (CA-HUM-129).

Sample ID Number	**Provenience**	**Depth**	**^{14}C Age**	**Material**	**2-sigma cal B.C./A.D. 1**	**Median[1]**
OS-63547	Unit N2 W16	0–10 cmbs	635 ± 35	*Callorhinus* bone	Off curve[2]	Off curve[2]
OS-57904	Unit NW2 SW 9	20–30 cmbs	1150 ± 25	*Mytilus* shell	A.D. 1406–1586	A.D. 1479
OS-63552	Unit N2 W16	30–40 cmbs	1270 ± 35	*Callorhinus* bone	A.D. 1307–1463	A.D. 1390
OS-63553	Unit NW2 SW7	30–40 cmbs	950 ± 30	*Callorhinus* bone	A.D. 1536–1806	A.D. 1660
OS-57902	Slump B	40–50 cmbs	1070 ± 25	*Mytilus* shell	A.D. 1465–1651	A.D. 1550
OS-63548	Unit NW2 SW10	40–50 cmbs	1470 ± 40	*Callorhinus* bone	A.D. 1098–1328	A.D. 1238
OS-63549	Unit NW1 SW6	50–60 cmbs	1050 ± 30	*Callorhinus* bone	A.D. 1475–1664	A.D. 1569
OS-63550	Unit N4 W16	60–70 cmbs	1040 ± 35	*Callorhinus* bone	A.D. 1477–1672	A.D. 1577
UCR-0884	Unit NW 1 SW 8	60–70 cmbs	1490 ± 100	Charcoal	A.D. 340–710	A.D. 552
UCR-0885	Unit N2 W18	75–80 cmbs	1860 ± 120	Charcoal	117 B.C.–A.D. 424	A.D. 158
OS-63551	Unit N3 W16	80–90 cmbs	1010 ± 30	*Callorhinus* bone	A.D. 1497–1687	A.D. 1598
UCR-0883	Unit NW 1 SW 10	95 cmbs	215 ± 100	Charcoal	A.D. 1610–1953	A.D. 1734
OS-57903	Slump B	90–100 cmbs	1250 ± 30	*Mytilus* shell	A.D. 1318–1474	A.D. 1406
OS-57905	Unit NW2 SW 9	100–110 cmbs	1370 ± 25	*Mytilus* shell	A.D. 1246–1414	A.D. 1323

[1] All dates calibrated using Calib 5.01 calibration software. Assays on Mytilus shell were corrected for the marine reservoir effect with a correction of $\Delta R = 308 \pm 40$.

[2] The date falls within modern range on the calibration curve with reservoir correction; it is possibly modern or historic.

Stone Lagoon in northern Humboldt County. Stone Lagoon is the second largest brackish lagoon in the region. Like the others, it is closed by a barrier beach during some but not all winters. The breach point for the lagoon lies 150 m north of CA-HUM-129. Fifty-one m^3 of deposits were excavated from *Tsahpek* over the course of two field seasons in 1976 and 1978. The excavation was supervised by John Milburn and Dave Fredrickson from Sonoma State University, and initial analysis was performed there (Milburn et al. 1979). Marker artifacts indicate a Gunther pattern occupation of the site. Radiocarbon assays from charcoal, fur seal bone, and shell place the likely occupation between cal A.D. 500 and 1730 (median probabilities; Table 4.1). In addition to an abundance of faunal remains at the site, 1,342 net sinkers were recovered, accounting for close to half of all major artifacts (Milburn et al. 1979).

Hildebrandt (in Milburn et al. 1979) analyzed a 20 percent sample of mammalian fauna from the first year's excavation; 100 percent of the mammalian and avian faunal assemblage was analyzed for this study. Additionally, close to 5,000 fish vertebrae were examined. Standard zooarchaeological analytical procedures were followed for mammalian and avian samples using comparative specimens from the zooarchaeological collection at the University of California, Davis, and from the Museum of Vertebrate Zoology, University of California, Berkeley. The fish vertebrae (whole and fragmented) were simply categorized as "salmonid" or "non-salmonid." This identification is possible due to the unique "primitive," rounded, and spongy appearance of salmonid bones relative to other orders of bony fish.

A total of 36,388 avian and mammalian specimens were analyzed. Of these, 29,902 were identifiable to class or lower taxonomic level.[1] Of this group, 18,680 were mammals and 11,222 were birds. Mammalian specimens accounted for 62 percent of NISP. There were also 23 snake vertebrae present. Twenty-eight mammal species were represented with an MNI of 76. These included 13 sea lions, seven artiodactyls, six sea otters, and six lagomorphs. More than 30 bird species were represented, with an MNI of 208 (Tables 4.2 and 4.3).[2]

It should be noted that the difficulty in differentiating between shaft fragments of avian and lagomorph long bones may have led to the misclassification of a few specimens classified as "unidentified bird." However, identified *Sylvilagus bachmani* and *Lepus californianus* elements make up only 1 percent

Table 4.2. NISP and MNI of Elements Identified to Order or Better from CA-HUM-129.

		NISP	MNI
Class Pisces			
Salmonid	Salmon	112	-
Non-salmonid	Not salmon	4,710	-
	Total (Pisces)	**4,822**	
Class Reptilia			
Crotalus sp.	Rattlesnake	22	1
Class Aves			
Gavia sp.	Loons	9	1
Podiciphidae	Grebes	86	20
Aechmorphus occidentalis	Western grebe	20	3
Podiceps podiceps	Pie-billed grebe	178	14
Pelicanus occidentalis	Brown pelican	28	2
Phalacrocorax sp.	Cormorants	18	2
Anseriformes	Ducks and geese	20	-
Anatidae	Ducks and geese	214	13
Large Anatidae		37	3
Medium Anatidae		31	7
Small Anatidae		10	2
Anserinae sp.	Geese and swans	80	**8**
*Branta*sp.	Brant/Canada goose	22	3
Cygnus sp.	Swan	1	1
Chen caerulescens	Snow goose	2	1
Anatinae	Ducks	511	104
Large Anatinae		209	18
Medium Anatinae		35	4
Small Anatinae		47	5
Anas sp.	Dabbling ducks	263	69
Small *Anas*		14	3
Large *Anas*		61	4
Anas acuta	Northern pintail	9	4
Anas americana	Gadwall	17	4
Anas clypeata	Northern shoveler	1	1
Anas cyanoptera	Cinnamon teal	206	24
Aythya sp.	Diving ducks	161	27
Melanitta sp.	Scoters	4	3
Lophytes cucullatus	Hooded merganser	1	1
Mergus sp.	Merganser	7	1
Oxyura jamaicensis	Ruddy duck	84	10
Falciniformes	Birds of prey	5	1
Cathartes aura	Turkey vulture	2	1
Accipitrinidae	Kites, hawks, and eagles	9	1
Buteo sp.	Large hawks	10	1
Class Aves (Con't)			
Aquila crysaetos	Golden Eagle	4	1
Calipella californica	California Quail	1	1
Areidae	Herons	11	3
Fulica americana	American Coot	605	47
Charadriformes	shore birds	7	
Scolopacidae	Sandpipers	1	1
Callindris sp.	Sandpipers	1	1
Laridae	Gulls	59	6
Alcidae	Alcids	4	2
Uria aalge	Common Murre	3	1
Cephus columna	Pidgeon Guillemot	2	1
Strigiformes	Owls	1	
Bubo virginianus	Great Horned Owl	1	1
Tyto alba	Barn Owl	2	2
Corvus sp.	Crows	2	1
	Total (Aves to Order)	**3138**	**208**
Class Mammalia			
Sorex sp.	Shrews	8	1
Scaponus sp.	Moles	5	3
Carnivora	Carnivores	26	--
Canis sp.	Dogs	138	2
Urocoyon sp.	Gray Fox	2	1
Ursa sp.	Bears	6	1
Proyon lotor	Racoon	20	1
Enhydra lutris	Sea Otter	334	6
Lutris canadensis	River Otter	4	1
Mephitis mephitis	Striped Skunk	37	2
Mustela sp.	Weasel/Mink	6	1
Felidae	Cats	4	1
Felis rufus	Bobcat	1	1
Pinnipedia	Seals and Sea Lions[1]	251	--
Otariidae	Fur Seals and Sea Lions	896	--
Arctocephiline	Fur Seals	1	1
Callorhinus ursinus	Northern fur seal	147	4
Eumetopias jubatus	Steller's Sea Lion	438	5
Zalophus californianus	California Sea Lion	192	3
Phoca vitulina	Harbor Seal	18	1
Cetacea	Whales and Dolphins	14	1
Delphinidae sp.	Dolphins and Allies	12	1

Table 4.2. (cont.)

		NISP	MNI
Class Mammalia (con't)			
Artiodactyla	Even-Toed Ungulates	516	--
Cervus elaphus	Elk[2]	259	4
odocolius hemionus	Black-tailed deer[3]	184	3
Rodentia	Rodents	49	
Erethizon dorsatum	Porcupine	1	1
Aplodontia rufa	Mountain Beaver	41	4
Sciuridae	Squirrels and Chipmunks	15	
Spermopholus sp.	Ground Squirrels	20	2
Scurius		9	2
Scurius griseus	Western Gray Squirrel	11	2
Thomymys bottae	Botta's Pocket Gopher	5	2
Peromyscus truei	Piñon Mouse	2	1
Microtus sp.	Vole	43	12
lagomorpha	Rabbits and Hares	24	
lepus californianus	Black-Tailed Jackrabbit	20	1
Sylvilagus bachmani	Brush Rabbit	111	5
	Total (Mammals to Order)	**3870**	**76**

Notes:

[1] "Pinnipedia" includes seals and sea lions but also sea otters whose rib fragments can often be mistaken for seal/sea lion

[2] Elk from Stone Lagoon are most likely Roosevelt Elk (*Cervus elaphus roosevelti*)

[3] Deer from Stone Lagoon are most likely Black-tailed deer.

Table 4.3. Summary NISP Data for the Faunal Assemblage from CA-HUM-129.

Bird		**Mammal**	
Identified to order	3,138	Identified to order	3870
Avian spp.	4,734	Mammal spp.	12,923
Very large bird	38	Marine mammal	36
Large bird	238	Large mammal	962
Medium to large birds	282	Medium to large mammal	498
Medium bird	2,705	Medium mammal	308
Small to medium bird	65	Small to medium mammal	53
Small bird	22	Small mammal	30
Total	11,222	**Total**	18,680
Percentage	38	**Percentage**	62

Notes: Size determinations based on body mass of animals. For the purposes of this paper, all can be considered simply Aves spp. or Mammalia spp.

of identified elements, whereas identified avian specimens make up 55 percent of the assemblage. Hence, if this error is present, it is minor.

The MNI for birds may be inflated relative to mammals due to differential butchering of the two types of animals. The majority of birds in the sample are smaller species, whereas the majority of mammals are medium to large species. The large terrestrial mammal elements were highly fragmented and spirally fractured, implying marrow extraction. While the destruction of long bones likely led to deflation of the MNI statistic in mammals, it simultaneously would have led to an inflation of NISP.

Despite the potential bias in the MNI statistic, the numbers of individual waterfowl are dramatically larger than those for either terrestrial or marine mammals. The number of *Fulica americana* (47) is larger than all pinnipeds, artiodactyls, and lagomorphs combined (27); the MNI for ducks and geese (112) is more than four times this number.

Further bias in the preservation of bird bone relative to mammal bone might have been introduced through differential butchering or disposal of large mammal bone. It is a common practice for hunter-gatherers to dispose of large mammal bones outside villages. In this case, these elements would most likely have been simply thrown onto the beach and washed out to sea. If this is true, a larger than expected proportion of small animals (such as birds) would be expected within village middens. However, the presence of more than 18,000 mammal bones at the site (more than 3,900 of which were large mammals) indicates that even if some bones were deposited this way, a great deal were not. Because there is no way to identify this potential bias, it is assumed that the faunal data reflect the relative contributions of various taxa to the diet.

A total of 4,822 fish vertebrae and vertebra segments was examined for traits diagnostic of the family Salmonidae. Of these, 112 (2.3 percent) were salmonid; the remaining 97.7 percent were not identified (Table 4.2). This appears to contradict the importance of salmon reported in the ethnographic record.

BIRD BEHAVIOR AS IT RELATES TO PROCUREMENT

Three major groups of birds dominate the avifaunal assemblage: ducks and geese, (Anatidae spp.), coots (*Fulica americana*), and grebes (Podiciphidae spp.). A brief description of the habitat preferences, escape behaviors, and diversity within each of these groups frames the arguments that follow. The scant ethnographic data indicate that hunting techniques were specialized to exploit the habitat choice and escape behaviors of each of these groups of waterfowl.

Ducks and Geese

Ducks and geese are by far the most common family of waterfowl in California. Twenty-seven species from the family Anatidae are native to northern California and occupy a number of ecological niches, including fresh- and saltwater, streams, ponds, lagoons, estuaries, bays, and the ocean (Cogswell 1977; Collings 1960; Terres 1980). The majority of ducks and geese identified in the Stone Lagoon sample are "dabbling" or surface-feeding ducks that live in calm water and feed on aquatic plants. The dabbling ducks are strong flyers, and most take off vertically when startled; some young adults dive when in danger. In contrast, bay ducks are expert divers and dive when frightened. Unlike the dabblers, bay ducks need a running start, akin to the taxiing of an airplane, to take off. Most ducks (*Anatinae* spp.) weigh between 1 and 3 kg. Geese (*Anserinae* sp.) can weigh as much as 4.5 kg (Cogswell 1977).

Coots and Grebes

The American coot (*Fulica americana*) is a member of the family Ralidae. Coots are much smaller on average than ducks (900 g) and are scavengers, feeding on shore and on and below the surface of the water. They cannot take off from a dead stop but, similar to bay ducks, must skim along the surface of the water (Cogswell 1977; Collings 1960; Terres 1980).

Grebes (family Podiciphidae) are smaller, diving waterfowl. Grebes range in size from 100 to 1,600 g. They are strong divers and powerful underwater swimmers but are slow on land and must "taxi" before taking off. Like the bay ducks, grebes tend to dive when startled.

ETHNOGRAPHIC BIRD PROCUREMENT

While the ethnographic accounts of birding are widespread, there is generally less than a passing mention of bird procurement techniques. The *Handbook of North American Indians*, volume 8: *California* contains only 11 references to waterfowl procurement in California (Heizer 1978). These references come from tribes throughout California, including the Tolowa in the northwest, the Atsugewi on the Modoc Plateau, the Eastern Miwok, the Yokuts, and the Costanoan. Powers's *Tribes of California* contains further mention of waterfowl procurement, by the Patwin, Maidu, and Yurok (Powers 1925).

Across the board, the ethnography refers to nets and basket traps as the primary procurement methods. Nets were used to exploit the escape behavior of different birds. Diving birds were captured by dropping berries and other bait to the bottom of a body of water and laying a net just below the surface. When the birds went after the bait, they were caught in the net and drowned.

Powers recorded a technique used by the Yurok for capturing diving waterfowl:

> On lagoons and shallow reaches of the river [the Yurok] have a way of trapping wild ducks which is ingenious. They sprinkle huckleberries or *salálberries* on the bottom, then stretch a coarse net a few inches under the surface of the water. Seeing the tempting decoy, the ducks dive for it, thrust their heads through the meshes of the net, and the feathers prevent their return. Thus they are drowned, and remain quiet with their tails elevated so that others are not frightened, and an abundant catch sometimes rewards the trapper [Powers 1925:50].

A similar technique is recorded by Curtis for the neighboring Wiyot: "Nets were set at night in places frequented by diving fowl, the lower edge being staked to the bottom, so that some of the birds, rising to the surface, would become entangled" (Curtis 1924:74).

Birds that fly when startled were taken by stretching nets across flyways. For instance, the Yokuts captured ducks and geese in long-handled nets as they flew by (Wallace 1978).

Other methods included using decoys to lure ducks within range of special arrows, slings, or thrown nets. This method would presumably be well suited for netting or clubbing birds that need to taxi before taking off.

Common to all these techniques is the targeting of multiple individuals. The species targeted are all gregarious, allowing for mass capture with little effort. In fact, Curtis makes only a brief mention of Wiyot individuals hunting lone ducks. Individuals hunted ducks with wooden arrows after luring them close to blinds in Humboldt Bay (Curtis 1924:73).

PAYOFFS ON MASS CAPTURE TECHNIQUES

The use of optimal foraging theory and specifically the diet breadth model (Charnov 1976; MacArthur and Pianka 1966; Schoener 1974) in California archaeology has become the norm (e.g., Basgall 1987; Bettinger et al. 1997; Bouey 1987; Broughton 1997, 1999; Hildebrandt and Jones 1992; Hildebrandt and McGuire 2002; Wohlgemuth 1996). These diet breadth studies often use body size as a proxy for post-encounter hunting return rates (e.g., Broughton 1999; Waguespack and Surovell 2003). Following this logic, birds have been discounted as low-ranked resources.

Madsen and Schmidt (1998) have challenged the notion that large size always equates to high caloric returns. They cite a number of examples from marsh settings of invertebrates (such as grasshoppers, Mormon crickets, and brine fly larvae) that offer extremely high payoffs in the right scenario—namely when they are "salted and sun-dried" in windrows adjacent to Great Basin lakes (Madsen and Schmitt 1998). When this is true, a forager can literally scoop up the insects and eat them without further processing.

However, Ugan (2005b), in compiling a number of studies on the payoffs of mass capture, finds that returns using mass capture techniques often do not greatly exceed the returns of capturing individuals of the same species. In these cases, the time saved in pursuit by mass capture techniques is outweighed by the high processing times, which account for the bulk of the overall search and handling times for these taxa. Ugan's findings suggest that fish and large invertebrates provide large payoffs when mass captured, sometimes in excess of 100,000 kcal per hour per person, but that mass captured birds and mammals do not. Several studies cited by Ugan provide return rates of between 500 and 1,300 kcal per hour per person for birds, in comparison to returns between 1,220 and 241,000 with a mean of about 8,000 kcal per hour per person for mass captured fish (Ugan 2005b).[3]

Surprisingly, modern ethnography among the Cree (Winterhalder 1981) and Inujjuamiut (Smith 1991), as well as experimental data from the Great Basin (Simms 1987), indicates that return rates of between 1,720 and 5,160 kcal per hour (Table 4.3) are possible using encounter hunting techniques (individual capture). These numbers may be inflated given modern hunting techniques (shotguns) and the large size of individuals hunted in these studies. It is unclear which species of ducks were taken in the two mass capture studies cited by Ugan (2005b), and therefore a comparison of body or meat weight is not possible between individual and mass capture techniques.

Assuming the general patterns of the data presented by Ugan hold, the zooarchaeological record at Stone Lagoon would appear to be dominated by extremely low-ranked taxa. The incongruity between the archaeological record and foraging theory, however, is explained by the broader context of foraging at the site.

MASS CAPTURE: TIME-MINIMIZING VERSUS ENERGY-MAXIMIZING STRATEGIES

Late-period California is characterized by intensive hunter-gatherer economies, densely packed populations, and specialized tool kits (Baumhoff 1963; Bennyhoff and Fredrickson 1994). These are all traits associated with "energy-maximizing"

Table 4.4. Return Rates for Various Bird Procurement Techniques.

			Return Rates[1]		
Animal	**Taxa**	**Hunting Method**	**Low**	**High**	**Source**
Eider duck	*Somateria mollissima*	Encounter	3,180	5,160	Smith (1991)
Canada goose	*Branta canadensis*	Encounter	1,720	3,460	Smith (1991)
Waterfowl	Not reported	Encounter	-	3,000	Winterhalder (1981)
Ducks	*Anas* sp.	Encounter	2,975	2,709	Simms (1987)
Ducks	Family Anatidae	Drive during molt	561	1,317	Simms (1987)
Ducks	Family Anatidae	Australian net hunt	492	867	Satterthwaite (1987)

Note: Based on Ugan 2005:Tables 1 and 3.

[1] All rates in kcal per hour.

subsistence economies (see Bettinger 2001). "Energy maximizing" is set in contrast to "time minimizing" in the classic "traveler-processor" model of Great Basin subsistence (Bettinger 1991, 2001; Bettinger and Baumhoff 1982). In this model, "travelers" tend to live in energy-rich environments where time is at a premium. To avoid opportunity costs from extended hunting (for instance, lost time that could be used to maintain social alliances, find mates, and so on), travelers are time minimizers who meet their energy requirements as quickly as possible. Travelers are expected to live in regions with low population densities, pursuing only high-ranked resources and moving to fresh resource patches often. Processors, on the other hand, live at high population densities and are often socially or geographically circumscribed. Processors do not need to move over great distances to participate in nonsubsistence activities—there is a readily available social cohort—and cannot move to alleviate resource stress; therefore, energy is in short supply but time to extract the energy is not.

The inhabitants of *Tsahpek* were certainly energy maximizers. The Coast Yurok were socially circumscribed by surrounding groups (Wiyot and Tolowa) and environmentally circumscribed on the coastal plain, with the Pacific Ocean to the west and the dense, resource-poor redwood forest to the east. This required the Coast Yurok to squeeze every last calorie out of the available environment, necessitating the harvest of large quantities of birds and small fish, especially during lean periods. This may explain why grebes, coots, and other year-round occupants of the lagoon (Robbins et al. 1966) make up the largest proportion of the avian assemblage at *Tsahpek*. Furthermore, in contrast to the seasonal availability of steelhead in the lagoon or other salmonids on nearby rivers, small fish would have been available year-round.

Despite providing lower returns than large mammals or fish, birds still outrank most plant foods and shellfish. While birds are costly to process, acorns and shellfish require a great deal more effort and were also evidently a large part of the aboriginal diet (Curtis 1924; Driver 1939; Kroeber and Barrett 1960). Acorns yield 790 kcal per hour (Bettinger et al. 1997) and mussel, the low-ranked staple shellfish on the north coast of California, yields between 400 and 500 kcal per hour (Jones and Richman 1995; Kennedy 2005). Furthermore, birds were a dependable meat source during the winter, when other resources were more difficult to procure. Sea lions are migratory and are not present on the north coast during the fall and winter (Scheffer 1958), and plant foods are often unavailable. Even if return rates were only slightly better for avifauna than for shellfish or plant foods, birds would have supplied much needed protein and fat. In the spring, the eggs of waterfowl could also be harvested. To maintain a year-round occupation of the coast, it was necessary for the inhabitants of *Tsahpek* to exploit a wide range of animal resources despite seemingly low caloric returns.

TYRANNY OF THE ETHNOGRAPHIC RECORD IN CALIFORNIA ZOOARCHAEOLOGY

California archaeology has benefited from an abundance of ethnographic literature. This record makes it tempting to turn to ethnography for answers when archaeological data are ambiguous or lacking.

This has especially been the case in northwestern California, where anthropologists have viewed salmon as the single most important food resource. While salmon were certainly important, particularly to populations living along rivers, ethnographic and archaeological research at the beginning of the twentieth century failed to account for other important resources, specifically small fish and waterfowl.

The anthropological emphasis on salmonids on the north coast of California likely stemmed from the culture area approach taken by Kroeber (Buckley 1989; Kroeber 1922, 1925). Kroeber viewed the Yurok as a "sub-climax" of the Northwest Coast cultures centered in British Columbia. The majority of similarities that Kroeber identified in these groups related to nonsubsistence traits such as the use of redwood dugouts and redwood plank houses and several sociopolitical traits related to prestige and religious ceremonies (Kroeber 1925). The social elaboration in the Northwest Coast culture "climax" area was possible because of the large amounts of protein that could be acquired and stored from key resources such as salmon and large marine mammals—sea lions and in some cases whales. The nonsubsistence affinities of the Yurok and their neighbors to peoples of the Northwest Coast likely biased the focus of Kroeber and other ethnographers when they recorded subsistence pursuits. Beyond this, the elaborate construction and attendant ceremonies of the Kepel fish dam and other fish weirs and dams (Kroeber and Barrett 1960; Waterman and Kroeber 1938) further substantiated the notion that the Yurok were very similar to peoples to the north. While some attention was paid to Coast Yurok sea mammal hunting and shellfish procurement, little attention was given to fish other than salmonids, river suckers, and surf smelt:

> The rest of the freshwater fauna [other than suckers] is notably poor; few in species, individuals also few and small [Kroeber and Barrett 1960:5].

> In the ocean, the Indians had more difficulty taking fish than in streams. There were undoubtedly more species of salt-water than riverine fishes available, but as some of these were probably never fished for and others were to be seen only sporadically, it is unnecessary to list all the species [Kroeber and Barrett 1960:6].

Early archaeology in northwest California appeared to corroborate the ethnography. Early excavations at Gunther Island, Tsurai, and Patrick's Point (Gould 1966; Heizer and Elsasser 1966) were done without screening. The field techniques biased the recovery of bone toward large mammals and large fish. These excavations and a lack of modern excavation on the coast—except the current study—have perpetuated the notion of salmon and marine mammals as protein staples of prehistoric northwestern Californians.

However, some of the historically densest populations in Yurok and Tolowa territories, and virtually all settlements in Wiyot territories, were on bays, estuaries, and lagoons, where salmon would have played a smaller role and acorn procurement would have required traveling some distance inland. These populations could not have been sustained by salmon and acorn alone. It is more likely that shellfish, smaller fish, and waterfowl made up a large portion of the Coast Yurok diet. The coastal record from Southern Athabaskan territory in southern Humboldt County substantiates the pattern. The majority of sites excavated by Levulett (1985) and Whitaker (2006, 2008) consist mainly of shellfish and fish species that inhabit intertidal waters.

California archaeology benefits from an ethnographic record that can offer excellent material for couching explanations. It is tempting to use ethnographic data from throughout the state to develop explanations of archaeological data at a particular site (much as this paper has done). However, the zooarchaeological findings of this study demonstrate the importance of using the ethnographic record with discretion and suspicion. This is not to say that the "tyranny of the ethnographic record" as it might be applied to Pleistocene hunter-gatherers (Wobst 1978) applies to California as well, but rather that the history of ethnographic and archaeological research must be taken into account prior to the wholesale adoption of ethnography as an explanatory tool. In California archaeology, we are fortunate to have a large body of ethnographic literature derived from groups that appear to have been present in California at least as early as the late prehistoric period. However, a strong correlation between the ethnographic and archaeological record should be identified prior to the adoption of an ethnography-based explanation for archaeological data (Binford 1967).

While it is tempting to focus on large-bodied mammals in zooarchaeological analysis, it is important to keep in mind the intensified economies of Late-period Californians. Energy-maximizing hunter-gatherers are likely to create assemblages that are dominated by smaller taxa. Furthermore, energy-maximizing foragers will spend a great deal more time procuring and processing smaller taxa while continuing to pursue large game when it is available. This is not a signal of resource depression or suboptimal adaptation but rather an adaptation resulting from social and economic elaboration.

SUMMARY

The emphasis in the ethnographic record on salmon, marine mammals, and acorns has been perpetuated in many modern archaeological studies, when in fact myriad resources appear to have made up the diet of coastal foragers in northwestern California. These energy-maximizing hunter-gatherers hunted the large-bodied taxa prevalently mentioned in the ethnographic record, but the majority of their caloric intake appears to have come from smaller taxa such as waterfowl and non-salmonid fish. This case emphasizes the caution necessary when using ethnography to make predictions about, or explain patterns in, the archaeological record. When using optimal foraging approaches, it is important to account for the degree to which late-period California hunter-gatherers practiced intensified subsistence economies.

This is not to say that the ethnographic record in California should be disregarded; rather we must acknowledge biases in the recording of subsistence culture. In fact, much of the bias appears to stem from the fact that mundane details of life, such as subsistence, often took a backseat to the ceremonial and nonsubsistence portions of culture not observable in the archaeological record. In this sense, the archaeological and zooarchaeological record can fill in pieces of the already rich record of Late-period California lifeways.

ACKNOWLEDGMENTS

I thank the editors of this volume, Michael Glassow and Terry Joslin, who reviewed and edited several versions of this paper. Robert Bettinger and two anonymous reviewers provided valuable comments as well. The Museum of Vertebrate Zoology at UC Berkeley and the UC Davis zooarchaeological lab gave me access to comparative collections, and Glenn Farris and Rick Fitzgerald at California State Parks worked hard to give me access to the Stone Lagoon fauna. Finally, I thank Christyann Darwent and Tim Carpenter for help identifying especially perplexing bone fragments.

NOTES

1. The Stone Lagoon collection is curated by the California Department of Parks and Recreation curation facility in West Sacramento, California.

2. MNIs were calculated for families, genera, and species. Genera and family MNI statistics are not simply a sum of all MNIs for members of the group at more specific taxonomic levels. Instead, bolded MNIs were calculated by combining the raw data from all taxonomic groups within a family or genera and then calculating a unique MNI statistic. The total avian MNI (208) is the sum of all family-level (and therefore nonredundant) MNIs. While I acknowledge that the standard level of analysis based on MNI is at the species level, the use of nonredundant elements at genus, family, or even class level provides an equally useful measurement of the relative contribution of these higher-level groups to the diet of the site inhabitants. This point is particularly germane in this case, where the research question dictates an analysis at these higher taxonomic levels. Similar to other MNI calculations, these statistics still underestimate the actual number of animals eaten at the site but provide a baseline for analysis.

3. While these foraging returns are measured in seemingly absurd values of kcal per hour per person, it is important to keep in mind that these are post-encounter return rates and therefore consider only pursuit and handling time. Furthermore, these returns might not be easily sustained over long periods but instead represent one-off events.

Chapter 5

Subtidal Shellfish Exploitation on the California Channel Islands:

Wavy Top (*Lithopoma undosum*) in the Middle Holocene

Jennifer E. Perry and Kristin M. Hoppa

Wavy top (*Lithopoma undosum*, formerly known as *Astraea undosa*) and red abalone (*Haliotis rufescens*) are among the largest marine gastropods of the California Bight (Figure 5.1). Whereas wavy top are found intertidally in warmer settings, red abalone occurs there in cooler conditions, resulting in different yet related implications for prehistoric shellfish exploitation (Glassow 1993b, 1994, 2002, 2005b; Morris et al. 1980; Myers 1986; Schwalm 1973; Sharp 2000; Tegner et al. 1992). Due to their dispersed distribution in lower intertidal and subtidal communities, both wavy top and red abalone are oftentimes regarded as having been more labor intensive to procure than mussels and other clustered and/or sessile species of the upper intertidal. Not surprisingly, California mussels (*Mytilus californianus)* and other species of the productive rocky intertidal zone are the most common and abundant shellfish species represented in middens on the Channel Islands and on the mainland coast of the Santa Barbara Channel (Erlandson 1994; Glassow 1993a, 1996, 2005b; Glassow and Wilcoxon 1988; Kennett 1998, 2005; Perry 2003, 2004, 2005; Rick 2007; Rick, Erlandson, et al. 2006; Sharp 2000; Vellanoweth et al. 2002; Vellanoweth et al. 2006). Nevertheless, wavy top and red abalone contributed unusually high proportions of shell weights and edible meat estimates in certain contexts on the Channel Islands, particularly during the middle Holocene (6500–3500 B.P.) (Byrd and Andrews 2002, 2003; Erlandson et al. 1992, Erlandson, Vellanoweth, et al. 2005; Glassow 1993a 1993b, 1994, 2002, 2005b; Greenwood 1978; Kennett 2005; Perry 2003; Reinman and Eberhart 1980; Rick, Robbins, and Ferguson 2006; Sharp 2000; Vellanoweth 1996; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2006; Walker and Snethkamp 1984).

The spatial distribution of middens with wavy top and/or red abalone correlates well with geographic variations in sea surface temperature (SST) around the Channel Islands. Ocean waters transition from cooler to warmer from north to south, and from west to east along the northern islands (Browne 1994; Engle 1994; Kennett 2005). Because of red abalone's cooler water preferences, its procurement has been well documented in middle Holocene deposits on western Santa Cruz, Santa Rosa, San Miguel, and San Nicolas islands, as well as on the coast of central California, and has come to be recognized as a marker of this time period (Erlandson, Vellanoweth, et al. 2005; Glassow 1993b, 1994, 2002, 2005b; Kennett 2005; Rick, Erlandson, et al. 2006; Sharp 2000; Vellanoweth et al. 2006; Walker and Snethkamp 1984). Interestingly, red abalone has also been found in middle and late Holocene

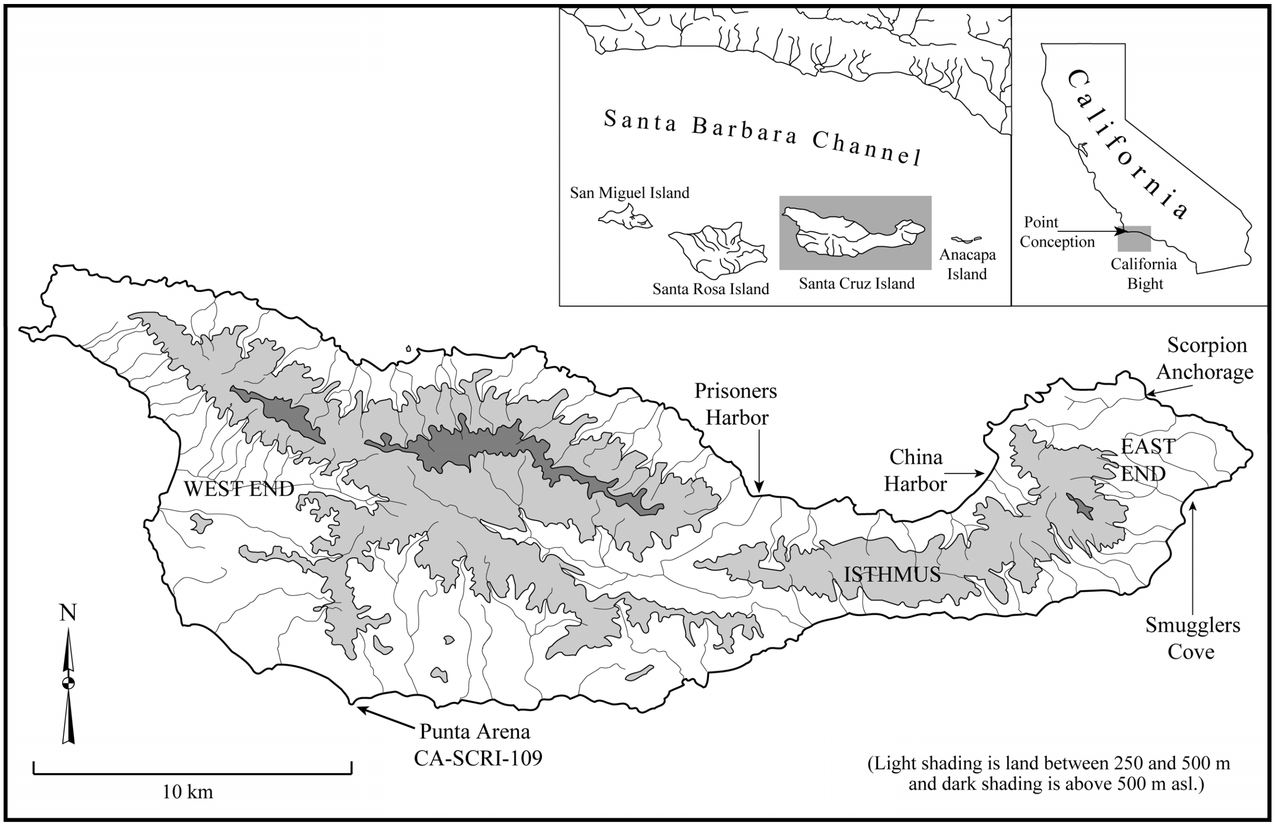


Figure 5.1. Santa Cruz Island.

sites on Santa Catalina, Santa Rosa, and San Miguel islands (Raab et al. 1995; Reinman and Eberhart 1980; Rick 2007). Explanations of its prevalence have focused to varying degrees on environmental and cultural factors, particularly sea surface temperature, population density and residential mobility, and preferences in resource procurement strategies. Although other variables are considered, Glassow (1993b, 2002) has hypothesized that red abalone was collected intertidally during cooler water intervals in the middle Holocene, while Sharp (2000) has emphasized the practice of subtidal diving.

Far less is known about warmer water subtidal species such as wavy top and pink abalone (*Haliotis corrugata*), which were similarly important to middle Holocene subsistence. Wavy top middens have been identified on Santa Cruz and Santa Barbara islands, as well as on the southern islands of Santa Catalina and San Clemente (Byrd and Andrews 2002, 2003; Erlandson et al. 1992; Perry 2003, 2004, 2005; Reinman and Eberhart 1980; Rick and Erlandson 2001). On eastern Santa Cruz and Santa Barbara islands, where water conditions are characteristically warmer than at red abalone midden locales, middle Holocene deposits have similarly high concentrations of wavy top (Perry 2003; Rick and Erlandson 2001). Whereas evidence of wavy top exploitation seemingly declines through time on the northern islands (Noah 2005), it is present in late Holocene midden deposits on Santa Catalina and San Clemente islands (Byrd and Andrews 2002; Reinman and Eberhart 1980).

In this study we focus on the shellfish assemblages in middle Holocene deposits on eastern Santa Cruz Island to evaluate the significance of wavy top collecting on the northern islands, as well as differences in subtidal shellfish exploitation throughout the Channel Islands (see Figure 5.1). To do so, we first discuss the natural history of wavy top, focusing on the relationship between fluctuating SST and the spatiotemporal distribution of wavy top in archaeological sites. Second, we assess different quantitative measures of dietary significance, including edible meat and protein estimates, as well as the use of the operculum to calculate the minimum number of individuals and to estimate individual size. Third, we present data on wavy top exploitation from faunal assemblages at CA-SCRI-693 and CA-SCRI-724 near Scorpion Anchorage on eastern Santa Cruz Island and then compare them to wavy top middens on western Santa Cruz, Santa Barbara, San Clemente, and Santa Catalina islands. Finally, we consider the relative emphasis on wavy top and red abalone during the middle Holocene in the context of broader trends in demography, subsistence, and technology on the Channel Islands. Together, spatial variability and diachronic trends in the contributions of these shellfish species strengthen insights into the dynamic relationship between environmental fluctuation and cultural practices throughout the California Bight.

THE NATURAL HISTORY OF WAVY TOP AND ITS ARCHAEOLOGICAL IMPLICATIONS

To assess the potential influence of changing SSTs, population densities, and/or subsistence strategies on the inclusion of wavy top and red abalone in the middle Holocene diet, it is necessary to understand the natural history of these subtidal species. Because of the emphasis on red abalone middens, and the comparatively limited knowledge about wavy top, our discussions are focused primarily on the latter. Relying on archaeological and biological studies, we consider the environmental conditions under which wavy top thrives, as well as what can be learned about its dietary importance (Alfaro 1994; Alfaro and Carpenter 1999; Halliday 1991; McConnaughey and McConnaughey 1988; Morris 1966; Morris et al. 1980; Myers 1986; Sharp 2000). The wavy top characteristics most relevant to archaeological investigations include its geographic and vertical distribution, as well as its age and growth patterns.

Studies of live wavy top populations have been conducted throughout the California Bight from Ensenada to Los Angeles, as well as on Santa Catalina Island. Of note, Cupul-Magaña and Torres-Moye (1996) carried out their research in Todos Santos Bay near Ensenada, Mexico; Schwalm (1973) at Point Loma, San Diego; Cox and Murray (2006) at Malaga Cove and Palos Verdes on the Los Angeles coast; and Alfaro (1994), Alfaro and Carpenter (1999), and Myers (1986) off the east coast of Santa Catalina Island. Although the degree of environmental variability between these study sites has resulted in differing accounts of size and behavior, the studies collectively provide a more complete picture of wavy top's versatility and distribution in the California Bight. According to Cupul-Magaña and Torres-Moye (1996), wavy top can grow up to 150 mm in basal diameter, although its reported maximum size is variable and likely dependent on location (Halliday 1991; Schwalm 1973).

Several environmental variables, including SST, water motion, and substrate, affect the settlement choices and survival of wavy top, as well as biological factors of predation and food availability (Alfaro 1994; Alfaro and Carpenter 1999; Cox and Murray 2006; Halliday 1991; Myers 1986; Schwalm 1973). Of these, it seems that predatory pressures may be more important than available food with respect to habitat selection and resulting survival rates. As herbivorous generalists, individuals of all sizes are equally mobile and do not aggregate, as they require room for grazing. Wavy top employ flight mechanisms such as climbing kelp against slow-moving predators such as whelks and sea stars but have no defense against fast-moving predators such as octopuses, lobsters, sea otters, and bat rays (Cox and Murray 2006; Myers 1986; Schwalm 1973). In addition to mobility, they exhibit flexibility in diet and vertical distribution: while wavy top in the intertidal zone exhibit preferences for fleshy algae (for example, *Macrocystis*), those at greater depths eat whatever plants are available (for example, coralline algae) (Alfaro 1994; Alfaro and Carpenter 1999; Halliday 1991; Leighton 1966; Myers 1986).

Geographic and Vertical Distribution

Although their specific temperature range is unknown, wavy top are typically present in warm waters along the California coast from Isla Asuncion, Baja California, to Point Conception at the northern extreme of the California Bight (McLean 1978; Morris et al. 1980; Sharp 2000:Appendix 4). Wavy top have been found in the waters surrounding seven of the eight Channel Islands. While common in the warm waters of Cedros and Santa Catalina, they do not usually occur in the cooler waters surrounding San Miguel Island and are limited to warmer waters along eastern Santa Rosa Island as well as to southern and eastern Santa Cruz Island (National Park Service 1982–1999; Sharp 2000). Comparable patterning in the geographic distribution of wavy top is evident in the archaeological record, with its highest contributions documented at sites near warmer waters and/or dating to warmer-water intervals (Byrd and Andrews 2002; Perry 2003; Reinman and Eberhart 1980; Sharp 2000).

Spatiotemporal variability in contemporary wavy top populations can be used to make inferences regarding the possible effects of warm-water intervals during the middle Holocene. The effects of short-term fluctuations in SST are evident in the Kelp Forest Monitoring Program data from Channel Islands National Park, which include an annual census of marine plant and animal species (National Park Service 1982–1999). The highest densities of wavy top in 17 years of monitoring were observed in 1999 on Anacapa, Santa Barbara Island, and on southern and eastern Santa Cruz Island. Correlated with higher population densities was a noticeable decrease in average size, which, as the kelp bed researchers proposed, may be associated with wavy top recruitment from the 1997–1998 El Niño (National Park Service 1982–1999:52). In addition to being able to recover from El Niño (or El Niño-Southern Oscillation, ENSO) events, wavy top seems to thrive in shallow urchin (*Strongylocentrotus* spp.) barrens such as those observed around Scorpion Anchorage on Santa Cruz Island (National Park Service 1982–1999). These barrens are the result of spiked urchin populations depleting all available kelp foods, such as when sea otter (*Enhydra lutris*) populations are diminished and thus urchin predation rates are low (Van Blaricom and Estes 1988). The warmer waters of ENSO events have also been linked to sea star wasting disease, causing a population crash for these predators of wavy top and sea urchin (Eckert et al. 2002).

Along with the flourishing of wavy top populations in urchin barrens and other suboptimal conditions, it seems that they respond relatively well to circumstances that can be devastating for other shellfish and marine species, such as the sea star. In support of this notion, increased recruitment among pink abalone populations was documented during and after the 1982–1983 El Niño, at the same time red abalone populations were depressed. This relationship suggests an inverse correlation between wavy top and pink abalone on the one hand and red abalone on the other (National Park Service 1982–1999). Although the timescales are different, these data provide examples of how wavy top populations can be positively affected by warm-water conditions, unlike sessile and/or cooler-water species such as mussels and red abalone, and therefore have had important implications for shellfish collecting strategies during and after ENSO-like events.

In addition to geographic distribution, various biological and physical factors influence the vertical distribution of wavy top in near-shore environments, and thus how this large gastropod may have ranked as a resource prehistorically. Wavy top may occur as deep as 80 m (Cox and Murray 2006:1296) but are most common between 8 and 16 m on Anacapa, Santa Cruz, and Santa Rosa islands, with the largest individuals (up to 138 mm basal diameter) occurring at an average of 16 m in depth (Glass and Foster 1984). Alfaro and Carpenter's (1999) study of wavy top at Bird Rock, Santa Catalina Island, identified four distinct habitat zones related to dominant plant species: *Eisensia* (2–3 m), *Lithothrix* (3–4 m), *Sargassum* (4–10 m), and *Macrocystis* (10–12 m). The *Eisensia* zone has the greatest amount of surge, which can dislodge individual wavy top from the marine substrate, while wavy tops in the *Macrocystis* zone experience the greatest pressure from predators such as *Octopus bimaculatus*. Although there is significant variability due to mobility and other factors, larger wavy top tend to be found at the lower depths of *Macrocystis* habitats, being able to survive predation and the effects of strong surge more effectively. The *Lithothrix* and *Sargassum* zones are comparatively more hospitable, but there is greater intraspecific competition for limited fleshy algae; and while these zones have higher population densities, they also have lower individual sizes on average (Alfaro and Carpenter 1999).

In other studies, Schwalm (1973) and Myers (1986) documented a general increase in size along the depth gradient, suggesting that wavy top of different sizes face different pressures. "In a manner similar to urchins, small (wavy top) may utilize the irregular substrata and increased algal cover in shallow water as camouflage from crab, lobster, octopus, and fish predation" (Myers 1986:46). In contrast, larger individuals may be able to avoid predation because of their size. Myers (1986:47) notes that "the shell morphology of *Astraea undosa* (thick shell, calcareous operculum, strong sculpture, low spire) suggests an adaptation that confers resistance to shell crushing above a critical size." Whereas red abalone populations are highly sensitive to fluctuation in SSTs, with temperatures of 24° C and above being fatal, wavy top are more flexible and resilient, seemingly being influenced by predation more than particular temperature thresholds (Alfaro 1994; Alfaro and Carpenter 1999; Myers 1986; Schwalm 1973).

Inferring Harvesting Methods Based on Wavy Top Characteristics

The relationship between size and depth of individual wavy top can yield insights into how they were harvested, contributing to arguments regarding subtidal diving activities (see Sharp 2000; Rick, Robbins, and Ferguson 2006). To assess procurement strategies at a given site, it is useful to evaluate the size of individuals represented. Even in site deposits with heavily fragmented shellfish constituents, it may be possible to reconstruct shell size using the operculum (Figure 5.2). This hard, teardrop-shaped shell is a nonrepetitive element, making it a reliable measure of the minimum number of individuals (MNI). Attached at the base, or "foot," of the wavy top, the operculum acts as a "trap door" and seals the animal within the shell when retracted. Its durability allows for excellent preservation, whereas the outer shell of the wavy top can be difficult to recognize due to degradation through time. Relying on Cupul-Magaña and Torres-Moye's (1996) study of wavy top growth rings, one can use the length of the operculum to determine the basal diameter of the wavy top, which is the measurement used to determine

Figure 5.2. Basal diameter and opercular diameter of wavy top.

overall size. In addition to documenting variations in individual size (and possible overexploitation), this measurement can be compared to zonation patterns to determine the likely depth at which a particular wavy top was collected. In his analysis of the shellfish assemblages at the Punta Arena site (CA-SCRI-109) on Santa Cruz Island, Sharp (2000) used this method to supplement his argument that wavy top, red abalone, and other typically subtidal species were likely harvested by diving.

In addition to inferring depth from opercular measurement, stable oxygen isotope analysis can be used to determine temperature (and related depth) differences between subtidal and intertidal species from the same sites and strata. Rick, Robbins, and Ferguson (2006) compared mussel with red abalone from Santa Rosa Island and found enough difference to suggest depth variation:

> The clear separation of average values between California mussels and black and red abalones from Unit 1 suggests that at least on occasion, if not frequently, people were diving in relatively shallow water for red abalone during the middle Holocene. Although human skeletal data are limited and variable, the presence of auditory exostosis (a condition caused by swimming in cold water) in some skeletons from Middle Holocene Channel Island sites also suggests that people may have been diving in the shallow subtidal to obtain abalone and other taxa [Rick, Robbins, and Ferguson 2006:248].

Combining all the available data, it seems reasonable to hypothesize that people were also diving for wavy top in shallow waters, particularly in contexts comparable to those we encountered on Santa Catalina, Cedros, and Santa Cruz islands. However, this interpretation does not rule out circumstances in which red abalone may have been opportunistically collected in the lower intertidal, as has been suggested by Glassow regarding cooler-water intervals in the middle Holocene (1993b, 2002).

METHODS AND RESULTS

Our research consisted of evaluating studies of live wavy top and relevant archaeological sites throughout the California Channel Islands, as well as conducting excavations at middle Holocene sites on Santa Cruz Island. Information about the natural history of wavy top was supplemented by our own observations and experiments with live wavy top populations on Santa Cruz, Santa Catalina, and Cedros islands. Our archaeological investigations expanded on data collected from previously tested middle Holocene sites on eastern and southwestern Santa Cruz Island (Glassow 2002, 2005a, 2005b; Perry 2003; Sharp 2000). In addition to excavating sites in the central valley and eastern coast of Santa Cruz Island, we visited middens containing wavy top and/or red abalone on Santa Rosa and Santa Barbara islands. By combining the study of living populations with archaeological research throughout the Channel Islands, we hope to gain a better understanding of wavy top harvesting, particularly during the middle Holocene, and the overall importance of subtidal shellfish exploitation in the California Bight.

Evaluating Contemporary Wavy Top Populations on the California Islands

In our study of living populations, we investigated harvesting and processing methods, as well as published meat and protein yield estimates (see Bleitz 1990; Bradford 1991; Erlandson 1994; Sharp 2000; Vellanoweth 1996). To evaluate procurement and processing strategies, in August 2006 we observed the contemporary exploitation of wavy top on Cedros Island off the Vizcaíno Peninsula on the west coast of Baja California. With the assistance of Matt Des Lauriers, we documented two episodes of wavy top collecting along the breakwater in El Pueblo on Cedros Island, where locals have been harvesting the snail commercially and for personal consumption. Alberto Espinoza (personal communication 2006) and his friend, both 16 years old, dove for wavy top between 2 and 5 m in depth, using masks but no fins or other special equipment. The wavy top shells were processed immediately using nothing more than an unmodified rock to crack the shell and a plastic bag to store and transport the edible meat. Espinoza used the rock to systematically strike at the inner whorl, thereby removing large sections of the shell and releasing the snail inside. After the shell was separated from the soft tissue, the guts were removed, leaving only the edible meat still attached to the operculum. The operculum was then removed with a knife before the meat was prepared for consumption. Wavy top, which Cedros Islanders prefer as a cream sauce (made with a blender rather than with the bowl mortar of the past), can be eaten both raw and cooked.

We further evaluated these processing techniques when collecting and harvesting wavy top with the assistance of Dave Daniels at Goat Harbor on the eastern coast of Santa Catalina Island. Located near Ripper's Cove, along with contemporary wavy top study sites, Goat Harbor is comparable to the environmental setting in which residents of CA-SCAI-26 collected large amounts of wavy top and black abalone during the late Holocene (Reinman and Eberhart 1980). Using snorkeling equipment, we easily harvested wavy top from between 2 and 4 m in depth on boulders interspersed within a kelp forest bordering Goat Harbor's sandy beach. We collected relatively large wavy top, ranging from 92.04 to 121.35 mm in basal diameter, and from 36.93 to 47.92 mm in opercular diameter, demonstrating that large individuals can be collected from fairly shallow waters. As we processed them for consumption, we measured their maximum basal and opercular diameters with digital calipers and determined their soft tissue, edible meat, and overall weight with a digital balance. We processed them with unmodified stones available on the beach and then ate them both raw and cooked.

To assess the living populations near CA-SCRI-693 and CA-SCRI-724, we also conducted limited scuba and snorkel surveys around Scorpion Anchorage on eastern Santa Cruz Island. There we observed large wavy top in somewhat lower population densities but were unable to collect them, as regulations of Channel Islands National Park forbid the taking of living, geological, or cultural resources in the Scorpion State Marine Reserve (California Department of Fish and Game 2007).

Interestingly, when assessing the meat and shell weights of the wavy top we collected, we derived a lower edible meat estimate than the .461 multiplier reported by Bleitz (1990), who conducted her study at Gallagher Beach, which is south of Goat Harbor on Santa Catalina Island. Bleitz (1990) and Bradford (1991) refer to estimates of soft tissue weight, which is different from edible meat weight in the case of wavy top, given that the guts are removed prior to consumption. Cedros Islanders consume the white meat of the wavy top only, citing the guts as being bitter because of the digested kelp and other plant foods. In our small sample from Goat Harbor, the soft tissue weight was consistently less than 50 percent of the total weight, with edible meat constituting an average of about 48 percent of the soft tissue weight, which suggests that the multiplier proposed by Bleitz (1990) and employed by Bradford (1991), Perry (2003), and Sharp (2000) may be an overestimate. Some factors involved include the relative thickness and heavy weight of the shell, the healthiness of the wavy top diet (for example, how much kelp is in their guts), and how much water is lost due to desiccation between the collection and the weighing of individual wavy top. All this suggests that additional assessments of edible meat for wavy top should be conducted on Santa Catalina Island given the healthy populations that currently reside there, as well as their proximity to relevant archaeological sites.

Nevertheless, based on the wavy top observed and/or harvested on Santa Cruz, Santa Catalina, and Cedros islands, large individuals with considerable amounts of edible meat can be encountered and harvested relatively easily between 2 and 4 m in depth. Wavy top collecting does not require specialized equipment or knowledge; unlike abalone, wavy top do not require a pry bar or other tools to harvest. Shallow diving such as this can be conducted even by children with relative ease, and no tools are needed aside from bags to store and transport the wavy top. Individual animals may also be caught during net fishing, but larger wavy top were likely collected by hand, whether intertidally or through subtidal diving (Victor Molina, personal communication 2006). Wavy top could be collected while engaging in other activities in rocky near-shore and kelp forest environments, such as shore fishing. Processing, not procurement, is the most time-consuming aspect of their exploitation, particularly breaking the shell and gutting the wavy top. However, the time investment is still fairly small when considering other labor-intensive activities such as acorn processing. Furthermore, the amount of edible meat yielded can be substantial compared to California mussel and other common shellfish species; for example, the individual wavy top we collected each yielded between 20 and 75 g of edible meat.

As the data from Cedros and Santa Catalina islands indicate, wavy top collecting can yield significant quantities of calories and protein within a short period of time, but this would need to be supplemented with carbohydrate-rich and fatty foods. Based on the time Espinoza (personal communication 2006) reported for collecting and processing wavy top, and by weighing the edible meat from his efforts, we derived an estimated yield of about 1 kg of edible meat per hour. According to the nutritional facts on the label for canned wavy top, sold as Caracol Top Shell by S.C. P.P. Pescadores Nacionales de Abulón, the local fishing cooperative, this translates into about 1,100 calories and 190 g of protein per hour, with limited carbohydrates and fat (Table 5.1). In contrast to edible meat estimates, these findings suggest that the current protein yield estimates for wavy top may be low (Bleitz 1990; Bradford 1991). Regardless, the nutritional facts highlight the caloric and protein value of wavy top, as well as its calcium contributions.

Table 5.1. Nutritional Facts from Commercially Harvested Wavy Top on Cedros Island.[a]

100 g Serving		**% of Daily Value**[b]
Calories	110	
Total fat	2 g	3%
Cholesterol	97 mg	32%
Sodium	200 mg	8%
Carbohydrates	4 g	1%
Dietary fiber	0 g	0%
Sugars	0 g	0%
Protein	19 g	27%
Vitamin A		0%
Vitamin C		0%
Calcium		4%
Iron		0%

[a] Based on label from Rocamar Caracol Top Shell.

[b] Percent of daily values are based on a 2,000-calorie diet.

In addition to their high meat and protein yields, wavy top are also advantageous with respect to transportation and storage, providing edible meat for at least two days if kept in saltwater and/or inside their shells (Alberto Espinoza and Victor Molina, personal communication 2006; Sharp 2000). Wavy top are the largest of the shellfish that can use the operculum to seal themselves inside the shell, thereby slowing down the rate of desiccation. This characteristic would have been particularly convenient for mobile human populations because wavy top can be processed with an unmodified stone and eaten raw, providing a hearty and convenient food source. In addition to nutritional concerns, food selection criteria likely included relative preservation, or the length of time particular resources remained edible after harvesting, especially considering the relative absence of terrestrial protein sources on the Channel Islands. That transportation costs and preservation rates may have been factors influencing wavy top harvesting is indicated by the presence of wavy top in shell scatters and small shell middens throughout eastern Santa Cruz Island, including at chert quarries (for example, CA-SCRI-408, CA-SCRI-412, and CA-SCRI-632).

In sum, all these characteristics help explain why wavy top are found at sites throughout eastern Santa Cruz Island, as well as on Santa Catalina, San Clemente, and Santa Barbara islands. They are relatively easy to collect and process, they are easy to transport and store in their shells, and they generate large quantities of meat and protein with minimal investment and no special tools. Although they do not tend to aggregate like California mussel, wavy top are fairly abundant in warm-water conditions, such as those observed on Santa Catalina Island and documented in some of the kelp forest monitoring sites on the northern Channel Islands, such as at Scorpion Anchorage on eastern Santa Cruz Island (National Park Service 1982–1999). Furthermore, their mobility, flexibility in food preferences, and tolerance of temperature fluctuations, as evidenced by their survival after ENSO events, would have rendered them a fairly reliable and attractive resource during warmer-water intervals of the middle Holocene.

Archaeological Investigations on Eastern Santa Cruz Island

Complementing these studies, our archaeological fieldwork has been focused largely on eastern Santa Cruz Island, as well as the island's central valley, with comparisons made to sites elsewhere on the Channel Islands. In particular, the Punta Arena site (CA-SCRI-109) on the southwest coast of Santa Cruz Island provides an interesting comparison due to its long occupational time span, from 8700 to 2000 B.P., and the significant amounts of both wavy top and red abalone in the site's deposits (Glassow 2002, 2005b; Sharp 2000). Sharp (2000:75) was the first to point out that middle Holocene deposits at Punta Arena contain a significantly higher percentage of wavy top than other "red abalone middens" recorded on San Miguel, Santa Rosa, and western Santa Cruz islands (Glassow 2002). Sharp (2000) speculates that this may be due in part to slightly warmer water temperatures on the south side of Santa Cruz Island. This relationship correlates well with live wavy top populations observed at Gull Island just off the coast of Punta Arena, which is one of the monitoring sites in the Kelp Forest Monitoring Program (National Park Service 1982–1989).

On eastern Santa Cruz Island, 24 archaeological sites are known to contain deposits dating to the middle Holocene, which collectively provide opportunities for supplementing our knowledge of red abalone middens with those characterized by wavy top (Clifford 2001; Kennett 1998, 2005; Perry 2003, 2004, 2005). Perry (2003, 2004, 2005) conducted auger testing at CA-SCRI-627, CA-SCRI-699, CA-SCRI-706, CA-SCRI-741, CA-SCRI-751, and CA-SCRI-752; more recently, we excavated column samples and/or larger units at CA-SCRI-693, CA-SCRI-698, and CA-SCRI-724 (Perry and Jazwa 2010) (Figure 5.3). At CA-SCRI-693 and CA-SCRI-698, testing consisted of one 20-x-20-cm column sample excavated from respective sea cliff exposures. One 1-×-1-m unit, two 1-×-.5-m units, and one 20-×-20-cm column sample were excavated at CA-SCRI-724. The resulting collections are currently stored in the Department of Anthropology at Pomona College as part of ongoing comparative analyses of collections from the eastern end and central valley of Santa Cruz Island.

Because the majority of these sites were likely seasonal camps or residential bases located in areas with little disturbance, they are relatively shallow and stratigraphically homogenous, and therefore were excavated in arbitrary 10-cm levels. We began the testing of each site by defining the site boundaries, establishing a grid system, and conducting auger testing at regular intervals along the major site axes to assess the depth and density of the midden deposits. We placed our units according to ground surface conditions and auger sample results, targeting the deepest deposits whenever possible.

All deposits from the excavated units were screened through 1/8-inch mesh in the field. All materials retained in the screen were bagged by arbitrary level and then transported to Pomona College, where they were wet-screened and sorted through 1/4-, 1/8-, and 1/16-inch mesh screens. The 1/4-inch faunal materials from unit 5S/5W were sorted and identified to the most specific taxonomic classification possible and then weighed and cataloged along with formal artifacts. The 1/8- and 1/16-inch materials were weighed in bulk to determine their overall weight contribution but were not sorted due to size and time constraints. The 1/4-inch materials from the two 1-×-.5-m units are in the process of being analyzed.

The column samples were excavated in arbitrary levels, in the case of CA-SCRI-724 corresponding to those excavated in our 1-×-1-m unit, unit 5S/5W. Each level was bagged separately without sorting in the field and then transported to the Collections Processing Lab at the University of California, Santa Barbara. There, Kristina Gill used a flotation machine to process the column samples; Hoppa is in the process of analyzing all materials less than 1/16 inch to identify macrobotanical remains. All of the 1/4- and 1/8-inch materials were then transported to the archaeology lab at Pomona College, where they were sorted and cataloged.

MNI, as well as edible meat and protein yields, were calculated for the 1/4- and 1/8-inch materials from the column samples, as well as the 1/4-inch materials from unit 5S/5W. We determined the

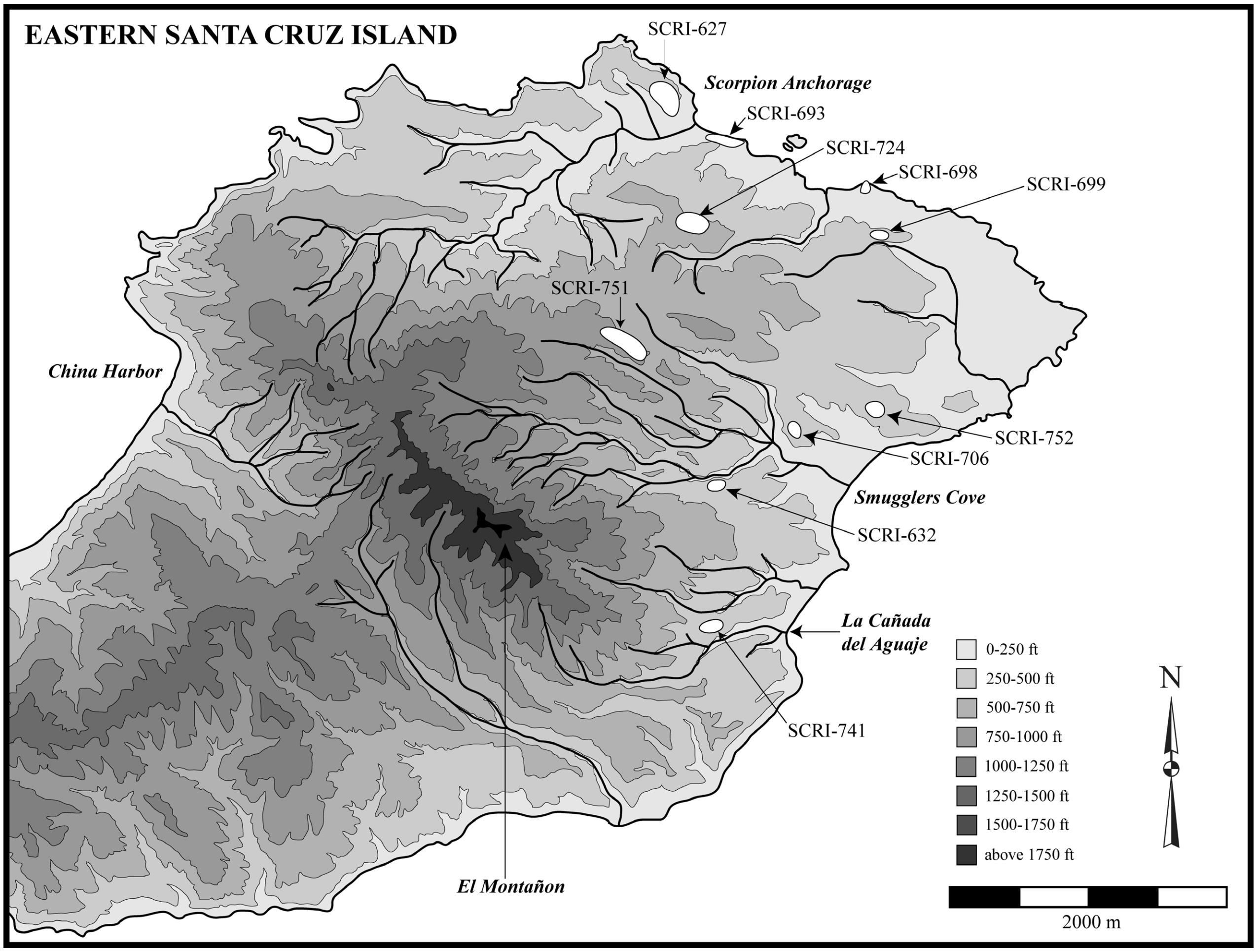


Figure 5.3. Middle Holocene sites on eastern Santa Cruz Island mentioned in text.

MNI for wavy top based on opercula count, and for California mussel by counting the hinges and dividing by two. We used the conversions in Table 5.2 to calculate meat and protein yields from shell weight, choosing to use the multiplier for wavy top reported in Bleitz (1990) to maintain consistency for intersite comparisons. We identified shellfish to the most specific taxonomic level possible but employed general categories for the bone fragments.

WAVY TOP EXPLOITATION ON EASTERN SANTA CRUZ ISLAND

Middle Holocene deposits on eastern Santa Cruz Island have yielded similar patterns indicative of the importance of subtidal shellfish exploitation, with comparatively stronger emphasis on intertidal shellfish during earlier and later periods. While exhibiting comparable patterns of intertidal and subtidal shellfish gathering, however, Punta Arena and the east end sites offer some important contrasts worthy of future research given their seemingly different roles in local subsistence-settlement rounds. Dispersed throughout coastal and interior settings on eastern Santa Cruz Island are 24 sites with middle Holocene deposits, of which at least 9 have wavy top contributions of more than 5 percent of the overall shell assemblage based on shell weight and edible meat estimates (Perry 2003, 2004) (Table 5.3). Most are single-component sites, such as small shell scatters associated with chert quarries in which wavy top seem to be the dominant shellfish; this is best exemplified at CA-SCRI-632, where no other species are evident. On the other

Table 5.2. Edible Meat and Protein Multipliers for Major Faunal Categories and Taxa.

	Edible Meat	Protein	Source
California mussel (*Mytilus californianus*)	0.298	0.144	Erlandson (1994:59)
Wavy top (*Lithopoma undosum*)*	0.461	0.19	Bleitz (1990) in Bradford (1990:30)
Black abalone (*Haliotis cracherodii*)	1.637	0.153	Bleitz (1990) in Bradford (1990:30)
Red abalone (*Haliotis rufescens*)	1.132	0.153	Koloseike (1969)
Other shellfish	0.332	0.153	Glassow and Wilcoxon (1988)
Fish bone	27.7	0.185	Erlandson (1994:59)
Sea mammal bone	24.2	0.1	Erlandson (1994:59)
Bird bone	15	0.21	Erlandson (1994:59)
Other bone	24.2	0.1	Glassow and Wilcoxon (1988)

*Protein multiplier derived from wavy top nutrition label (S.C. P.P. Pescadores Nacionales de Abulón).

Table 5.3. Radiocarbon Dates from Middle Holocene Sites on Eastern Santa Cruz Island Mentioned in Text.

Site Designation CA-SCRI-	^{14}C Sample[a] Depth (cm)	^{14}C Lab Number	^{14}C ± σ Years B.P. δ^{13}C Corrected	δ^{13}C o/oo	Cal Years ± 2σ
627	Surface	β-216760	5480 ± 80	0.6	B.C. 3890 (3650) 3500
627	Surface	β-216761	5700 ± 40	0.6	B.C. 3990 (3930) 3780
632	Surface	β-190380	4780 ± 50	1.2	B.C. 2910 (2850) 2630
693	30	β-203416	4520 ± 70	1.5	B.C. 2900 (2790) 2560
693	65	β-203417	4760 ± 70	1.3	B.C. 3310 (3040) 2880
698	20–30	β-167971	5800 ± 50	0.0	B.C. 4160 (3990) 3910
699	63–75	β-164525	4200 ± 80	0.8	B.C. 2280 (2020) 1770
699	28–39	β-172034	3700 ± 70	0.2	B.C. 3540 (3360) 3170
706	30–42	β-167976	4210 ± 60	0.0	B.C. 2230 (2030) 1870
724	20–30	β-222704	5330 ± 70	-2.0	B.C. 3920 (3730) 3620
724	30–40	β-222705	5500 ± 60	1.6	B.C. 4040 (3940) 3780
724	50–60	β-226843	5680 ± 90	2.6	B.C. 4330 (4150) 3940
741	24–35	β-172033	3780 ± 80	0.3	B.C. 1960 (1740) 1560
741	58–66	β-164524	4110 ± 80	0.5	B.C. 2440 (2200) 1970
751	29–39	β-167973	4740 ± 50	0.0	B.C. 2890 (2790) 2580
751	77–85	β-167974	4830 ± 50	0.0	B.C. 3010 (2870) 2740
751b	20–30	β-172036	3990 ± 70	0.0	B.C. 3900 (3690) 3480
752	26–35	β-168346	4370 ± 60	0.0	B.C. 2450 (2270) 2270
752	65–75	β-190382	5120 ± 100	2.7	B.C. 3520 (3310) 2910

Note: INTCAL98 radiocarbon age calibration (Stuiver et al. 1998) [not in reference list].

[a] All radicarbon samples are marine shell and were dated by Beta Analytic, Inc.

[b] From a different locus than the other two radiocarbon dates reported.

end of the spectrum, large, high-density shell middens extending to 50 to 100 cm in depth, such as the extensive deposits of CA-SCRI-724, have also been identified.

Similar to middle Holocene deposits throughout the Santa Barbara Channel, at these sites shellfish represent the most significant part of the diet, which was supplemented with fishing as well as sea mammal and bird hunting (Perry 2003, 2005). Strong emphasis was placed on near-shore shellfish and fish species obtained from the waters above the rocky intertidal, subtidal, and kelp forest habitats; sandy beaches are relatively limited on eastern Santa Cruz Island. Commonly represented near-shore fish include California sheephead and surfperch, as well as sharks and rays. Female and juvenile seals and California sea lions are also present, indicating that islanders targeted rookeries and haul-outs comparable to those in the vicinity today, such as at Potato Harbor. In addition, digging stick weights, as well as bowl mortars and bedrock mortars, suggest that plants common to grasslands, such as corms

Table 5.4. Weight and Edible Meat Estimates for Major Shellfish Constituents at CA-SCRI-693, SCRI-698, and SCRI-724.

	California Mussel			Wavy Top		
Site and Unit Designation	**Weight (g)**	**Edible Meat (g)**	**% of Meat**	**Weight (g)**	**Edible Meat (g)**	**% of Meat**
CA-SCRI-693, column sample 1	10,480.54	3,122.89	54.55%	853.34	393.39	6.87%
CA-SCRI-698, column sample 1	1,511.10	450.31	54.33%	21.40	9.87	1.19%
CA-SCRI-724, unit 5S/5W	38,979.09	11,615.77	42.70%	12,237.45	5,641.46	20.74%
CA-SCRI-724, column sample 1	4,804.54	1,431.75	53.78%	1,167.95	538.42	20.22%

	Black Abalone			Red Abalone		
Site and Unit Designation	**Weight (g)**	**Edible Meat (g)**	**%**	**Weight (g)**	**Edible Meat (g)**	**% of Meat**
CA-SCRI-693, column sample 1	523.66	857.23	14.97%	61.33	69.43	1.21%
CA-SCRI-698, column sample 1[a]	0.00	0.00	0.00%	0.00	0.00	0.00%
CA-SCRI-724, unit 5S/5W	1,727.80	2,828.41	10.40%	349.89	396.08	1.46%
CA-SCRI-724, column sample 1	67.52	110.53	4.15%	1.35	1.53	0.06%

	Miscellaneous Barnacles			Other Shellfish		
Site and Unit Designation	**Weight (g)**	**Edible Meat (g)**	**% of Meat**	**Weight (g)**	**Edible Meat (g)**	**% of Meat**
CA-SCRI-693, column sample 1	2,046.73	648.53	11.33%	1,907.07	633.15	11.06%
CA-SCRI-698, column sample 1	1,058.38	351.38	42.40%	51.98	17.26	2.08%
CA-SCRI-724, unit 5S/5W	10,842.24	3,599.62	13.23%	4,676.02	3,120.35	11.47%
CA-SCRI-724, column sample 1	555.75	184.50	6.93%	870.00	395.49	14.86%

[a] 5.17 grams of undifferented abalone

(for example, *Dichelostemma capitatum*), were of importance to the inhabitants of eastern Santa Cruz Island; however, in what ways and to what extent is currently unknown (Perry 2003, 2004, 2005).

In contrast to other middle Holocene sites in the Santa Barbara Channel region, where California mussel constitutes 90 to 95 percent of the shell weights and edible meat estimates, it rarely exceeds more than 65 percent in these sites (Glassow 1993a, 1996; Perry 2003). Wavy top is consistently one of the top three shellfish taxa at all but two of these sites, representing between 7 and 20 percent of edible meat estimates (Table 5.4). Significantly, most of these sites fall within a warmer-water interval identified between 5900 and 3800 B.P. Conversely, red abalone is absent from most of the faunal assemblages, representing 1 percent or less of the edible meat estimates for shellfish species recovered from CA-SCRI-693 and CA-SCRI-724. The limited amount of red abalone in these sites is consistent with the warmer waters of eastern Santa Cruz Island, particularly during warmer-water episodes of the middle Holocene.

The highest percentages of California mussel have been found at CA-SCRI-698 and CA-SCRI-699; CA-SCRI-698 dates slightly earlier, to a period of inferred cooler-water conditions from 6300 to 5900 B.P. (Kennett 2005:65–66; Kennett and Kennett 2000; Perry 2003) (see Table 5.3). Whereas California mussel represents 51 and 54 percent of the total edible meat estimates at CA-SCRI-698 and CA-SCRI-699, respectively, wavy top represents only 1 and 2 percent. CA-SCRI-698 and CA-SCRI-699 are located within 500 m of one another, about 1,500 m east of Scorpion Anchorage, where rocky intertidal habitat is dominant and coastal access is limited, therefore constraining opportunities for subtidal diving. Complicating our interpretations of fluctuating SSTs are local differences in resource availability, most notably between the northern and southern shorelines of eastern Santa Cruz Island. Most sites with components dating between 6300 and 5900 B.P. need to be tested to better distinguish between the influences of intraregional and temporal variability.

Wavy Top Exploitation at Scorpion Anchorage (CA-SCRI-693 and CA-SCRI-724)

Located within 500 m of each other above and south of Scorpion Anchorage, respectively, CA-SCRI-693 and CA-SCRI-724 are both large, dense middens dating to the middle Holocene. Modern marine resources include abundant shellfish and fish in rocky intertidal sandy beach and kelp forest habitats, as well as nearby shores serving as haul-outs for sea lions and seals. Additionally, the large Scorpion Rocks immediately east of the anchorage offer not only a rich marine environment but also roosting areas for seabirds. Three chert quarries are also located in the vicinity, including outcrops at CA-SCRI-693 and near CA-SCRI-724 and mining pits at CA-SCRI-627. Freshwater is seasonally available at two nearby seeps, as well as farther south in Scorpion Canyon, the largest watershed on the east end. Collectively, these varied resources render Scorpion Anchorage one of the most productive resource areas on eastern Santa Cruz Island.

Of the three sites with column sample data, CA-SCRI-693, CA-SCRI-724, and CA-SCRI-698 to the east, the deepest deposits are located at CA-SCRI-693, where dense midden terminates at 110 cm; in contrast, CA-SCRI-698 is highly eroded and deposits extend no more than 40 cm in depth. At CA-SCRI-724, although our unit was terminated at 60 cm, auger testing indicates that deposits extend to at least 80 cm. Formal artifacts recovered from CA-SCRI-693 include tarring pebbles, basalt hammerstones, nondescript ground stone fragments, modified bird bone, and a disk bead of California mussel, as well as nondescript chert biface fragments, cores, flakes, and debitage (Perry and Jazwa 2010). In addition, small obsidian flakes and deer bone tools highlight trading relationships with the mainland. When evaluating these data, it is important to keep in mind that CA-SCRI-693 was likely larger in the past, having been subjected to substantial sea cliff erosion; therefore, the column sample offers only a limited glimpse into the complexity of this site.

Artifacts recovered from the well-preserved deposits of CA-SCRI-724 include sandstone bowl mortar and pestle fragments, such as a bowl with an incised design around the rim; a sandstone digging stick weight fragment; shale and basalt hammerstones; and chert tools, cores, flakes, and debitage. Contracting-stem dart points, nondescript bifaces, and an abundance of biface thinning flakes highlight the flint knapping activities conducted at this site, which is reasonable given its proximity to CA-SCRI-611, an intensively used quarry of high-quality chert (Perry and Jazwa 2010). Barrel and spire-ground Olivella (*Olivella biplicata*) beads and small amounts of bead-making detritus, as well as disk beads of Pismo clam (*Tivela stulturom*) and some large unmodified fragments of Pismo clam, were also recovered. Neither of these species is common to Scorpion Anchorage but may have been harvested at Potato Harbor and/or sandy beaches farther east. Overall, the relatively high density of cultural materials, high artifact diversity, and evidence of tool production at CA-SCRI-693 and CA-SCRI-724, as well as a possible living surface encountered at an average of 50 cm in unit 5S/5W at CA-SCRI-724, indicate that they were likely seasonal residential bases representing the ongoing inclusion of Scorpion Anchorage in the subsistence round. In contrast, the lower density, depth, and diversity of cultural materials at CA-SCRI-698 suggest that it likely served as a short-term encampment (Perry 2003).

Despite extensive erosion, subsistence diversity during the middle Holocene is well represented at CA-SCRI-693. Based on edible meat estimates, 85 percent of the faunal assemblage consists of California mussel, sea mammal, fish, black abalone, and wavy top, listed in order of prevalence. California mussel represents 34 percent of the edible meat estimates for all faunal constituents and 60 percent of the shellfish, whereas wavy top is 4 and 8 percent, respectively. Near-shore fishes constitute 7 percent of the total edible meat, and sea mammals 22 percent, adding to the diversity

Table 5.5. Weight and Edible Meat Estimates of Major Faunal Constituents at CA-SCRI-693.

	Weight (g)	%	Meat Estimate (g)	%
California mussel	10,480.54	74.90%	3,122.89	34.88%
Wavy top	853.34	6.10%	393.39	4.39%
Black abalone	523.66	3.74%	592.78	6.62%
Red abalone	61.33	0.44%	69.43	0.78%
Other shellfish	1,907.07	13.63%	686.52	7.67%
Fish	25.11	0.18%	695.56	7.77%
Sea mammal	87.90	0.63%	2,127.18	23.76%
Bird	3.74	0.03%	56.10	0.63%
Other bone	49.17	0.35%	1,209.44	13.51%
Total fauna	13,991.86		8,953.29	

of subsistence activities documented in middle Holocene sites elsewhere on the northern Channel Islands (Glassow 2002, 2005a, 2005b; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2002; Vellanoweth et al. 2006).

Faunal assemblages at CA-SCRI-724 reflect subsistence activities similar to those at CA-SCRI-693, including fishing and sea mammal hunting, but in different proportions (Table 5.5). A total of 76.2 kg of shellfish remains were analyzed from CA-SCRI-724—68.8 kg of 1/4-inch materials in unit 5S/5W and the remainder from the 1/4- and 1/8-inch materials from the column sample. Based on edible meat estimates, California mussel, wavy top, and black abalone are the most common shellfish species, listed in order of abundance. In the column sample, California mussel is the dominant shellfish, constituting 64 percent of the shell weight and 54 percent of edible meat estimates; wavy top is the second-ranked shellfish species, at 16 and 20 percent, respectively. Similar proportions are represented in the larger unit, with California mussel contributing 57 and 43 percent, and wavy top 18 and 21 percent, respectively. Black abalone, assorted barnacles, sea urchin, and 14 other minor taxa contribute the remainder of the shellfish.

One of the obvious differences between the faunal assemblages from CA-SCRI-693 and CA-SCRI-724 is the greater reliance on wavy top exploitation at the latter. The highest proportions of wavy top with respect to MNI, shell weight, and edible meat estimates at CA-SCRI-724 were recovered from the 20 to 30- and 30 to 40-cm levels, which are also the levels that contain the smallest average opercular lengths. In the 20 to 30- and 30 to 40- cm levels of the column sample, wavy top contributes 37 and 68 percent of the estimated protein, respectively. The most productive level was from 30 to 40 cm, in which wavy top represents 28 and 45 percent of the edible meat estimates from the unit and column sample, respectively. The smaller average size does not necessarily reflect overexploitation, as these levels also contain very large opercula. Rather, the average sizes may be skewed in levels with fewer wavy top due to a small sample size; the 50 to 60-cm level has the largest average size but contained only two measurable opercula.

From the .62 m^3 of analyzed deposits at CA-SCRI-724, we recovered 66 measurable opercula and 79 partial opercula, for a total MNI of 145 (Table 5.6). Those measured ranged from 22.5 to

Table 5.6. Wavy Top and California Mussel MNI at CA-SCRI-724.

Unit	Level	Wavy Top MNI	California Mussel MNI
Unit 5S/5W	0–10 cm	11	360
	10–20 cm	28	346
	20–30 cm	34	953
	30–40 cm	31	2,117
	40–50 cm	30	1,488
	50–60 cm	4	170
Column sample 1	0–10 cm	0	17
	10–20 cm	2	12
	20–30 cm	1	25
	30–40 cm	1	50
	40–50 cm	3	49
Total		145	5,587

56.27 mm, with an average length of 44.17 mm. From the 1.58 m^3 excavated at CA-SCRI-109, there were 111 measurable opercula and 51 partial opercula, for a total MNI of 162. Those measured ranged from 11 to 56 mm, with an average length of 35.6 mm (Sharp 2000:Appendix 7) (Table 5.7). Considering that the volume of excavated materials at CA-SCRI-109 is roughly 2.5 times that of CA-SCRI-724, it is evident that large opercula consistently occur in higher densities at CA-SCRI-724. Based on Cupul-Magaña and Torres-Moye's (1996) study of age and growth, 58 of the 64 measured opercula represent individuals that were over 12 years old; three were over 11, two over 8, and one over 5, which suggests that these wavy top were likely harvested subtidally.

Although reconstructed wavy top sizes do not suggest overexploitation, we considered whether their increased collection resulted from the overexploitation of other resources, particularly California mussel, which is the most common shellfish species. The MNI for California mussel from the .62 m^3 of analyzed deposits at CA-SCRI-724 is 5,587. The MNI from the .27 m^3 of analyzed column samples at CA-SCRI-109 is 1,901 (Sharp 2000:Appendix 7). This translates to roughly 9,011 mussels per cubic meter at CA-SCRI-724, compared to 7,041 at CA-SCRI-109, again reflecting the high shellfish densities at CA-SCRI-724. Although mussel shells were too fragmented to accurately reconstruct sizes, our observations during sorting suggest that they range in size throughout each level from small to large, perhaps reflecting a stripping rather than plucking collection strategy (see Jones and Richman 1995). The presence of large mussels and wavy top indicates a relatively healthy marine environment not subject to intensive exploitation.

Coupled with the tight clustering of calibrated radiocarbon dates at CA-SCRI-724 (see Table 5.2) and fairly homogenous midden deposits, these data suggest that wavy top may have been intensively harvested during particular seasons and/or years during warmer-water episodes of the middle Holocene. At other times they were less important or largely ignored, as indicated by the faunal constituents at CA-SCRI-693 and CA-SCRI-698, respectively. As a result, wavy top populations had time to recover from human predation. Seasonal procurement of wavy top and other subtidal shellfish species would have continued to be productive in contexts of lower population density and high residential mobility during the middle Holocene.

WAVY TOP EXPLOITATION DURING THE MIDDLE HOLOCENE

Consistent with faunal data from middle Holocene sites throughout the northern Channel Islands, it is evident that the exploitation of near-shore species, especially shellfish, dominated the middle Holocene diet of people living at Scorpion Anchorage and on eastern Santa Cruz Island (Erlandson Vellanoweth, et al. 2005; Glassow 1993a; Kennett 2005; Perry 2003, 2004; Rick, Erlandson, et al. 2006, Rick, Robbins, and Ferguson 2006; Sharp 2000; Vellanoweth et al. 2006). Whereas California mussel is the single most important faunal constituent based on shell weight and edible meat estimates, fish, sea mammals, birds, and other shellfish provided variable contributions. Middle Holocene faunal assemblages include relatively high proportions of wavy top on eastern and southern Santa Cruz and Santa Barbara islands, as well as red abalone on western Santa Cruz, Santa Rosa, and San Miguel islands (Byrd and Andrews 2002; Erlandson et al. 1992; Glassow 1993a, 1993b, 2002, 2005b; Greenwood 1978; Perry 2003; Reinman and Eberhart 1980; Sharp 2000; Rick, Robbins, and Ferguson 2006; Vellanoweth 1996; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2006). The existing chronology for the wavy top middens on Santa Cruz Island coincides well with the warmer-water interval between 5900 and 3800 B.P. (Kennett 2005; Kennett and Kennett 2000). In particular, conditions were warmer between 5900 and 5200 B.P., followed by significantly warmer conditions between 5200 and 3800 B.P. Thus far, every site on eastern Santa Cruz Island in which there is an abundance of wavy top dates within these time frames. Middle Holocene sites on western Santa Cruz and Santa Barbara islands are now discussed to emphasize the relationship between wavy top and

Table 5.7. MNI and Maximum Opercular Diameter of Wavy Top at CA-SCRI-109 and SCRI-724.

Site	Unit	Level	MNI	Measurable Individuals	Individual Measurements (mm)	Average Length (mm)
CA-SCRI-109	South	Stratum 1	1	0		
CA-SCRI-109	South	Stratum 2	5	2	42, 56	49.00
CA-SCRI-109	North	Stratum 1	5	2	24, 55	39.50
CA-SCRI-109	North	Stratum 2	9	7	30, 36, 40, 42, 49, 52, 56	43.60
CA-SCRI-109	North	Stratum 3	1	1	33	33.00
CA-SCRI-109	North	Stratum 4	1	0		
CA-SCRI-109	North	Stratum 5	17	13	30, 32, 33, 35, 36, 38, 39, 39, 42, 43, 44, 46, 53	39.20
CA-SCRI-109	North	Stratum 6	0	0		
CA-SCRI-109	North	Stratum 7	3	1	45	45.00
CA-SCRI-109	North	Stratum 8	10	6	31, 41, 44, 45, 52, 56	44.80
CA-SCRI-109	North	Stratum 9	16	11	24, 34, 34, 42, 45, 46, 47, 48, 51, 52, 53	43.30
CA-SCRI-109	North	Stratum 10	5	2	22, 47	34.50
CA-SCRI-109	North	Stratum 11	1	0		
CA-SCRI-109	North	Stratum 12	9	5	42, 42, 52, 56, 59	50.20
CA-SCRI-109	North	Stratum 13	43	40	11, 12, 13, 14, 15, 15, 16, 17, 17, 17, 17, 17, 17, 17, 17, 19, 19, 20, 21, 22, 22, 22, 27, 27, 30, 30, 31, 34, 34, 36, 39, 39, 39, 40, 42, 45, 47, 52, 52, 56	26.90
CA-SCRI-109	North	Stratum 14	4	3	25, 28, 35	29.30
CA-SCRI-109	North	Stratum 15	15	9	14, 22, 36, 39, 39, 45, 47, 52, 52, 52	44.20
CA-SCRI-109	North	Stratum 16	5	4	11, 22, 25, 37	23.80
CA-SCRI-109	North	Stratum 17	2	2	14, 24	19.00
CA-SCRI-109	North	Stratum 18	5	1	23	23.00
Total count for site			157	109		
CA-SCRI-724	Unit 5S/5W	0–10 cm	11	5	36, 45, 46, 47, 50	44.67
CA-SCRI-724	Unit 5S/5W	10–20 cm	28	10	35, 37, 40, 42, 45, 46, 47, 51, 53, 56	45.29
CA-SCRI-724	Unit 5S/5W	20–30 cm	34	11	27, 35, 37, 41, 41, 43, 45, 48, 48, 50, 50	42.30
CA-SCRI-724	Unit 5S/5W	30–40 cm	31	18	23, 28, 35, 36, 36, 36, 40, 41, 41, 41, 43, 43, 43, 44, 46, 47, 52, 55	40.56
CA-SCRI-724	Unit 5S/5W	40–50 cm	30	17	35, 37, 40, 41, 42, 42, 43, 43, 43, 44, 45, 45, 48, 48, 48, 49, 50	43.73
CA-SCRI-724	Unit 5S/5W	50–60 cm	4	3	46, 47, 52	48.49
CA-SCRI-724	Column sample 1	0–10 cm	0	0		
CA-SCRI-724	Column sample 1	10–20 cm	2	0		
CA-SCRI-724	Column sample 1	20–30 cm	1	1	39	39.49
CA-SCRI-724	Column sample 1	30–40 cm	1	1	52	52.35
CA-SCRI-724	Column sample 1	40–50 cm	3	0		
Total count for site			145	66		

[a] Data for CA-SCRI-109 derived from Appendix 7 in Sharp (2000).

red abalone. The occurrence of wavy top and red abalone at sites elsewhere on the California Channel Islands also is considered.

The Punta Arena Site (CA-SCRI-109) on Southwestern Santa Cruz Island

Whereas sites on Santa Rosa, San Miguel, and western Santa Cruz islands have yielded significant insights into red abalone exploitation, less is known about the relative contributions of wavy top. With deposits dating from 8800 to 2000 B.P., some of the most significant evidence for the relationship between red abalone and wavy top is found at the Punta Arena site (CA-SCRI-109) (Glassow 1993b, 2002, 2005b; Glassow et al. 2008; Sharp 2000). Situated on the southwestern coast of Santa Cruz Island, Punta Arena is located on a promontory with convenient access to a range of marine and terrestrial habitats and resources, including sandy beaches and rocky intertidal areas, as well as freshwater sources. The large site size and dense deposits extending to 2.5 m in depth indicate that Punta Arena was repeatedly included in the seasonal rounds of the middle Holocene (Glassow 2002, 2005a, 2005b; Glassow et al. 2008; Sharp 2000).

Although the Punta Arena site is referred to as a red abalone midden, wavy top is the second most important shellfish in terms of both shell and edible meat weight, the first being California mussel (Sharp 2000:65). Significantly, wavy top is one of the few shellfish species present in all strata. It contributes an estimated 7 percent of the total edible meat estimates for shellfish, dropping from 9 to 2 percent from the middle to late Holocene (Sharp 2000). In the middle Holocene deposits, Sharp (2000) observes a shift from an intensive focus on California mussel to increased emphasis on subtidal species, including wavy top as well as pink and red abalone, which combined represent between 2 and 82 percent of the edible meat estimates.

That wavy top is present in all strata at Punta Arena, whereas red abalone is absent from some strata, is possibly related to the flexibility and resilience of the wavy top, which are known to be mobile and able to withstand significant temperature fluctuations. The persistence of relatively large wavy top through all strata at Punta Arena highlights its inclusion in the diet regardless of fluctuations in SST, suggesting that some subtidal diving was occurring at different points in time (Sharp 2000). That being said, the relative abundance of subtidal species in middle Holocene deposits on Santa Cruz Island indicates that there were unique environmental and/or cultural factors operating at this time.

Santa Barbara Island

Similar patterns in relative shellfish contributions are also evident in middle Holocene deposits on small and remote Santa Barbara Island (Erlandson et al. 1992; Glassow 1977; Greenwood 1978; Rick 2001; Rick and Erlandson 2001). CA-SBI-1 dates to 3830–3640 cal B.P., and SBI-2 has yielded dates of 3340–2750, 3610–3390, and 3890–3670 cal B.P. (1σ) (Rick 2001:62). Visually dominated by wavy top and abalone (*Haliotis corrugata* and *cracherodii*), these two sites are among the more extensive on the island (Erlandson et al. 1992; Greenwood 1978). SBI-2 is a comparatively large site, with dense deposits that have yielded mano and pestle fragments, as well as evidence of quartz and basalt tool manufacture (Erlandson et al. 1992:91; Greenwood 1978:13; Rozaire 1978b). Our field visit to Santa Barbara Island in 2007 confirmed these assessments, with SBI-2 exemplifying the methods of wavy top processing noted elsewhere based on mostly intact shells with the bottoms fractured off, inner whorls, and opercula of large size.

Differences in site characteristics between SBI-1 and SBI-2 on the one hand, and SBI-12 on the other, indicate changes from the middle to late Holocene similar to those observed on the northern Channel Islands (Erlandson et al. 1992; Rick 2001; Rick and Erlandson 2001). Two radiocarbon dates of 670–560 and 770–630 cal B.P. (1σ) place the occupation of SBI-12 squarely within the late Holocene (Rick 2001:62; Rick and Erlandson 2001:299). As at SBI-2, shellfish gathering appears to have been the primary subsistence activity, along with limited tool production. Black abalone is the single most important species, at 66 percent of the edible meat; owl limpet is second at 23 percent, followed by other minor taxa (Rick and Erlandson 2001:301).

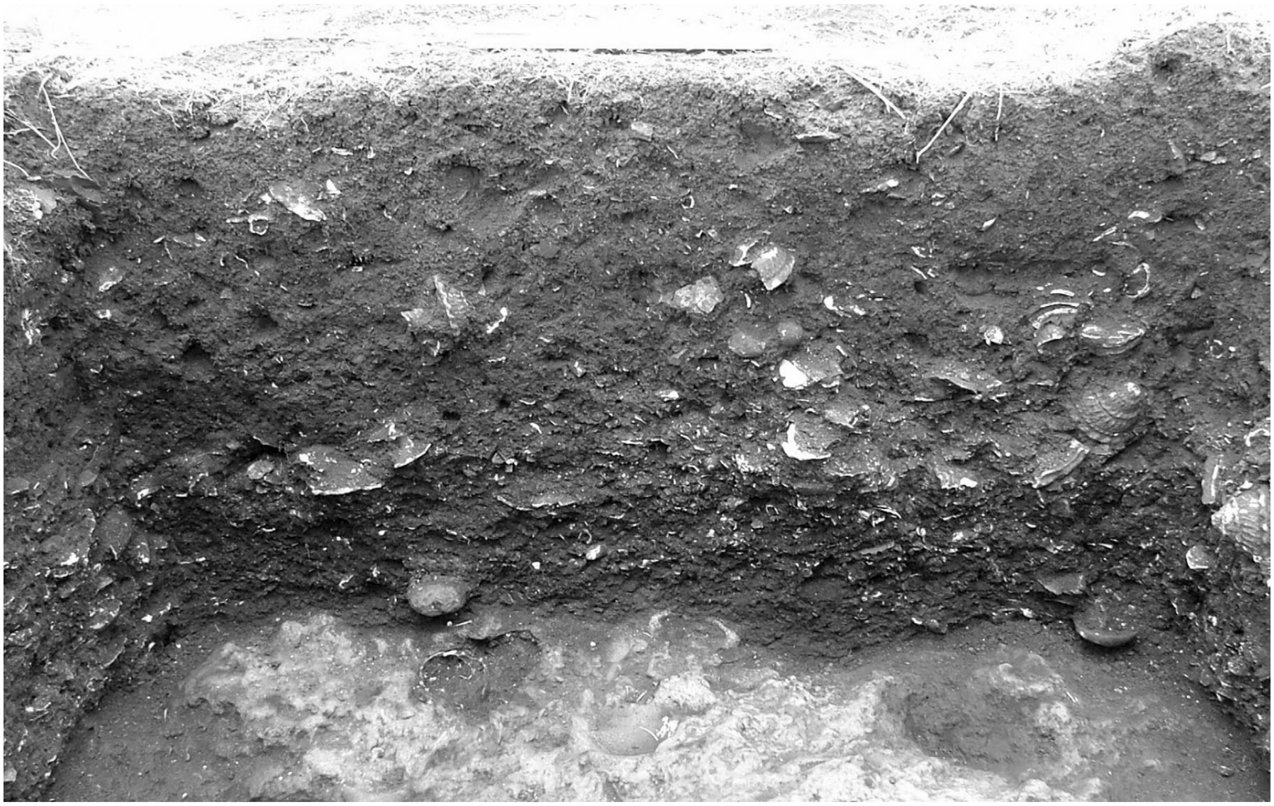


Figure 5.4. North sidewall of 1 x 1 m unit 5S/5W, CA-SCRI-724, with abundant wavy top.

Significantly, no wavy top are reported from this site. Based on these limited data it appears that Santa Cruz, Santa Rosa, and Santa Barbara islands share commonalities in subsistence and residential mobility during the middle Holocene and document the subsequent decline of subtidal shellfish exploitation during the late Holocene.

Explaining Subtidal Shellfish Exploitation in the Middle Holocene

Based on these disparate data sources, we argue that rather than temperature fluctuations affecting changes in the vertical distribution of wavy top, as they do in the case of red abalone, they instead influence wavy top's geographic range and relative abundance. Wavy top and pink abalone appear to be more abundant in warmer-water conditions, as suggested by the kelp monitoring data as well as by their general prevalence in the waters surrounding the southern Channel Islands and in Baja California. Their abundance, flexibility, and preference for warm-water and/or suboptimal conditions are likely part of the explanation for the more intensive wavy top exploitation during the middle Holocene on Santa Cruz Island, as well as in late Holocene deposits on Santa Catalina and San Clemente islands (Byrd and Andrews 2002; Reinman and Eberhart 1980).

It is also important to consider broader trends in subsistence strategies, including the kinds of decision making and time allocation that resulted in the inclusion or avoidance of subtidal shellfish. During the early and middle Holocene, shore fishing in near-shore rocky and kelp forest habitats was common, as exemplified in the fish assemblages at Punta Arena and other northern Channel Island sites (Erlandson, Vellanoweth, et al. 2005; Glassow 2002, 2005b; Glassow et al. 2008; Kennett 2005; Sharp 2000; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2002; Vellanoweth et al. 2006).

Wavy top could be readily identified and opportunistically collected while shore fishing or through netting, the latter having been documented on Cedros Island. So long as marine exploitation was concentrated in near-shore habitats, wavy top would have been encountered at a relatively high rate, and arguably collected upon encounter because of their large meat package and high nutritional yields.

Middle Holocene exploitation of wavy top, red abalone, and other subtidal species appears to be related to several environmental and cultural factors, including changes in SST, particularly to warmer conditions, as well as lower population densities and higher residential mobility compared to the late Holocene. The emphasis on wavy top on Santa Cruz and Santa Barbara islands appears to be a primarily middle Holocene phenomenon associated with warmer-water intervals between around 5900 and 3800 B.P., and especially warm conditions after 5200 B.P. In contrast, red abalone middens tend to date between 6800 and 4800 B.P., with most dates occurring between 6400 and 5200 B.P. (Glassow 1993b, 1994, 2002; 2005a, 2005b; Kennett 2005; Vellanoweth 1996; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2006). Preferences for subtidal diving are indicated by the co-occurrence of wavy top and red abalone in faunal assemblages from warm-water settings, such as on Santa Catalina Island, as red abalone would have been found only in cooler, deeper waters.

SUBTIDAL SHELLFISH EXPLOITATION IN THE LATE HOLOCENE

Associated with the declining importance of shellfish gathering after the middle Holocene, wavy top, red abalone, and other subtidal species represent far less of the late Holocene diet on the northern Channel Islands (see Arnold and Graesch 2001; Glassow 1993a; Kennett 2005; Perry 2003; Rick and Erlandson 2001). The decline of subtidal shellfish exploitation on northern islands cannot be explained by environmental factors alone; increased population densities and associated changes in resource procurement strategies also are factors. Species such as wavy top may have been largely ignored on the northern islands later in time because (a) it was more subject to overexploitation in contexts of higher population density and/or (b) its collection, and subtidal diving in general, conflicted with other marine-oriented activities such as offshore fishing (Sharp 2000). Ongoing reliance on red abalone to some degree has been identified on Santa Rosa and San Miguel islands, where populations continue to be abundant (Rick 2007). On Santa Cruz Island, however, evidence of red abalone exploitation during the late Holocene is limited primarily to bead manufacture at village sites on its western end (Arnold and Graesch 2001:90–91).

Although wavy top and red abalone are present in late Holocene deposits on Santa Catalina, San Clemente, and Santa Rosa islands (Byrd and Andrews 2002; Reinman and Eberhart 1980), it appears that their dietary contributions, along with other shellfish species, declined as other subsistence strategies became increasingly important in the California Bight (Erlandson et al. 1992; Glassow 1993a; Sharp 2000). It is possible that subtidal shellfish exploitation fell out of the subsistence round as conditions became cooler and as greater emphasis was placed on offshore activities that resulted in higher yields, such as fishing, to support increased population densities in the late Holocene (Kennett 2005). The exceptions indicate that there were specific circumstances under which subtidal species continued to be harvested, most likely in contexts of relatively high abundance.

Late Holocene Wavy Top Exploitation on San Clemente and Santa Catalina Islands

The major exceptions to the middle Holocene pattern of wavy top exploitation emerging on the northern Channel Islands are on Santa Catalina and San Clemente islands, two of the southern Channel Islands. Middle and late Holocene sites on San Clemente Island, southwest of Santa Catalina Island, have yielded unusually large quantities of wavy top, pink abalone, and other subtidal species (Byrd and Andrews 2002, 2003; Salls 1991, 1992). Although a very small site, LT-46 exhibits relatively high artifact diversity, including metate, bowl mortar, and pestle fragments, as well as a digging stick weight and a steatite whale effigy (Byrd and Andrews 2003). This shell midden dates to the middle Holocene based on one radiocarbon date of 3470–3240 cal B.P. (1σ). Here wavy top contributes 52 percent of the shell weight, while black abalone and black turban contribute 14 and 13 percent, respectively (Byrd and Andrews 2003).

In contrast, CA-SCLI-1413 and CA-SCLI-1788, both located on the center of the plateau that dominates the island's terrain, are relatively large and dense shell middens dating to the late Holocene. Byrd and Andrews (2002) report two radiocarbon dates from CA-SCLI-1413 and one from CA-SCLI-1718, all between 1800 and 1200 cal B.P. The dominant shellfish at both sites are wavy top, black turban (*Tegula funebralis*), and black and green abalone (*Haliotis cracherodii* and *H. fulgens*, respectively). Wavy top contributes 54 percent of the shell weight at CA-SCLI-1413, with black turban ranking second at 20 percent (Byrd and Andrews 2002). At CA-SCLI-1788, wavy top represents 25 percent of the shell weight, with comparably higher proportions of abalones and black turban.

Large quantities of wavy top have also been found at Ripper's Cove, CA-SCAI-26, a large shell midden and small steatite quarry on the east side of Santa Catalina Island north of Goat Harbor. The extensive deposits date to the Late and protohistoric periods based on four uncalibrated radiocarbon dates and diagnostic artifacts (Reinman and Eberhart 1980:72). Twenty-eight 1-×-1-m units were excavated in 1977 by a team from California State University, Los Angeles (Reinman and Eberhart 1980:65); the shellfish analysis was subsequently conducted by Bradford (1991). The significance of this site is indicated through the recovery of burials and numerous formal artifacts, including shell fishhooks; bone tools such as gorges and awls; projectile points; pitted stones; manos; pestles; steatite comals, bowl mortars, and effigies; and beads of bone, shell, and steatite (Reinman and Eberhart 1980).

Based on Bradford's (1991) shellfish analysis, black abalone, wavy top, and red abalone were identified as the dominant shellfish species, collectively comprising about 90 percent of the edible meat estimates for shellfish constituents. Although the relative contributions of black abalone and wavy top vary between site areas, units, and levels, wavy top represents about 50 percent and 34 percent of the total shell weights and edible meat estimates, respectively. Bradford (1991:46–48) observed an increase in wavy top in the upper levels of the excavation units, which she proposes may be a response to declined black abalone populations during periods of overexploitation. Her analysis implies that whenever the individual size and/or density of intertidal black abalone declined below a certain level, people increased their emphasis on subtidal shellfish resources such as wavy top (and, by extension, red abalone). Although it is not possible to evaluate Bradford's (1991) hypothesis with the existing data, the relationship between black abalone and larger subtidal shellfish species (wavy top and pink abalone) has also been observed at Eel Point (Salls 1991, 1992), suggesting a broader pattern.

In sum, inhabitants of Santa Catalina and San Clemente islands appear to have selectively targeted relatively large meat packages in intertidal and subtidal habitats, depending on fluctuations in their relative abundance throughout the middle and late Holocene. Whether this practice was common on Santa Catalina Island during the late Holocene is unknown based on the limited archaeological research done on the island, and particularly the lack of comparably dated sites near each other. However, the shellfish assemblages at CA-SCLI-1413 and CA-SCLI-1788 suggest that similar subsistence activities were conducted on San Clemente Island during the late Holocene (Byrd and Andrews 2002; see Raab 1992). Furthermore, these limited data hint at what may have been a common subsistence strategy during the late Holocene throughout the southern Channel Islands, where characteristically warmer waters favor wavy top populations today. How population density and residential mobility influenced these resource preferences on the southern islands is not well understood, but it is possible that subtidal shellfish exploitation continued to be viable in contexts of lower human population densities when compared to the northern Channel Islands.

LIMITATIONS AND FUTURE DIRECTIONS

Despite the contributions of this study to our understanding of subtidal shellfish exploitation through time, and especially wavy top exploitation during the middle Holocene, limitations include small sample sizes and accordingly insufficient data for thorough intra-island and inter-island comparisons. Less studied warm-water areas, including Anacapa Island and the southern Channel Islands, should be targeted to supplement our understanding of subtidal shellfish exploitation during the middle Holocene. Obtaining faunal assemblages from both middle and late Holocene midden deposits on Santa Catalina Island would provide significant insights, especially given the complementary studies of live wavy top populations nearby (Alfaro 1994; Alfaro and Carpenter 1999; Myers 1986).

Furthermore, while we conducted scuba and snorkel surveys around eastern Santa Cruz and Santa Catalina Islands, we were unable to sufficiently evaluate procurement and processing techniques as well as dietary yields. Our limited harvesting observations and experiments suggest the meat and protein multipliers may not be accurate, and it is only by studying live populations of wavy top that we can test our quantitative methods of reconstructing individual sizes and their dietary contributions. Future research should include careful evaluation of recent kelp forest conditions and changes in wavy top populations, additional experimental harvesting to evaluate more effectively edible meat estimates, and further documentation of contemporary wavy top exploitation techniques, such as those practiced in Ensenada and on Cedros Island in Baja California.

Stable oxygen isotope analysis offers another line of evidence for evaluating the relationship between SST and the particular shellfish species targeted across varying faunal assemblages. For wavy top it may be possible to infer the depth of collection, and therefore the prevalence of subtidal diving, as was done with the comparison of California mussel and red abalone on Santa Rosa Island (Rick, Robbins, and Ferguson et al. 2006; Sharp 2000). It would be interesting to compare the isotope values of mussel with both wavy top and red abalone from middle Holocene sites throughout the Channel Islands to evaluate the relationship between the latter two species with respect to near-shore subsistence activities. Overall, targeting species that are unique to middle Holocene middens on Santa Barbara, Anacapa, and Santa Cruz islands, such as wavy top, complements the substantial body of research on red abalone and California mussel middens (Glassow 1993b, 1994, 2002, 2005b; Erlandson, Vellanoweth, et al. 2005; Kennett 2005; Rick, Erlandson, et al. 2006; Rick, Robbins, and Ferguson 2006; Sharp 2000; Vellanoweth 1996; Vellanoweth and Erlandson 1999; Vellanoweth et al. 2006; Walker and Snethkamp 1984).

Faunal assemblages from Santa Rosa and San Miguel islands, as well as Santa Catalina and San Clemente islands, indicate that exploitation of subtidal shellfish species continued well into the late Holocene, implying inter-island variability in shellfish populations and associated foraging strategies through time. In citing Seapy and Littler's (1980) study of contemporary invertebrate populations from all the Channel Islands as well as sites on the mainland, Sharp (2000:16) emphasizes the relationship between shellfish distribution and SST: "[C]luster analysis broke the island into three groups: a colder water group containing San Miguel, San Nicolas, and Santa Rosa Islands, a warm water group containing San Clemente and Santa Catalina Island, and an intermediate group of Santa Barbara, Santa Cruz, and Anacapa." Shell middens of the colder-water group have yielded relatively higher contributions of red abalone regardless of time period, whereas the warm-water group has evidence of wavy top exploitation during the late Holocene (Byrd and Andrews 2002; Reinman and Eberhart 1980). Generally speaking, for the intermediate group of islands, red abalone tend to be found in middle Holocene sites on western Santa Cruz, and wavy top on eastern Santa Cruz and Santa Barbara (Erlandson et al. 1992; Glassow 1993a, 1993b, 2002, 2005b; Greenwood 1978; Perry 2003).

With cooler-water conditions persisting on Santa Rosa and San Miguel islands, it is expected that red abalone was always relatively abundant, resulting in it always being included in the diet (see Rick 2007).

Furthermore, the persistent warm-water conditions of Santa Catalina and San Clemente islands, as well as Cedros Island, support larger wavy top populations, suggesting that they were usually targeted when in abundance, given relatively high encounter rates as well as high meat and protein yields. In contrast to these extremes, the mixed waters surrounding Santa Cruz, Anacapa, and Santa Barbara islands supported fluctuating shellfish populations. In these environments, subtidal shellfish species would not have been reliable resources in the context of higher human population densities during the late Holocene. Instead, islanders turned their attention to fishing, expanding their efforts to include offshore waters (e.g., Colten 2001; Glassow 1993a; Kennett 1998, 2005; Noah 2005). Fishing could be conducted more intensively, and fish could be more effectively stored in large quantities for local consumption and exchange. Fishing was therefore more conducive to supporting higher population densities on the Channel Islands (Glassow 1993a; Kennett 2005). From this perspective, in combination with red abalone and other subtidal shellfish species, wavy top exploitation in the middle Holocene offers important insights into broader variability and change in residential mobility, subsistence, and technology through time on the Channel Islands and throughout the California Bight.

ACKNOWLEDGMENTS

First, we thank those who assisted us in the fieldwork and/or laboratory analysis: Ahmed Ali, Danielle Brown, Dave Daniels, Bill Duncan, Dan Gladwell, Ciara Fernandez, Carrie Fields, Lisa Hosales, Robert Howard, Gary Jones, Amy McManus, Elyse Rodriguez, Katie Ryan, Alan Theng, and Colorado Mountain College. We are also grateful to those who have influenced our ideas about wavy top exploitation, including Sherri Andrews, Matt Des Lauriers, Alberto Espinoza, Mike Glassow, Terry Joslin, Dustin McKenzie, Victor Molina, and John Sharp. We also thank Ann Huston, Kelly Minas, and Lulis Cuevas at Channel Islands National Park for their support. Our research was made possible through a Hirsch Research Initiation Grant, as well as support from the Haynes Foundation and Channel Islands National Park. Finally, we thank two anonymous reviewers and the editors of this volume for their helpful comments.

CHAPTER 6

A Native Californian's Meal of Coho Salmon (*Oncorhynchus kisutch*) Has Legal Consequences for Conservation Biology

KENNETH W. GOBALET

Seven members of the salmon and trout genus *Oncorhynchus* are found in the North American waters of the Pacific Ocean and in streams from Alaska to Baja California, Mexico (Behnke 2002). Pink salmon (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), Chinook salmon (*O. tshawytscha*), and steelhead rainbow trout (*O. mykiss)* have entered the streams of California at least as far south as the Sacramento–San Joaquin river system (Hallock and Fry 1967). Virtually all salmonid populations have experienced a general decline in California, which is the location of the southern extreme of their ranges and Chinook salmon populations in the Central Valley are severely depleted (Moyle 2002, Yoshiyama et al. 2001). Sockeye, pink, and chum salmon have been rare for at least the past century this far south. Nehlsen et al. (1991) listed at least 11 extinct steelhead stocks and 6 stocks having a high risk of extinction from San Francisco southward along the coast. Though Brown et al. (1994) state that coho salmon may range as far south as the Big Sur River, Swift et al. (1993) find no well-authenticated reports of any wild salmon entering streams south of Monterey Bay.

These are more than esoteric considerations for fisheries biologists, because coho salmon are the most endangered salmon population on the West Coast of North America, and the populations in central California were federally listed as endangered in 2006 (Miller 2010). Protecting endangered species has legal consequences, and having accurate information regarding the ranges of threatened species in particular can be quite controversial because there are considerable monetary ramifications. For instance, if coho salmon are native to coastal streams, development and lumbering may have to be curtailed to preserve their freshwater stream spawning habitat.

Supported by lumbering interests in Santa Cruz and San Mateo counties, Kacyznski and Alvarado (2006) have used the lack of coho salmon remains in the archaeological record south of San Francisco as evidence that coho were not native to the streams in attempts to reverse the listing of coho as endangered. This would thus allow the cutting of redwood forests. What the archaeological record has to say about the distribution of this endangered fish thus has considerable relevance for economic and conservation interests today and complements the theme of this volume.

The southern extent of the spawning streams of coho salmon (*Oncorhynchus kisutch*) in central California has been designated at least as far south as the San Lorenzo River in Santa Cruz County or in other tributaries of Monterey Bay (Behnke

2002:37; Lee et al. 1980:94; Moyle 2002:247; Snyder 1912). Despite this, only steelhead rainbow trout (*O. mykiss*), and no definitive salmon remains, have been reported from coastal California archaeological sites south of San Francisco (Gobalet et al. 2004).

Kacyznski and Alvarado (2006) prominently cited the negative evidence of Gobalet (1990), Gobalet and Jones (1995), and Gobalet et al. (2004) to attempt to discredit over 100 years of fishery research that establishes coho salmon as natives in streams south of San Francisco. They advocate establishing the southern extent of coho salmon spawning as San Francisco, not Monterey Bay. This would relax the protective measures in place for the spawning streams of coho salmon, and lumbering and other development could commence. Recent archaeological excavations of coastal California sites have been given particular attention to see if additional archaeological materials can establish coho salmon in the archaeological record and thus lend additional support to the overwhelming evidence for the native status of coho salmon south of San Francisco (Adams et al. 2007). Fish remains from archaeological sites on Elkhorn Slough associated with the drainages of the Pajaro and Salinas rivers, previously identified as steelhead rainbow trout by Gobalet (1990, 1993), were reexamined to determine if coho salmon might have been misidentified as steelhead rainbow trout.

For all coastal California, the documentation of coho salmon consists of only Follett's (1966) report from Del Norte County (CA-DNO-11) and either Chinook salmon (*O. tshawytscha*) or coho salmon from De Haven Creek in Mendocino County (CA-MEN-2307) (Gobalet et al. 2004). Only 14 elements of coho salmon have been identified from tributary streams of San Francisco and Suisun bays in Alameda and Contra Costa counties (Gobalet et al. 2004:813). Coho salmon are extremely rare in the archaeological record, in part because of poor preservation and the difficulty of discriminating among species of *Oncorhynchus* based on limited skeletal materials (Gobalet et al. 2004:825–826). For coastal central California, there is no question that Native Americans were using both trout and salmon, because the dialects of Ohlonean, the language of native peoples living in this region, had names for both. Trout were called *uuyi* in the Soledad dialect; *uui* in the Santa Cruz dialect; and *xirru* (pronounced he-roo or hiru) in the Monterey dialect. Salmon were called *tallen* (tal-in) in the Soledad dialect; *hu-ra-ka* (urak or uraka) in the Santa Cruz dialect; *ur-ak* (u-rak or uraka) in the Monterey dialect; *chipal urak* in the Santa Clara dialect; and *uraka* (hoo-ye) in the San Juan Bautista dialect (Mark Hylkema, personal communication 2006). Because steelhead rainbow trout and coho salmon are the only two salmonids known to enter coastal streams south of San Francisco to spawn (Moyle 2002), they are the likely fishes named by the Ohlone.

The archaeological record has been partially successful in helping to reconstruct past faunal assemblages in California and thus in documenting species presence not confirmed by other methods (Gobalet 2004). On the one hand, Gobalet (1990, 1993) confirmed the presence of thicktail chub (*Gila crassicauda*), Sacramento pikeminnow (*Ptychocheilus grandis*), and Sacramento perch (*Archoplites interruptus*) in the Pajaro and Salinas rivers with remains from archaeological sites on the margin of Elkhorn Slough in Monterey County. Schulz (1995) independently corroborated the findings of thicktail chub and Sacramento perch at an inland archaeological site on the Pajaro River. On the other hand, these excavations failed to document hardhead (*Mylopharodon conocephalus*) and splittail (*Pogonichthys macrolepidotus*), also expected from the drainage.

The archaeological record can be unpredictable. Along with northern anchovy (*Engraulis mordax*) and Pacific sardine (*Sardinops sagax*), Pacific pompano (*Peprilus simillimus*) are among the most abundant pelagic fishes of southern California (Allen and Pondella 2006:91). Pacific pompano are a schooling species and reach 29 cm in length (Love 1996:324), yet they are unknown in the California archaeological record, while northern anchovy and Pacific sardine are common when screens smaller than 1/8-inch mesh are used. Based on the archaeological record alone, Pacific tomcod (*Microgadus proximus*) would be thought to be rare because only four elements were identified among the over 105,000 archaeological remains from sites on San Francisco

Bay (Gobalet et al. 2004:812). In the nineteenth century, however, Pacific tomcod were so abundant that they supported a commercial fishery on the Bay (Goode 1884; Hooper 1875). Wolf-eels (*Anarrhichthys ocellatus*) are common from central California northward, reach at least 82 cm in length, are found in very shallow waters, are good to eat (Love 1996), and have easily recognizable caniniform (more than 1.5 cm high) and molariform (to 1 cm long) teeth (Figure 6.1). Despite the examination of hundreds of thousands of fish remains from hundreds of coastal California archaeological sites, wolf-eel remains have been reported only from Diablo Canyon, San Luis Obispo County (CA-SLO-2) by Fitch (1972). If we relied on the archaeological record alone, we would conclude that wolf-eels are extremely rare and absent north of Diablo Cove. Despite extensive anecdotal and historical evidence that the Indians of the Central Valley of California were harvesting colossal quantities of salmon (primarily Chinook salmon) (Yoshiyama 1999), the archaeological record of the region demonstrates the importance of Sacramento perch and not salmon to the native inhabitants of the region (Gobalet et al. 2004). Only common fishes used by the Indians seem to persist in the archaeological record, and even this is problematic. When something does appear in the archaeological record, it probably represented a common item. The purpose of the study reported here was to search for coho salmon remains in the recently excavated archaeological materials south of San Francisco and to reexamine salmonid remains previously reported from Elkhorn Slough to see if coho salmon were in fact represented.

METHODS AND MATERIALS

Materials were identified using fish skeletons housed in the Biology Department, California State University, Bakersfield (CSUB), and from the California Academy of Sciences, San Francisco, as well as specimens of *O. mykiss* from the Department of Anthropology University of California, Davis (catalog numbers 5025 and 5007). Notably, the CSUB collection contains 26 *O. kisutch*. Fish names follow Nelson et al. (2004).

Diane Gifford-Gonzales of the University of California, Santa Cruz, provided fish remains from CA-SMA-18, Año Nuevo State Park, from an excavation conducted by Mark Hylkema. Sherri Gust provided the remains from CA-SBA-3505H, a Victorian household in Santa Barbara dating from about 1860 to 1900. Sandi Flint of Applied Earthworks provided the materials from CA-SMA-151 (Pillar Point, San Mateo County). John Douglass and Dave Maxwell of Statistical Research Inc. provided the Playa Vista (CA-LAN-54, CA-LAN-62, CA-LAN-63, CA-LAN-64, CA-LAN-193, CA-LAN-211) remains, and Jennifer Farquhar, Albion Environmental Inc., sent the gravels from CA-SCR-25/81, from which a few remains were sorted.

Salmonid centra from CA-SMA-18 were independently evaluated by three fish skeletal identification experts: K. W. Gobalet, Jereme Gaeta (University of Wisconsin, Madison), and Gerald R. Smith (University of Michigan). The three were not informed of the determinations of the others; the evaluations were thus "blind."

Salmonid materials from CA-MNT-228 and CA-MNT-229, curated by the Moss Landing Marine Laboratory, Monterey County, and on loan to the Department of Anthropology, University of California, Santa Cruz, were reexamined thanks to the generosity of Diane Gifford-Gonzales and Cristie Boone. Gobalet and Jones (1995) previously reported these as steelhead rainbow trout. Growth rings of eight possible coho vertebrae were "read" by the author and Tim Carpenter (ArchaeoMetrics, Woodland, California) to exclude from consideration those that were not three years of age, the age coho salmon spawn and die (Moyle 2002:249). Vertebral centra provided the most precise estimator of the age in a cyprinid when compared with scales and otoliths (Hawkins et al. 2004).

RESULTS

Salmonid remains continue to be rare among archaeological materials recovered from sites south

Figure 6.1. Skull (top) and dorsal view of the mandible (bottom) of a wolf-eel (*Anarrhichthys ocellatus*). Note the caniniform teeth close to the quarter and the crushing molariform teeth to the right.

Table 6.1. Fish Remains from CA-SMA-18, CA-SMA-151, and SCR-25/-81 as Number of Specimens Identified.

Taxon	Common Name	SMA-18	SMA-151	SCR-25/-81
Triakidae/Carcharhinidae	Requiem and hound sharks	1		
Raja sp.	Skate		1	
Clupeidae	Herring family	32	15	
Sardinops sagax	Pacific sardine	3	3	
Engraulis mordax	Northern anchovy	1	17	1
Osmeridae	Smelt family	6	57	
Porichthys notatus	Plainfin midshipman		6	
Oncorhynchus kisutch	Coho salmon	2		
Merluccius productus	Pacific hake	1		
Gobiesox meandricus	Northern clingfish	1		
Atherinopsidae	New World silversides	7	3	1
Sebastes sp	Rockfishes	98	5	1
Hexagrammos sp.	Greenling	56	25	
Ophiodon elongatus	Lingcod	29	2	1
Cottidae	Sculpin family	9		1
Scorpaenicthys marmoratus	Cabezon	79	23	
Leptocottus armatus	Pacific staghorn sculpin		2	
Archoplites interruptus	Sacramento perch			1
Embiotocidae	Surfperch family	203	228	
Amphistichus sp.	Surfperch			
Embiotoca sp.	Striped or black surfperch	2	2	
Stichaeidae	Prickleback family	26	92	
Cebidichthys violaceus	Monkeyface prickleback	2		
Xiphister sp.	Rock or black prickleback	5		
Clinidae	Clinid family	1	2	
Gibbonsia sp.	Kelpfish	4	1	
Platichthys sellatus	Starry flounder			1

of San Francisco. Only 2 elements (.19 percent) were identified among 1,059 remains recovered from three prehistoric sites in San Mateo and Santa Cruz counties (Table 6.1); 9 (.17 percent) among the 5,418 remains from six prehistoric sites in Los Angeles County (Table 6.2); and 1 (.47 percent) among 209 historic remains from a Victorian household in Santa Barbara, California (Table 6.3). These percentages are remarkably consistent with the .40 percent previously found by Gobalet et al. (2004:825) for sites in San Mateo and Santa Cruz counties and the .20 percent for archaeological sites in coastal California from Monterey County to Santa Barbara County. Noteworthy are nine steelhead vertebrae among the remains at Playa Vista in Los Angeles County, a single coho salmon vertebra at CA-SBA-3505H, and two coho salmon vertebrae at CA-SMA-18 in Año Nuevo State Reserve. Of the vertebrae from CA-SMA-18, one was determined to be coho salmon by Gobalet, Gaeta, and Smith (see "Methods and Materials") (Figure 6.2), and the second was identified as coho salmon by Gobalet and Gaeta. Smith was equivocal but decided upon steelhead for this vertebra. Of the eight vertebrae singled out for close scrutiny from archaeological sites CA-MNT-228 and CA-MNT-229 on Elkhorn Slough, three (CA-MNT-228 accession number 72, catalog number 974, unit 9, 140–150 cm; CA-MNT-229 unit 14, 120–140 cm; CA-MNT-229 unit 31, 120–140 cm) were possibly coho salmon (Figure 6.3). The surface architecture and three-year age were consistent with this determination.

DISCUSSION AND CONCLUSIONS

With the finding of coho salmon vertebrae at Año Nuevo State Reserve, located at the boundary of San Mateo and Santa Cruz counties, the coastal

Table 6.2. Fish Remains from Playa Vista, Los Angeles County.[1]

Taxon	Common Name	Number of Specimens
Elasmobranchimorphi	Sharks and rays	498
Triakidae and Carcharhinidae	Hound and requiem sharks	44
Carcharhinus brachyurus	Narrowtooth shark	1
Galeorhinus galeus	Tope	16
Triakis semifasciata	Leopard shark	12
Isurus oxyrinchus	Shortfin mako	1
Lamna ditropis	Salmon shark	1
Notorhynchus cepedianus	Broadnose sevengill shark	1
Squatina californica	Pacific angel shark	112
Rajiformes	Rays, skates	169
Rhinobatis productus	Shovelnose guitarfish	213
Platyrhinoidis triseriata	Thornback	35
Myliobatis californica	Bat ray	190
Clupeidae	Herrings	1,699
Clupea pallasi	Pacific herring	1
Sardinops sagax	Pacific sardine	95
Engraulidae	Anchovies	177
Gila orcutti	Arroyo chub	36
Oncorhynchus mykiss	Steelhead rainbow trout	9
Poricthys sp.	Midshipman	6
Mugil cephalus	Striped mullet	1
Atherinopsidae	New World silversides	813
Gasterosteus aculeatus	Threespine stickleback	3
Sebastes sp.	Rockfishes	12
Cottidae	Sculpins	4
Leptocottus armatus	Pacific staghorn sculpin	7
Paralabrax sp.	Bass	3
Paralabrax clathratus	Kelp bass	3
Seriola lalandi	Yellowtail jack	15
Xenistius californiensis	Salema	1
Sciaenidae	Drums and croakers	326
Atractoscion nobilis	White sea bass	3
Roncador stearnsi	Spotfin croaker	3
Genyonemus lineatus	White croaker	19
Menticirrhus undulatus	California corbina	14
Umbrina roncador	Yellowfin croaker	4
Seriphus politus	Queenfish	11
Embiotocidae	Surfperches	214
Amphistichus sp.	Barred, calico, redtail surfperch	34
Rhacochilus vacca	Pile perch	1
Semicossyphus pulcher	California sheephead	12
Oxyjulis californica	Senorita	213
Gobiidae	Gobies	16
Gillichthys mirabilis	Longjaw mudsucker	101
Sphyraene argentea	Pacific barracuda	27
Scombridae	Mackerels	11
Sarda chiliensis	Pacific bonito	1
Thunnus sp.	Tuna	2
Thunnus alalunga	Albacore	4
Scomber japonicus	Pacific chub mackerel	118
Plueronectiformes	Flounders	106

[1] Playa Vista assemblages of fish remains are from CA-LAN-54, CA-LAN-62, CA-LAN-63, CA-LAN-64, CA-LAN-193, CA-LAN-211.

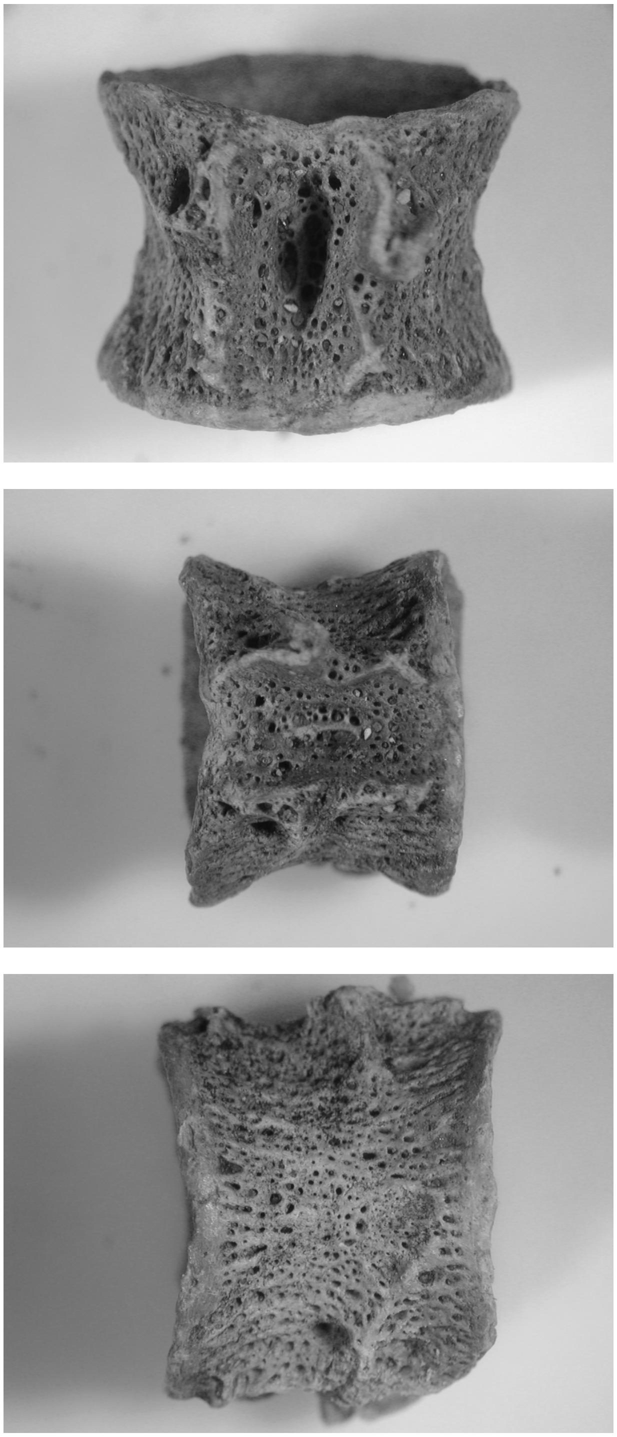


Figure 6.2. Top dorsal, middle ventral, and bottom lateral views of Coho salmon (*Oncorhynchus kisutch*) vertebra from Año Nuevo State Reserve; archaeological site CA-SMA-18, NS/W6, 20–40 cm, specimen number 162-4.

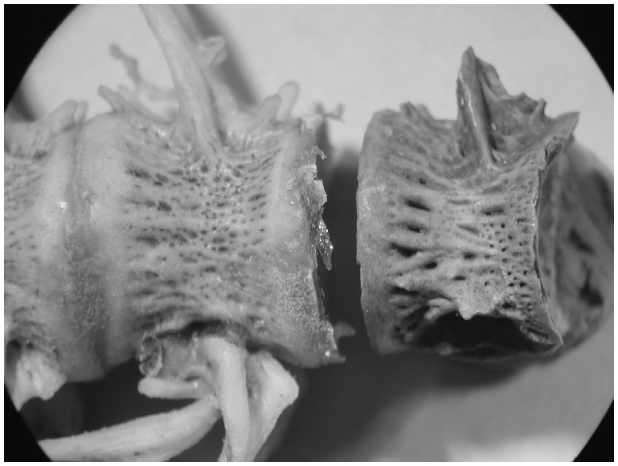


Figure 6.3. Coho salmon (*Oncorhynchus kisutch*) vertebra from Elkhorn Slough, Monterey County (right), archaeological site CA-MNT-229 (unit 14, 120–140 cm, 14-057), beside vertebra number 31 of *O. kisutch*, female, 625-mm SL in collection at CSUB.

California archaeological record for coho salmon south of San Francisco is now as extensive as the archaeological record of coho salmon north of San Francisco. This finding contradicts the use of the archaeological record as negative evidence by Kacyznski and Alvarado (2006) in their argument that coho salmon were not native to streams south of San Francisco. Salmon and steelhead, however, possibly could be taken from the ocean. Nonetheless, capture would be much easier in freshwater when salmonids congregate during spawning runs (Gobalet et al. 2004). If marine capture of salmon was extensively undertaken by the local Native Americans, one would expect the salmon to be Chinook rather than coho because the majority of the recreational marine catch today in California is Chinook salmon (Love 1996:105). The coho salmon remains found at CA-SMA-18 were thus most likely procured about 5 km south, in Waddell Creek, the nearest coho salmon spawning stream. Lending further support to the likelihood of transport to Año Nuevo State Preserve are numerous instances of fishes being transported from the point of capture in California to distant sites of utilization (Gobalet 1992; Gobalet et al. 2004). Among the materials recovered in the city of Santa Cruz (CA-SCR-25/81; Table 6.1) is a tiny Sacramento

Table 6.3. Fish Remains from SBA-3505H.

Taxon	Common Name	Number of Elements
Clupeidae	Herrings and sardines	40
Sardinops sagax	Pacific sardine	3
Engraulidae	Anchovy	2
Oncorhynchus kisutch	Coho salmon	1
Atherinopsidae	New World silversides	13
Sebastes sp.	Rockfishes	30
Scorpaenichthys marmoratus	Cabezon	2
Paralabrax sp.	Bass	7
Serioloa lalandi	Yellowtail jack	2
Trachurus symmetricus	Jack mackerel	9
Sciaenidae	Drums and croakers	12
Atractoscion nobilis	White sea bass	5
Genynomemus lineatus	White croaker	6
Embiotocidae	Surfperches	14
Sphyraena argentea	Pacific barracuda	37
Semicoccyphus pulcher	California sheephead	11
Thunnus sp.	Tuna	1
Scomber japonicus	Pacific mackerel	4
Pleuronectiformes	Flounders	4
Paralichthys californicus	California halibut	6

perch vertebra. The nearest known population of this species was in the Pajaro River, 25 km away, in an aquatic system from which they have since been extirpated (Moyle 2002). Waddell Creek would have been easily accessible to the local Ohlone Quiroste tribelet for the exploitation of spawning coho salmon.

The parsimonious explanation for the coho salmon vertebra found among the late-nineteenth-century materials in Santa Barbara (Table 6.3) was the capture of the specimen from local marine waters. No evidence suggests coho salmon ascended rivers to spawn this far south. Coho salmon are common in the Pacific Ocean from Santa Barbara northward (Miller and Lea 1972). The fishes listed in Table 6.3 are all local to Santa Barbara and include large and commercially exploited rockfishes, croakers, surfperches, Pacific barracuda, and California sheephead. There is, however, the slight possibility of rail transport from northern California commencing in the 1890s. The bulk of the rail transport at that time, however, was lobster and abalone from southern California to San Francisco, rather than in the reverse direction (Love, personal communication 2005; Love 2006). Ice, in the form of large blocks, became increasingly affordable in the late nineteenth century to facilitate longevity of perishable goods (Oaks 2002). As difficult as the skeletal materials of members of *Oncorhynchus* are to tell apart, this identification of coho salmon, like all identifications, should be considered tentative until confirmed by independent specialists (Gobalet 2001).

The nine steelhead rainbow trout vertebrae identified among the over 5,000 fish remains from the Playa Vista sites in Los Angeles County (Table 6.2) complement the findings of Gobalet et al. (2004) of this species as far south as San Diego. Steelhead were likely ascending Centinela Creek, Ballona Creek, or the Los Angeles River when they were captured. Further evidence that local Native Americans were exploiting exclusively freshwater fishes was the presence of 36 elements (including pharyngeal jaws) of the arroyo chub (*Gila orcutti*), an exclusively freshwater minnow, in the archaeological sample. These findings corroborate Salls's (1988) identification of steelhead from the Centinela Creek region.

There is no question that steelhead rainbow trout ascended coastal streams throughout California, and archaeological evidence supports this. We now have definitive archaeological evidence that coho salmon ascended coastal California streams at least as far south as Santa Cruz County. Three salmonid vertebrae from sites on Elkhorn Slough (Monterey County) are tentatively identified as coho salmon as well. If confirmed by another specialist, these will extend the range of coho salmon in the archaeological record to the estuary of the Salinas River. This lends support to the position of Brown et al. (1994) that the southern extent of coho salmon distribution in coastal streams is as far south as Big Sur, Monterey County.

ACKNOWLEDGEMENTS

The following individuals provided assistance, materials, information, or financial support for this study: Robert Behnke, Bob Berlage, Cristie Boone, Robert O. Briggs, Virginia Butler, Tim Carpenter, David Catania, Chris Darwent, John Douglass, Jennifer Farquhar, Sandi Flint, Jereme Gaeta, Dianne Gifford-Gonzales, Mike Glassow, Sherri Gust, Terry Hansen, James Harwood, Mark Hylkema, Milton Love, Dennis McEwen, Dave Maxwell, Peter Moyle, Phil Pister, Jeff Seigel, Gerald R. Smith, Camm C. Swift, and Thomas J. Weseloh. Chris Doggett photographed the images for Figures 6.1 and 6.2.

CHAPTER 7

If Mussels Weighed a Ton:

Problems with Quantifying Santa Barbara Channel Archaeofaunas

DIANE GIFFORD-GONZALEZ AND WILLIAM R. HILDEBRANDT

Quantification lies at the heart of zooarchaeological analysis because it assures comparability between samples. Over the last 40 years, specific quantitative measures have emerged as universal units of comparison, several of them borrowing time-tested forms from paleontology (Grayson 1984; Lyman 1994a; Reitz and Wing 1999). These measures include number of identifiable specimens (NISP), minimum number of elements (MNE), and minimum number of individuals (MNI). A lively debate continues over the best modes for calculating these measures, limitations on their uses in various contexts (for example, aggregation effects and MNI), taphonomic interactions with the measures, and the use of other measures such as MAU (minimum animal units). However, no one involved in these debates views such indices as absolute, "real" counts of bone elements or individual animals. Rather, these are seen as standardized measures that provide a means to compare the relative proportions of various taxa or of age/sex classes within a taxon. They are deemed useful for monitoring both diachronic changes in relative taxonomic proportions and synchronic variations in taxa or osteological elements across geographic space.

In contrast to other parts of North America and most of the world, archaeologists working on Santa Barbara Channel sites since the late 1980s have continued earlier Californian archaeological practices of basing their quantitative analyses on weights of archaeofaunal molluscan shell and vertebrate bone, and have further estimated *absolute amounts* of meat available for consumption from the shell and bone weights. As summarized in Mason et al. (1998), this analytical technique of quantifying and comparing shell and bone weights per volumetric unit was pioneered by archaeologists at the University of California, Berkeley, in the early twentieth century and was later introduced to southern California archaeology by Clement Meighan of UCLA. Conversions of shell and bone weights to meat weights were introduced in their contemporary form to southern California by Glassow and Wilcoxon (1988) of UC Santa Barbara. Despite ever-increasing refinements of excavation techniques and research questions, archaeologists trained at UC Santa Barbara have consistently used this approach, with some minor refinements in meat conversion ratios, since that time (Kennett 2005; Rick 2004; cf. Rick 2007; Vellanoweth et al. 2000). Mason et al. (1998) referred to the shell/bone weight:meat weight approach as the California School of Midden Analysis, but here we prefer to call it the Santa Barbara School of Midden Analysis (SBSMA) because many other contemporary Californian practitioners do not use this approach.

This chapter explores problems with the SBSMA in relation to comparisons of marine bivalves, fish of various sizes, and marine mammals. We begin with a brief recapitulation of the method as developed by Glassow and Wilcoxon (1988) and its various applications in the Channel Islands. We then present some concrete examples, exploring how and why this index of dietary intake fails in intertaxonomic comparisons. By examining archaeofaunal cases in concert with modern anatomical data, we hope to demonstrate the ranges of error inherent in the SBSMA when applied to vertebrates. Finally, we discuss wider issues in archaeofaunal quantification in the region and suggest some alternative strategies for analyzing and presenting archaeofaunal data.

METHODOLOGICAL ISSUES

Glassow and Wilcoxon (1988) used extant data in the literature on average meat yields per invertebrate (California mussels, clams as a class) and vertebrates—near-shore marine fish, sea mammal (an average of California sea lion and harbor seal), mule deer, brush rabbit, cottontail rabbit, and jackrabbit (each taken individually)—to construct conversion factors for the shell or bone weights of the taxa in question. The weight of shell or bone attributed to any given taxonomic group, regardless of whether it is a discrete species or an averaged mix of taxa (sometimes at very high levels of taxonomic lumping), is multiplied by this factor to produce the total meat weight "yield" of the taxon. Vellanoweth et al. (2000) later augmented conversion values for invertebrates by listing black and red abalone, owl limpets, platform mussel, sea urchin, and univalve turbans. In contrast to such fine subdivision of invertebrates, Rick's analysis (2004) uses gross "fish," bird," and "sea mammal" categories to compare various San Miguel Island sites

At first glance, absolute meat weight values may seem to provide greater precision in reconstructing past diets than do the relative measures found in the mainstream zooarchaeological literature, suggesting that the former approach can identify a concrete amount of consumable food and thereby a means of assessing energetic and behavioral ecological trade-offs. However, several key assumptions used by the absolute meat weight approach are not supportable across taxa, especially when comparing the dietary contributions of invertebrates to vertebrates. One base assumption is that the presence of a shell or bone necessarily implies no more or no less than a specific correlated meat weight. Thus mussel shells weighed in aggregate are assumed to represent a net aggregate of individuals, each with an average weight of its two valves and each with an average weight of associated meat. This approach is problematic when vertebrates are analyzed, as zooarchaeologists have acknowledged for many years that the presence of a few osteological elements does not necessarily imply the presence of the entire carcass in a site (Binford 1981; Lyman 1994b). A second base assumption, and the most contestable, is that the weight of the bones of a given vertebrate taxon in a sample invariably has a predictable relationship to the meat yield of that taxon, regardless of transport trade-offs.

The SBSMA assumes that shellfish and pinnipeds (or cetaceans) were on average subject to identical butchery and transport decisions in moving from their acquisition sites to their ultimate deposition at a residential site. Mussels are typically assumed to be transported to residential sites whole, and converting archaeological shell weight to meat weight may be more or less unproblematic, although it is acknowledged in debates over the SBSMA that different bivalve taxa vary widely in shell weight to meat weight ratios (for example, thick-shelled Pismo clams versus relatively thin-shelled mussels), with possible differences in taphonomic effects and sampling errors (Claassen 2000; Glassow 2000; Mason et al. 1998).

Pinnipeds and cetaceans, however, are often butchered where acquired, with the goals of subdividing larger carcasses into transportable units and, more critically to this discussion, lightening the weight of transported parts by discard and abandonment of low-utility skeletal segments at the butchery site. The ratio of larger vertebrate bone weight to meat weight is thus not a straightforward calculation, and it differs substantially from the more straightforward shellfish conversion calculation.

Although this qualitative difference in invertebrate versus vertebrate processing is sometimes noted as a potential complication in SBSMA data reports, it is typically ignored in the analytical phase of research, where meat weights for all taxa are treated as comparable indices of dietary abundance, regardless of the prior likelihood of transport-related deletions of larger vertebrates' skeletal parts. This situation produces potentially inaccurate estimates and thus poorly grounded interpretations of archaeofaunal data in otherwise elegant studies. The incongruities inherent to the SBSMA are especially crucial as discussions in coastal Californian archaeology have increasingly focused on historical ecology and on the role and impacts of humans in coastal ecosystems, and as researchers trained in the Santa Barbara approach continue to take the lead in many of these discussions. While it might be objected that each of zooarchaeology's quantitative measures are flawed in one way or another (Glassow 2000), which they are, the specimen weight to meat weight conversion uses one of the grossest forms of data recoverable from faunal remains, in that hard parts of all taxa are treated equally. This form of "black box" analysis ignores or dismisses the last 40 years of development in zooarchaeology. Other approaches, such as combining NISP with a careful analysis of element frequencies by age/sex class, can reveal much about the differential impacts of transport on different taxa and different age/sex classes of mammals (Rogers and Broughton 2001). These topics will be taken up again at the end of this paper, when suggestions are made for more productive approaches to archaeofaunal quantification.

PINNIPED BUTCHERY PATTERNS

It is instructive to examine anatomical data derived from modern pinnipeds. Table 7.1 shows the bone weights and meat weights, as well as ratios of bone to meat weights, of different parts of a phocid (leopard seal, *Hydrurga leptonyx*) carcass as recorded by Lyman et al. (1992), and similar statistics as generated by Savelle et al. (1996) from otariid (California sea lion, *Zalophus californianus*) carcasses (see also Diab 1998).

Several points can be noted. First, the relative proportions of meat on different segments of the phocid and otariid bodies vary markedly, and the overall bone to meat weight ratios also differ. Any bone weight:meat weight conversion factor that "averages" phocids and otariids masks these anatomical differences, which may condition handling and transport decisions. It is worth noting, however, that both taxonomic groups have the highest meat utility values for the cervical vertebrae and ribs.

If the whole skeleton were at a site, then the relative weights of the archaeological bone of various elements should mimic the relative weights of the actual skeletal segments. That is, archaeofaunal percentages for various body segments should approach those of the unmodified skeleton. If, however, low-utility skeletal elements are overrepresented in the archaeofaunal sample, as they may be at large animal butchery sites, then the bone weight:meat weight conversions could differ. Likewise, the greater the number of body segment elements discarded prior to transport of useful parts (skin, meat, fat, viscera), the less and less representative any meat weight estimate from skeletal weights will be once the material reaches its ultimate destination.

A ZOOARCHAEOLOGICAL CASE: THE MOSS LANDING HILL SITE

One of us (Gifford-Gonzalez) is investigating the northern fur seal (*Callorhinus ursinus*) and other specimens from the Moss Landing Hill Site (CA-MNT-234) at the head of Monterey Bay. The archaeological materials from this site are curated by the Moss Landing Marine Laboratory of California State University, Moss Landing. Hildebrandt and Jones (1992, 2002; see also Jones and Hildebrandt 1995) have hypothesized that in earlier prehistoric times, this species had mainland rookeries from Monterey to the northern California coast, and Lyman (1989, 1991) has asserted that the species bred along the Oregon coast as well. Recent collaborative research by an inter-institutional team of zooarchaeologists, paleontological geochemists, and marine mammal ecologists has supported these claims through several independent lines of isotopic and age-sex mortality data (Newsome et al. 2007). Among the most pressing needs of such historical

Table 7.1. Bone Weights, Meat Weights, and Percent Meat Utility Indices for Body Segments of a Phocid and an Otariid.

	Bone Weight (grams)	% Skeleton	Meat Weight (grams)	Bone:Meat Ratio	% MUI
Phocid (Leopard Seal)					
Skull	3,822	12.5	6,650	1:1.7	10.0
Vertebrae/ribs	13,137	42.8	66,652	1:5.1	100.0
Scapula	1,104	3.6	11,006	1:10.0	16.5
Forelimb	2,322	7.6	1,810	1:.8	2.7
Pelvis/sacrum	2,465	8.1	5,608	1:2.3	8.4
Hind limb	1,960	6.4	4,122	1:2.1	6.2
Flippers	5,860	19.1	6,238	1:1.1	9.4
Total	30,670	100.0	102,086	1:3.3	N/A
Otariid (California sea lion)					
Skull	1,414	3.6	7,800	1:5.5	30.7
Vertebrae/ribs					
Cervicals	1,234	3.1	24,083	1:19.5	94.8
Thoracics	1,730	4.4	5,599	1:3.2	22.0
Lumbars	584	1.5	3,499	1:6.0	13.8
Ribs	29,058	73.4	25,402	1:.9	100.0
Subtotal vertebrae/ribs	32,606	82.4	58,583	1:1.8	-
Scapula	115	.3	7,575	1:65.9	28.6
Forelimb	1,051	2.7	4,004	1:3.8	13.7
Pelvis/sacrum	544	1.4	5,424	1:10.0	21.4
Hind limb	417	1.1	1,615	1:3.9	5.2
Flippers	3,449	8.7	804	1:.2	3.3
Total	39,593	100.0	85,805	1:2.2	N/A

ecological research is obtaining accurate data on age and sex classes represented in archaeofaunal samples, as these testify to human off-take tactics and their overall sustainability over time (Etnier 2002; Lyman 2003).

The CA-MNT-234 primary midden comprises the largest sample of the species between the Channel Islands and the Ozette site in Washington's Olympic Peninsula (Gifford-Gonzalez et al. 2005). The greater than 50 percent proportionate dominance of northern fur seals and low representation of terrestrial mammals in the primary midden, as well as patterns of artifact representation (Milliken et al. 1999), strongly suggest that this site is a specialized processing area, especially given its proximity (1.5 km) to a coeval large residential site, CA-MNT-229.

The site therefore offers special opportunities to explore the age/sex structure of the species, which would have been the highest-ranked prey species on the central California coast acquired by aboriginal hunters. Moreover, the assemblage permits assessment of human handling tactics, including dismemberment and transport, as the analytical program focused on the species as a whole and upon age/sex classes within it. Gifford-Gonzalez undertook total assemblage analysis of mammals and birds, with identification of all elements of the skeleton, including vertebrae, ribs, carpals, tarsals, metacarpals, metatarsals, and phalanges of pinnipeds, all of which on close inspection can be assigned to species.

The Moss Landing northern fur seal sample illustrates the scale and dimensions of differential transport decisions on an assemblage of different age and sex classes of the same pinniped species. Adult females of the species weigh 30 to 50 kg live weight, adult males range between 185 and 275 kg, and newborn pups weigh 4.5 to 5.5 kg (Gentry and Kooyman 1986). Arguing from first principles, one would assume that young-of-the-year could be transported whole to the processing site from where they were acquired, as could be females, especially if their viscera were removed near the acquisition site. On the other hand, it is expected that subadult and adult males aged approximately 7 to 15 years would present different challenges to human carriers and would more likely be selectively transported.

Table 7.2 presents summary data on the presence of different body segments, grouped according to a "template" derived from Aleut fur seal butchery practices (Scheffer 1948). It should be noted that the hind limb long bones of eared seals are enclosed within the overall trunk, with only the bones of the ankle and foot exposed as the hind flippers (Figure 7.1). Thus the femur, patella, tibia, and fibula are normally handled as part of the trunk, in contrast with the forelimb, in which the humerus and radius-ulna are outside the trunk.

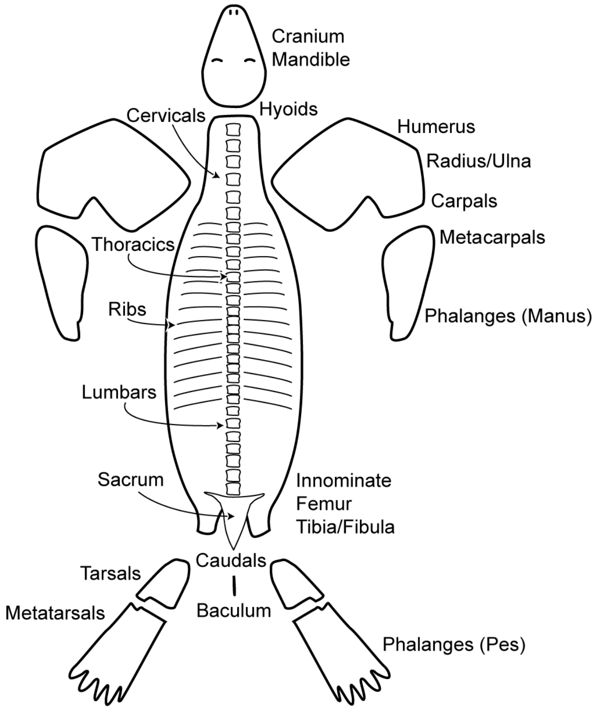


Figure 7.1. Diagram of butchery units of northern fur seal showing the osteological elements present in each: head, trunk, forelimb, fore and hind flippers.

In the CA-MNT-234 sample, young-of-the-year are represented by specimens from all body segments, approaching the natural proportions in the body (Table 7.2) despite the delicacy of their bones. This suggests that they entered the site whole and, despite being processed (as evidenced by human gnaw marks, cut marks, and thermal alteration), destructive taphonomic effects were minor. Juvenile females and adult females (Table 7.2) generally follow the same pattern but with some underrepresentation of the trunk and overrepresentation of the flippers (see "Discussion"). Young-of-the-year and female elements also occur in similar ratios of MNI to NISP,[1] reflecting similar human handling decisions, transport, and taphonomic effects.

By contrast, the larger subadult and adult males, three to four times the size of females, are represented by a very different pattern of element frequencies (Table 7.2), reflecting different processing and selective transport decisions and taphonomic effects. Bones of the head, both cranium and mandible, are overrepresented by 10 times in comparison with their natural occurrence in the body and in comparison with frequencies of females and young-of-the-year (Table 7.2).

This may seem counterintuitive, given the sizes of the animals and their heads, but their skulls would offer the brain for human consumption or hide curing (see "Discussion"), as well as tongue and cheek muscles, and are ranked relatively high in the otariid percent meat utility index (Savelle et al. 1996). The trunk is somewhat overrepresented relative to an otariid body as a whole or to the other age/sex classes (Table 7.2), but this overrepresentation is more striking if one notes that ribs account for most of this variance, being present in double the amount predicted from their frequencies in the otariid skeleton (38 percent versus 19 percent). It should be noted that to reduce double counting, rib NISP is based on counts of proximal fragments and not on dissociated shaft fragments. Otariid ribs

Table 7.2. Northern Fur Seal Body Segment Representation at CA-MNT-234 (Moss Landing Hill Site).

Aleut Butchery Segment	Elements in Segment	Body N	∑ NISP per Butchery Segment	Body %	MNT-234 YOY NISP	MNT-234 YOY SUM Segment	MNT-234 YOY %	MNT-234 YOY MNI/NISP	MNT-234 F ≥ 2 year NISP	MNT-234 F ≥ 2 year SUM Segment	MNT-234 F ≥ 2 year %	MNT-234 F ≥ 2 year MNI/NISP	MNT-234 M ≥ 2 year NISP	MNT-234 M ≥ 2 year SUM Segment	MNT-234 M ≥ 2 year %	MNT-234 M ≥ 2 year MNI/NISP
								.05				.03				.09
Head	Head ∑		3	1.9		24	4.0			87	6.3			21	24.1	
	Cranium	1			10		.0		50		3.6		10		11.5	
	Dentary	2	2	1.3	28		.0		37		2.7		11		12.6	
Trunk	Trunk ∑		68	42.8		248	41.0			331	24.0			44	50.6	
	Cervicals	7		4.4	32		5.3		74		5.4		1		.1	
	Thoracics	14		8.8	36		6.0		65		4.7		0		.0	
	Ribs	30		18.9	117		19.3		248		18.0		33		37.9	
	Lumbars	5		3.1	7		1.2		27		2.0		2		2.3	
	Sacrals	4		2.5	2		.3		11		.8		0		.0	
	Innominate	2		1.3	21		3.5		27		2.0		2		2.3	
	Femur	2		1.3	16		2.6		29		2.1		0		.0	
	Tibia	2		1.3	14		2.3		41		3.0		4		4.6	
	Fibula	2		1.3	3		.5		10		.8		2		2.3	
Foreleg	Foreleg ∑		8	5.0		73	12.1			114	8.3			9	10.3	
	Scapula	2		1.3	9		1.5		37		2.7		3		3.4	
	Humerus	2		1.3	37		6.1		25		1.8		3		3.4	
	Radius	2		1.3	14		2.3		25		1.8		1		1.1	
	Ulna	2		1.3	13		2.1		27		2.1		2		2.3	
Flippers	Flippers ∑		78	49.1		260	43.0			847	61.4			13	14.9	
	Carpals	16		10.1	40		6.6		16		1.2		2		2.3	
	Tarsals	14		8.8	22		3.6		52		3.8		3		3.4	
	Metacarpals	10		6.3	17		4.1		41		3.0		4		4.6	
	Metatarsals	10		6.3	18		3.0		11		.8		2		2.3	
	Phalanges	28		17.6	163		26.9		727		52.7		1		1.1	Site total
	Grand totals		159	100.0		605	100.0			1,379	100.0			87	100.0	2,071

Note: Presence of bone elements of body segments of three age/sex classes in comparison to representation in the northern fur seal body. Body segments are grouped according to Aleut fur seal butchery practices (Scheffer 1948) (Figure 1). Hind limb long bones of eared seals are enclosed within the trunk, with only the bones of the ankle and foot outside the trunk as hind flippers.

rank 100 percent on the percent meat utility index (Savelle et al. 1996). Thus the frequencies of male skull and rib elements are those one would predict to be selectively transported based on meat utility.

Another important fact can be gleaned from the ratio of MNI to NISP for males. At .09, this is two to three times that of females and young-of-the-year (Table 7.2). This means that relatively more individual males are represented by relatively fewer bone specimens. Applying the SBSMA meat weight conversions to the weights of their bones would totally obscure the fact that only 87 specimens from the larger males represent the acquisition of at least eight individuals.

The high representation of female flippers and male skulls in excess of those predicted raises another line of argument relevant to processes structuring the larger vertebrates' element frequencies (and hence bone weights) at sites. Although the focus of this paper is the bone:meat weight conversion, it should be noted that the SBSMA approach generally ignores the last 20 years' discussion of the role of fat in the diet of human foragers (De Nigris and Mengoni Goñalons 2005; Lupo 1998; Mulville and Outram 2005; Outram 2001; Speth 1983; Speth and Spielmann 1983). The sole exception is Glassow's (1993b:89) concluding discussion of shifts from shellfishing to fishing on Santa Cruz Island, which pointed out that marine mammals, despite their scanty representation in midden deposits, may have offset lows in starchy plant foods by adding fats to compensate for the lack of readily assimilated carbohydrates. However, later research on shifts in taxonomic frequencies in the Bight of California has tended to ignore this consideration, as well as transport decisions in larger vertebrates. To return to the case cited here, although low in muscle mass, pinniped flippers are rich in insulating fat and are considered a delicacy when roasted by groups preying regularly on eared seals (Kroeber and Barrett 1960; Scheffer 1948). Brains are rich in essential fatty acids, proteins, and fats, which are especially relevant to the nutritional health of developing fetuses, infants, and younger weaned children still developing neural tissues (Speth and Spielmann 1983).

CONTRASTIVE ZOOARCHAEOLOGICAL CASES: POINT ST. GEORGE AND SHELTER COVE

The potential ranges of error inherent in the SBSMA approach can be further evaluated by comparing otariid meat weight estimates from a site that is believed to be a butchery locality to those from a site that appears to be a residential base. We begin with the anatomical data generated for the California sea lion by Savelle et al. (1996:Table 1), which show the bone and meat weights for each major part of the body. If a complete skeleton were deposited in an archaeological site, the relative weights of the archaeological skeletal elements should be similar to that presented in Table 7.1, and the simple bone-to-meat weight ratio of 1:2.2 for otariids would produce an accurate meat weight estimate at the site. But, as demonstrated by the two cases below, the complete skeleton assumption required by the SBSMA is often not realized, creating high levels of error when the bone:meat weight conversions are made.

The samples come from two sites on California's north coast, CA-DNO-11 (curated at the University of California, Berkeley) and CA-HUM-182 (curated at the University of California, Davis). Table 7.3 presents the relative weights of the archaeofaunal remains from the two sites (first column) and how they differ from the actual Savelle et al. (1996) sea lion bone weights (second column). At Point St. George (CA-DNO-11), within an area of the site thought to be a butchery locus by Gould (1966; see also Hildebrandt 1981), some skeletal parts are underrepresented (for example, vertebrae and ribs, .51), while others are found in relative abundances much greater than in the actual animal (for example, hind limb—11.82 times greater). These correction factors are then multiplied by the corresponding meat weights for each skeletal part, producing an absolute meat weight estimate of 161,439.9 g, which is almost double the value of the natural animal.

The underrepresentation of vertebrae and ribs at CA-DNO-11 makes good sense, as they are the largest meat producers (high percent meat utility indices; Table 7.1) and were probably transported

Table 7.3. Estimated Otariid Meat Weights from a Butchery Locale and a Residential Site.

	% Archaeological Skeletal Parts by Weight	Difference from Otariid Skeleton		Meat Weight of Otariid Skeletal Parts		Meat Weight Estimate
CA-DNO-11 (Butchery)						
Skull	7.5	2.08	x	7,800	=	16,224.0
Vert/rib	42.0	.51	x	58,583	=	297,877.3
Scapula	2.0	6.67	x	7,575	=	50,525.2
Forelimb	21.0	7.78	x	4,004	=	31,151.1
Pelvis/sacrum	3.5	2.50	x	5,424	=	13,560.0
Hind limb	13.0	11.82	x	1,615	=	19,089.3
Flippers	11.0	1.26	x	804	=	1,013.0
Total	100.0					161,439.9
CA-HUM-182 (Residential)						
Skull	9.0	2.5	x	7,800	=	19,500.0
Vert/rib	6.0	.07	x	58,583	=	4,100.8
Scapula	.0	0	x	7,575	=	.0
Forelimb	12.0	4.44	x	4,004	=	17,777.8
Pelvis/sacrum	.0	.00	x	5,424	=	.0
Hind limb	6.0	5.45	x	1,615	=	8,801.8
Flippers	67.0	7.7	x	804	=	6,190.8
Total	100.0					56,371.2

to the residential site for cooking as a single unit (particularly the rack of ribs). The scapula, which has the highest meat yield on the body (1:65.9), was obviously filleted out at the butchery area, given the overrepresentation of scapula bone within this portion of the site.

A completely different pattern is revealed at CA-HUM-182, a residential site at Shelter Cove (Hildebrandt 1981; Levulett 1985) but is not entirely complementary with the findings at CA-DNO-11. Vertebrae and ribs remain underrepresented, which is unexpected, but the presence/absence of several other body parts seems to correspond with the more residential setting of this site. The scapula, for example, which was overrepresented at CA-DNO-11, is completely absent at CA-HUM-182, probably reflecting the off-site processing of this meat-rich element. Flipper bones, in contrast, are found at a rate that is almost eight times that of the normal skeleton. Although flippers have the lowest bone-to-meat ratio (1:.2) and percent meat utility index (3.3 percent) on the sea lion skeleton, as mentioned above, their high fat and culinary value among many groups living along the north coast of California no doubt contributed to their abundance in the deposits of CA-HUM-182.

The absence of meat-rich elements like the scapula, combined with the abundance of the less productive flipper bones, results in a meat weight estimate of 56,371.2 g for CA-HUM-182 (Table 7.3). This estimate is almost three times less than CA-DNO-11 and only 65.7 percent of the actual animal. Moreover, if we were to use a single bone-to-meat ratio for all sea lion bone found at CA-HUM-182, the absence of heavy elements like the scapula, combined with the abundant presence of lightweight elements like flipper bones, would make these differences even greater.

Although we do not completely understand the full range of butchering patterns exhibited at both sites, this analysis does show that large animals are represented differentially in the archaeological record, depending on the function of the site. This finding is quite similar to the differential treatment of male and female northern fur seals at the Moss Landing Hill site, based simply on their size. Both of these examples show that the processing of large mammals is complicated, and much more complicated than the processing of mussels. Whereas off-site processing of mussels makes little sense within 5 km of the coast (Bird and Bliege Bird 1997), this is not the case for sea lions. It follows, therefore, that the use of simple shell/bone-to-meat ratios to determine how much shellfish and marine mammal meat were actually consumed is a questionable enterprise. Unless the archaeological sample comes from a sea lion butchering area, which rarely occurs during most excavations, the absolute amount of sea lion meat will almost always be significantly underrepresented.

Because of these complicating factors, we should be asking a little less from the archaeological record. Rather than making estimates of absolute meat yields, we should be satisfied with calculating simple indices (for example, mussel shell versus sea lion bone) and seeing how these indices change over time. As discussed in more detail below, changes in these indices can tell us a great deal about prehistoric adaptive shifts without knowing whether people ate more kilograms of sea lion than mussel in a given amount of time. We admit, however, that indices based on NISP also suffer from differential butchering patterns based on animal size and site function, but like much of the archaeological record, these complicating factors tend to even out as the number and size of our samples increase.

DISCUSSION

Based on the above considerations, we feel there is no reason that the more widely used indices such as NISP and MNI, or ratios based upon them, cannot be used to pursue many of the questions emerging from Channel Islands research concerning human interactions with fauna. This section offers some examples of comparative analyses using NISP and related indices and explores the need for thorough and careful zooarchaeological analysis as the fundamental precondition of comparison.

Hildebrandt and Jones (2002) used NISP from an array of sites to test the hypothesis that highly ranked terrestrial breeding pinnipeds would be depleted early in time, followed by a broadening of the diet breadth, this signaled by increasing NISP of more elusive aquatic breeders such as sea otters and harbor seals. Tests of this hypothesis have stimulated a great deal of interesting research and debate (some ongoing between the authors of this paper), with no need for absolute meat weights. With regard to the Santa Barbara Channel region, Bernard (2004) has made excellent headway into the origins of pelagic fishing using a pelagic fish index based on NISP. Her work has major implications for the origins of high-quality oceangoing canoes, prestige fishing, and the emergence of socioeconomic complexity. We are also happy to note that Torbin Rick, a former practitioner of the SBSMA approach, recently published an outstanding monograph on the prehistory of San Miguel Island using relative frequency data to great advantage.

In terrestrial environments, a variety of researchers have used variations of the artiodactyl index—the relative proportions of artiodactyls to small, lower-ranked game, based again on NISP—to explore shifts in human hunting strategies over time (for example, Broughton 1999; Byers et al. 2005; Dean 2001; Hildebrandt and McGuire 2002; Stiner et al. 2000). This research has produced surprising results in California and the western Great Basin, as standard prey choice models would predict a trans-Holocene shift from large game to the use of a more diversified set of smaller prey, but the archaeological record shows the opposite trend in many places. These findings have led to debates about climate change, gender differentiated fitness, currency shifts from calories to prestige, and now costly signaling theory (see McGuire and Hildebrandt 2005; McGuire et al. 2007).

Certainly, there is a need to work with NISP just as circumspectly as with other indices because of the potential for varied effects of intertaxonomic variations in numbers of skeletal parts, differential transport of these parts, and divergent taphonomic histories of individual archaeofaunas in compared sets. These problems associated with the use of NISP (or MNI, for that matter) do not render it useless, however. NISP has the virtue of being as close to the actual count of identifiable specimens as one can get. It is precisely the work of zooarchaeological analysis to sort out which datasets can bear comparison and which cannot (Ugan 2005b), using a set of first principles and systematic analytic steps. These include inspection of element frequencies of various body segments within a given taxon or across taxa and experimental manipulation such as the MNI:NISP ratio as illustrated in the Gifford-Gonzalez case study above. These simple steps can go a long way to assessing whether one should proceed with a comparison, and how.

Finally, it is important for California zooarchaeologists to start identifying all elements that are identifiable instead of avoiding fragmentary or just plain difficult specimens, such as vertebrae, ribs, carpals, tarsals, metacarpals, metatarsals, and phalanges of closely related pinniped species (see Figure 7.2). Precisely because some age/sex classes may *only* be represented by such elements due to differential transport, these elements elucidate the transport histories of a taxon and assemblage. With the help of comparative specimens, it is possible to distinguish very closely related taxa, the exception being some but not all elements of northern and Guadalupe fur seals (*Arctocephalus townsendi)*. In the 1950s, it may have been acceptable to relegate such elements to "pinniped indeterminate" or other trash-basket categories, but it is no longer so. Likewise, it should be obvious from the Moss Landing example that "enhancing" sample size by assigning the same proportion of species represented by the more readily identifiable elements to unanalyzed "mammal indeterminate marine" (see Porcasi et al. 2000) is imprudent.

Figure 7.2. First metacarpal of male northern fur seal, *Callorhinus ursinus*, and male California sea lion, *Zalophus californianus*, showing morphological differences in proximal articulation (top) and dorsal views (bottom). (Photo: C. E. Hughes.)

To give a concrete case where such a total analysis strategy may refine our understanding of Channel Island archaeology, Kennett (2005) has noted the low representation of pinnipeds in many Middle-period residential sites, despite the logical prediction that this top-ranked resource should be present in greater numbers. One possible explanation is that a mid-Holocene climate perturbation reduced the rookeries on San Miguel Island, which did not itself have primary or secondary village sites until the Late period (Kennett 2005:128–153). Identifying all pinniped specimens in Middle-period Santa Rosa Island village archaeofaunas, to which San Miguel pinnipeds would have been transported, could elucidate this phenomenon, perhaps creating an alternative to the climatically conditioned model. It is possible that San Miguel's Point Bennett area did host multiple pinniped species' rookeries, as it does today, and that hunters from Santa Rosa villages butchered prey on San Miguel and drastically reduced the "bone load" before taking the meat back to their residential sites in boats. Based on our experience with other transported assemblages, a test of this hypothesis would entail looking for rib segments, flipper segments, and perhaps fragmentary cranial parts in the Santa Rosa residential archaeofaunal assemblages. If these elements are truly absent, then the climatic hypothesis is at least sustained.

CONCLUSIONS

We believe that the examples presented here convincingly demonstrate that intertaxonomic differences in processing, transport, and post-depositional preservation are significant, and these should rule out the use of one-step conversions of shell and bone weights to absolute meat weights for all species recovered in the archaeological record. We also believe that indices applied by zooarchaeologists in most other parts of the world, in combination with careful analysis of element frequencies, can be used to address research questions of interest to practitioners working in the Channel Islands region. While the use of relative frequency data does not produce estimates of the absolute amount of food consumed at a particular location, particularly when comparing taxonomically divergent species to one another (for example, mussels versus sea lions), it is the directionality of change over time and space that concerns us the most. If, for example, the diversity of prey species within an archaeological record increases over time, and this increase is due to the addition of low-ranking species (that is, those with low caloric return rates), then one could conclude that there was a broadening of the diet breadth due to the depletion of the higher-ranked species. This type of explanation, which is fully consistent with the behavioral ecological orientation of most Santa Barbara Channel archaeologists, does not require absolute meat weight estimates. In fact, the test implications of most models currently developed in the region would be assessed in a more straightforward manner if relative frequency data were used.

NOTE

1. MNI here is derived by a combination of two methods. First, a count was made of all unique ages derived by Etnier's (2002; see also Newsome et al. 2007) logistical growth curves, discarding all but one age estimate made on differing bone elements that fell together within those elements' error ranges. This age-specific count was augmented by the traditional most-numerous right or left symmetrical element (for example, left fully fused humeri) of specimens that could not be measured and hence aged using the Etnier method.

CHAPTER 8

Fragmentation, Identification, and Interpretation of Faunal Remains from Late Holocene Tecolote Canyon, Santa Barbara County, California

TORBEN C. RICK AND JON M. ERLANDSON

The Tecolote Canyon region of Santa Barbara County has a remarkable archaeological record spanning at least 9,000 years. For over a century, the canyon and the surrounding area have attracted the attention of archaeologists, including the early depredations of the Reverend Stephen Bowers, the more extensive and systematic research by David Banks Rogers (1929), and a series of cultural resource management projects over the last 25 years (DuBarton 1991; Erlandson 1988a; Erlandson, Rick, and Vellanoweth 2008; Kornfeld et al. 1980). These projects have resulted in an impressive assemblage of faunal remains, artifacts, and archaeological features—the latter including ceremonial dance floors, cemeteries, and sweat lodges (Erlandson, Rick, and Vellanoweth 2008; Rogers 1929). Despite this rich collection of materials, several taphonomic processes have hindered interpretations of the Tecolote archaeological record (Erlandson 1984; Erlandson and Rockwell 1987; Johnson 1989). As with many California mainland archaeological sites, bioturbation, looting, plowing, and oil, rail, highway, and other development projects have compromised the integrity of the Tecolote archaeological deposits, resulting in stratigraphic mixing, burning of many constituents, and a high degree of fragmentation.

In this paper, we present faunal data, including shellfish, fish, mammal, bird, and amphibian/reptile remains, from three of the canyon's archaeological sites excavated by WESTEC Services/ERCE archaeologists in the 1980s and by teams led by Erlandson and Vellanoweth in the 1990s (Figure 8.1). Our analysis of vertebrate and invertebrate faunal remains from CA-SBA-72, CA-SBA-73, and CA-SBA-1674 includes materials that date from about 2,300 to 400 years ago, an important time for a variety of social and cultural changes in Chumash society (Erlandson and Rick 2002; Gamble 2008). Here we focus on the major methodological obstacles associated with the Tecolote Canyon faunal assemblage. Using a fragmentation index that compares bone NISP to weight and shell MNI to weight, we compare the Tecolote Canyon data to assemblages from San Miguel Island of similar age. These data quantify the degree of preservation of the Tecolote assemblage, illustrating how the fragmentation of these materials may influence identification and interpretation of the faunal remains.

ENVIRONMENTAL AND CULTURAL CONTEXT

With a coastline trending east-west, the Santa Barbara Channel area has a Mediterranean climate, with cool wet winters and warm dry summers.

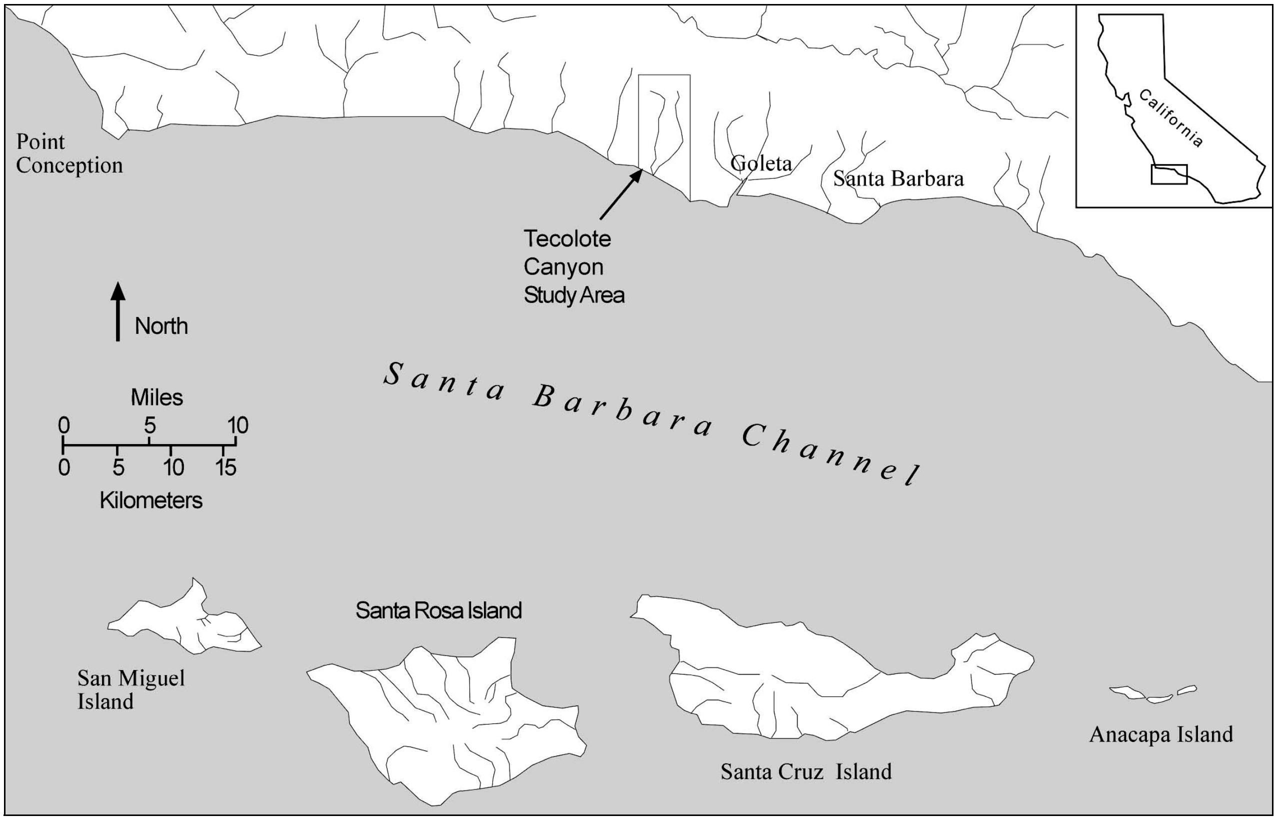


Figure 8.1. The Santa Barbara Channel region and Tecolote Canyon study area (adapted from Erlandson, Rick, and Vellanoweth 2008).

Terrestrial resources are diverse, influenced by differences in elevation, rainfall, aspect, landform, and bedrock, which create an array of microenvironments between the mountains and sea (Lantis et al. 1973:186). Streams, estuaries, and the open ocean are also important features of local ecosystems. Sandy, rocky, and muddy intertidal or near-shore communities, kelp forests, and pelagic or deep water zones foster particularly productive coastal habitats.

Tecolote Canyon is located about 50 km east of Point Conception and 43 km west of Rincon Point. The closest productive estuary is located at the Goleta Slough about 6 km or less to the east. Closer to Tecolote Canyon, the shoreline is flanked by steep sea cliffs up to 30 m high, broken by occasional coastal canyons with small freshwater or brackish marshes at their mouths. Sand or sandy cobble beaches flank much of the current shoreline near the canyon mouth, with just a few rocky outcrops supporting small populations of California mussels and other rocky shore shellfish. Just offshore, however, are abundant and highly productive kelp forests.

Archaeological research suggests that people used the diverse terrestrial and marine resources in the canyon for at least 9,000 years (Erlandson, Rick, and Vellanoweth 2008). Numerous archaeological sites in the Tecolote Canyon area have been dated to the early and middle Holocene, but the most intensive occupation occurred during the last 2,300 years, when the Chumash and their ancestors established a series of villages around the canyon mouth.

LATE HOLOCENE TECOLOTE SITES: CA-SBA-72, CA-SBA-73, AND CA-SBA-1674

Several archaeological sites at the mouth of Tecolote Canyon contain evidence of Chumash occupations during the late Holocene, from roughly 2,300 to 400 years ago. Three large sites (CA-SBA-71, CA-SBA-72, and CA-SBA-73) contain the remnants of several separate (but overlapping) village occupations, and a smaller site (CA-SBA-1674) nearby also contains the remnants of a late Holocene occupation (Erlandson, Rick, and Vellanoweth 2008). CA-SBA-71 and CA-SBA-72 were also occupied during the early or middle Holocene. Here we present data from three late Holocene sites located at the canyon mouth, including CA-SBA-72, CA-SBA-73, and CA-SBA-1674.

CA-SBA-72

CA-SBA-72 is a large and complex site with a long record of human occupation. Rogers (1929) worked extensively at CA-SBA-72 in the 1920s, providing much of the foundation for our understanding of the site. Knowledge of the structure, contents, and chronology of the site was expanded by excavations by UCSB archaeologists in 1979–1980 (Kornfeld et al. 1980), by a WESTEC/ERCE team in 1988 (Erlandson and Cooley 1988a), and by a Hutash Consultants team in 1997 (Erlandson, Rick, and Vellanoweth 2008). Several factors, including intensive farming prior to Rogers's work and heavy alteration by the construction of oil facilities beginning in the 1930s, have actively degraded the site. In recent decades, the site was also heavily disturbed by looters, vandals, and grave robbers.

Rogers estimated that CA-SBA-72 extended for about 180 m (600 feet) north to south and 90 m (300 feet) east to west. More recent fieldwork extended the northern site boundaries to the base of the fill slope for the Southern Pacific Railroad, some 700 feet from the beach. The late Holocene occupation of CA-SBA-72 is bracketed between about A.D. 50 and 1450 (1900 and 500 cal B.P.; Table 8.1). The radiocarbon chronology suggests that the northern site area (CA-SBA-72N) is generally older than the southern (CA-SBA-72S; see King 1980). However, the recovery of some later artifacts in the northern site area and earlier artifact types in the southern area suggests that people used and occupied much of CA-SBA-72 throughout the last 2,000 years.

CA-SBA-73

CA-SBA-73 is located just west of CA-SBA-72 and also contains northern and southern loci. The Reverend Stephen Bowers was likely the first to work at the site, in 1877 (Benson 1997; see Erlandson, Rick, and Vellanoweth 2008), followed by F. W. Putnam in 1908 (King 1980) and D. B. Rogers (1929) in the 1920s. More recently, archaeological teams from UCSB worked at CA-SBA-73 in 1979 (Kornfeld et al. 1980), 1981 (Moore et al. 1982), 1987 (Erlandson 1987), and 1988. Teams from WESTEC/ERCE and Hutash Consultants worked at the site in 1988 (Erlandson and Cooley 1988b) and in the 1990s (Erlandson, Rick, and Vellanoweth 2008), respectively.

Based on his field research, Rogers (1929) indicated that this large shell midden extended over 210 m (700 feet) north to south, from the beach to the railroad tracks, and was about 90 m (300 feet) wide. As with CA-SBA-72, Rogers divided the site into northern and southern sections, with a northern residential area on a slightly elevated knoll about 90 m (300 feet) long and 45 m (150 feet) wide, and two cemeteries south of the knoll. Rogers excavated 9 articulated burials and one reburial in the northern cemetery and 15 articulated burials in the southern cemetery. No radiocarbon dates are available for the two cemeteries, but King (1980) suggested they were used between A.D. 300 and 900, a proposition supported by two dates of ca. A.D. 800 for residential deposits in unit 11.

Eleven radiocarbon dates from CA-SBA-73 indicate an occupation spanning from approximately 40 B.C. to A.D. 1540. Similar to CA-SBA-72, the southern portion of CA-SBA-73 generally seems to be younger than the northern portion, but the available dates indicate several centuries of overlap in the occupation of the two loci. Six of the eight radiocarbon dates available from CA-SBA-72S have calibrated intercepts that fall between about A.D. 1000 and 1500, but two dates also suggest a somewhat earlier occupation, between about A.D. 600 and 1000. Three dates on shell from the CA-SBA-73N midden range from about 50 B.C. (2000 cal B.P.) to A.D. 850 (1100 cal B.P.) (Table 8.1).

CA-SBA-1674

Located west of CA-SBA-73, CA-SBA-1674 is a small shell midden (approximately 30 × 40 m in area), first recorded and excavated in 1979 by UCSB archaeologists (Kornfeld et al. 1980). There have long been questions about whether CA-SBA-1674 was a remnant of an intact archaeological site or a cluster of materials redeposited from CA-SBA-73. Despite extensive testing and consultation with experts in local geology and soils, this question has never been fully resolved (see Erlandson, Rick, and Vellanoweth 2008). Surface survey and test excavations at CA-SBA-1674 defined a small and shallow shell midden surrounded by a diffuse scatter of chipped stone tools to the north, south, and west, typical of many shell middens in the Santa Barbara Channel area. The small size of the site and the low density of the materials it contained suggested that it was occupied for a relatively brief time, perhaps during a single occupation. CA-SBA-1674 has evidence for massive historical disturbances to the west, north, and east of the site, and no intact cultural features (such as fire hearths and rock ovens) were found. Four radiocarbon dates from CA-SBA-1674 suggest at least two occupations spanning about 500 years (Table 8.1). Because all four dates from CA-SBA-1674 overlap with the chronology of CA-SBA-73S, it seems most likely that the archaeological materials at CA-SBA-1674 were redeposited from CA-SBA-73S during the restoration of the area after the abandonment of oil-related facilities (Erlandson, Rick, and Vellanoweth 2008).

TECOLOTE CANYON FAUNAL REMAINS

A large assemblage of faunal remains was recovered from the three archaeological sites. Because of the size of the assemblage, and the heavy disturbance of the lower Tecolote Canyon area, we focused on shellfish and vertebrate remains from a few key index units excavated at each site. These units were among the most productive of numerous test units excavated at each site, and their deposits were the least disturbed. Of our four analyzed samples from CA-SBA-72, two are from CA-SBA-72N (column sample 1 [25 × 25 cm, .075 m^3] and unit 2 [.5 × 1 m, .65 m^3]), while two others (unit 5 [.5 × 1 m, .8 m^3] and column sample 5 [25 × 25 cm, .013 m^3]) are from CA-SBA-72S. At CA-SBA-73, four index units, two in the northern site area (unit 22 [1 × 1 m, .6 m^3] and column sample 11 [25 × 25 cm, .063 m^3]) and two in the southern area (units 59 [1 × 1 m, 1.2 m^3] and 98-25 [1 × 1 m and 1.4 m^3]) were analyzed. Preservation of faunal remains at CA-SBA-1674 was relatively poor, with most specimens fragmented or burned. We analyzed the shellfish and vertebrate remains from unit 4 (1 x 1 m, .6 m^3) and column sample 4 (25 × 25 cm, .038 m^3). All analyzed faunal remains are from 1/8-inch screen residuals.

Because of the high degree of fragmentation and burning on much of the sample, our identification procedures were conservative, with many of the bones and shells identified only to general animal categories. Weights and NISP or total bone and tooth counts were recorded for all vertebrates (Lyman 2008; Reitz and Wing 1999). All shellfish were weighed, and MNI estimates were recorded based on the value of nonrepetitive elements—sided hinges for bivalves and the total count of spires or opercula for gastropods (see Erlandson, Rick, and Vellanoweth 2008). The materials reported here were analyzed by personnel from WESTEC/ERCE and the University of Oregon using comparative collections housed at the University of California, Santa Barbara, University of Oregon, Santa Barbara Museum of Natural History, California Academy of Sciences, and National Marine Mammal Laboratory in Seattle. The Tecolote Canyon collections are now curated by the Repository for Archaeological Collections, University of California, Santa Barbara.

Shellfish Remains from CA-SBA-72

A minimum of 3,872 individuals and at least 41 taxa were identified from over 28 kg of shell recovered from the CA-SBA-72 index units (Table 8.2). Pismo clam (*Tivela stulorum*) (about 35 percent by weight and 12 percent by MNI) is the most abundant taxon by weight in the two index units. California mussel is next (about 15 percent by weight and 22 percent by MNI), and littleneck clams (*Protothaca* spp.) comprise about 9.6 percent of the weight. Estuarine species, including *Chione* spp. (Venus clams; more than 4 percent by weight) and oyster and scallops (about 6 percent by weight each) are also present in

Table 8.1. Late Holocene Radiocarbon Dates from CA-SBA-72, CA-SBA-73, and CA-SBA-1674.

Site Area (CA-)	Lab Number	Dated Material	Provenience	Measured ^{14}C Age	Conventional ^{14}C Age	Calendar Age Range (cal B.P., 1δ)
SBA-72N	HCRL-11	Marine shell	Burial 2	1540 ± 70	1970 ± 70	1350 (1290) 1230
	UCR-1114	Marine shell	N150/E430: 90 cm	1710 ± 90	2140 ± 90	1560 (1470) 1340
	Beta-28031	Pismo clam	Unit 88-5: 140–160 cm	2060 ± 70	2490 ± 70	1950 (1870) 1790
SBA-72S	HCRL-9	Marine shell	Burial 5	740 ± 50	1160 ± 50	560 (530) 500
	UCR-1115	Marine shell	N25/E554: 60–70cm	780 ± 80	1210 ± 80	640 (550) 510
	Beta-140983	*Olivella* bead	N25/E554: 60–70 cm	840 ± 40	1280 ± 40	660 (630) 570
	HCRL-10a	Marine shell	Burial 5	970 ± 60	1400 ± 60	780 (710) 660
	UCR-1117	Marine shell	Burial 7: trench 4D	1060 ± 80	1490 ± 80	910 (790) 710
	HCRL-10	Marine shell	Burial 2	1080 ± 60	1510 ± 60	910 (830) 740
	HCRL-12	Marine shell	Burial 1	1200 ± 70	1600 ± 80	990 (920) 830
	UCR-1118	*Olivella* beads	Burial 1: trench 6B	1270 ± 80	1700 ± 80	1130 (1010) 930
SBA-73N	Beta-196354	Venus clam	Unit 11: 80–100 cm	1420 ± 40	1840 ± 40	1240 (1180) 1130
	Beta-196898	Venus clam	Unit 11: 20-40 cm	1470 ±70	1890 ± 70	1290 (1240) 1160
	Beta-8938	Marine shell	N200/E365: 40–50 cm	2090 ± 70	2520 ± 70	1990 (1900) 1820
SBA-73S	Beta-196355	*Mytilus* bead	Unit 60: 60–80 cm	670 ± 40	1020 ± 40	480 (450) 410
	Beta-140984	*Olivella* bead	N20/E330: 60–70 cm	820 ± 40	1260 ± 40	650 (620) 550
	Beta-19723	Turban shell	Test Unit 2: 0–20 cm	1000 ± 60	1430 ± 60	820 (730) 670
	Beta-144256	Littleneck clam	Trench 98-25: 65 cm	1080 ± 60	1500 ± 70	910 (820) 730
	Beta-196356	Venus clam	Unit 60: 60–80 cm	1120 ± 40	1540 ± 40	920 (890) 800
	Beta-8939	Marine shell	N20/E330: 110–120 cm	1210 ± 70	1640 ± 70	1040 (950) 900
	Beta-19724	Abalone shell	Test unit 2: 20–40 cm	1320 ± 60	1750 ± 60	1160 (1060) 980
	Beta-144255	Venus clam	Trench 98-25: 40 cm	1610 ± 100	2040 ±100	1480 (1340) 1270
SBA-1674	Beta-196359	*Olivella* cup bead	Unit 4: 20–40 cm	610 ± 40	1020 ± 40	480 (450) 410
	Beta-196358	Venus clam	Unit 4: 20–40 cm	730 ± 40	1140 ± 40	540 (520) 500
	Beta-196357	Venus clam	Unit 4: 0–20 cm	800 ± 40	1220 ± 40	630 (560) 540
	Beta-8296	Marine shell	N60/E240: 10–20 cm	1240 ± 60	1670 ± 60	1060 (970) 920

Note: Dates were calibrated with Calib 4.3 (Stuiver and Reimer 1993) using a ΔR of 225 ± 35 years. ^{13}C/^{12}C ratios were either determined by the ^{14}C labs or 430 years were added. Compiled from Erlandson, Rick, and Vellanoweth (2008).

the assemblage. These data demonstrate that people obtained shellfish from rocky intertidal habitats, sandy surf-swept beaches, and bays or estuaries. The estuarine shellfish may have been obtained from the Goleta Slough, possibly through trade with people living at the large Chumash towns that existed in the area.

The CA-SBA-72N (unit 2 and CS 1) materials date between about 2000 and 1000 cal B.P., while the CA-SBA-72S (unit/CS 5) materials date between about 1000 and 500 cal B.P. Despite their differing ages, these samples contain a similar suite of rocky intertidal, sandy beach, and estuarine shellfish. For example, Pismo clam and mussel shell comprise about 20 to 23 percent of the weight in CS 1 and about 10 to 16 percent in unit 2, with estuarine Venus clams contributing between 10 and 20 percent by weight and oyster making up about 7 to 13 percent. In the CA-SBA-72S samples, Pismo clam makes up roughly 33 to 40 percent of the shell weight, followed by mussels with about 14 to 16 percent and several estuarine taxa that each make up less than 10 percent of the shell.

Shellfish Remains from CA-SBA-73

Nearly 12 kg of shell from at least 980 individual shellfish and at least 33 different types of shellfish were identified in the four index unit collections (Table 8.2). Most of these (76 percent) came from unit 98-25, with the other three units accounting for about 24 percent of the total shellfish weight. Littleneck clams make up about 34 percent of the weight of the identified shell from the index units, followed by Venus clams (about 19 percent by weight), oysters and undifferentiated clams (each about 8 percent by weight), and Pismo clams (about

Table 8.2. Late Holocene Shellfish and Invertebrate Remains from SBA-72, SBA-73, and SBA-1674.

	SBA-72				SBA-73				SBA-1674			
	Weight (g)	% Weight	MNI	% MNI	Weight (g)	% Weight	MNI	% MNI	Weight (g)	% Weight	MNI	% MNI
Amphineura	96.45	.34	20	.52	29.92	.25	11	1.12	-	-	-	-
Astraea undosa	81.18	.28	10	.26	208.42	1.77	11	1.12	2.21	1.37	1	1.85
Barnacle undiff.	153.34	.54	25	.65	53.88	.46	17	1.73	.12	.07	1	1.85
Cardiidae	24.02	.08	7	.18	.91	.01	1	.10	-	-	-	-
Chamidae	13.23	.05	1	.03	-	-	-	-	-	-	-	-
Chione californiensis	39.24	.14	13	.34	77.98	.66	11	1.12	.13	.08	1	1.85
Chione undatella	1,137.64	3.98	58	1.50	1,615.96	13.69	116	11.84	16.58	10.25	4	7.41
Chione sp.	37.64	.13	9	.23	543.38	4.60	5	.51				
Clam undiff.	2648.01	9.26	25	.65	930.90	7.89	19	1.94	27.76	17.17	6	11.11
Crepidula sp.	35.15	.12	95	2.45	22.66	.19	60	6.12	.08	.05	1	1.85
Cryptochiton stelleri	11.96	.04	7	.18	.27	.00	1	.10	-	-	-	-
Cypraea spadica	14.66	.05	11	.28	6.34	.05	6	.61	-	-	-	-
Decapoda	1,019.14	3.56	24	.62	428.21	3.63	17	1.73	.32	.20	2	3.70
Donax gouldii	1.76	.01	2	.05	-	-	-	-	-	-	-	-
Donax sp.	.60	.00	1	.03	-	-	-	-	-	-	-	-
Fissurella volcano	2.03	.01	7	.18	-	-	-	-	-	-	-	-
Gastropoda	44.57	.16	55	1.42	66.68	.56	20	2.04	.84	.52	2	3.70
Haliotis rufescens	6.43	.02	4	.10	39.02	.33	2	.20	-	-	-	-
Haliotis spp.	396.79	1.39	17	.44	81.20	.69	11	1.12	3.85	2.38	4	7.41
Hinnites giganteus	45.74	.16	5	.13	48.79	.41	10	1.02	-	-	-	-
Ischnochiton conspicuous	61.64	.22	12	.31	40.84	.35	11	1.12	.19	.12	2	3.70
Limpet undiff.	1.75	.01	13	.34	2.21	.02	11	1.12	-	-	-	-
Megathura crenulata	56.69	.20	12	.31	4.54	.04	6	.61	-	-	-	-
Mitra idae	7.27	.03	2	.05	-	-	-	-	-	-	-	-
Mytilus californianus	4,162.67	14.55	844	21.80	494.56	4.19	81	8.27	14.69	9.09	4	7.41
Nacre undiff.	16.48	.06	1	.03	-	-	-	-	-	-	-	-
Nassiarus sp.	.18	.00	1	.03	-	-	-	-	-	-	-	-
Norrisia norrissii	34.73	.12	4	.10	10.74	.09	6	.61	-	-	-	-
Ostrea lurida	1,693.79	5.92	113	2.92	1,029.25	8.72	53	5.41	24.94	15.42	6	11.11
Oyster undiff.	3.74	.01	1	.03	-	-	-	-	-	-	-	-
Pectinidae	1,657.20	5.79	740	19.11	393.22	3.33	127	12.96	.03	.02	2	3.70
Pododesmus sp.	-	-	-	-	1.32	.01	2	.20	-	-	-	-
Polinices lewisii	7.90	.03	1	.03	2.24	.02	1	.10	-	-	-	-
Polinices spp.	2.88	.01	1	.03	-	-	-	-	-	-	-	-
Pollicipes polymerus	34.69	.12	19	.49	6.03	.05	10	1.02	.28	.17	3	5.56
Protothaca laciniata	-	-	-	-	14.76	.13	3	.31	-	-	-	-
Protothaca staminea	2,731.54	9.55	214	5.53	4,000.15	33.88	217	22.14	30.53	18.88	8	14.81
Psammobiidae	44.76	.16	19	.49	25.36	.21	6	.61	.57	.35	1	1.85
Sanguinolaria nuttallii	42.73	.15	20	.52	13.46	.11	11	1.12	-	-	-	-
Saxidomus nuttalli	242.75	.85	19	.49	433.49	3.67	15	1.53	1.28	.79	1	1.85
Septifer bifurcatus	826.02	2.89	920	23.76	38.58	.33	36	3.67	.04	.02	1	1.85
Serpulorbis squamigerus	35.57	.12	12	.31	15.67	.13	8	.82	-	-	-	-
Siliqua patula	.15	.00	1	.03	-	-	-	-	-	-	-	-
Strongylocentrotus sp.	70.06	.24	15	.39	35.24	0.30	12	1.22	.04	.02	1	1.85
Tagelus californianus	7.34	.03	6	.15	-	-	-	-	-	-	-	-
Tegula spp.	121.75	.43	14	.36	61.26	0.52	8	.82	-	-	-	-
Tivela stultorum	10,054.57	35.15	461	11.91	643.10	5.45	37	3.78	27.06	16.74	3	5.56
Trachycardium quadragenarium	4.46	.02	3	.08	0.38	.00	1	.10	-	-	-	-
Trivia californiana	.26	.00	2	.05	-	-	-	-	-	-	-	-
Undiff. shell	873.85	3.05	-	-	384.75	3.26	-	-	10.15	6.28	-	-
Total	28,606.99	100.00	3,872	100.00	11,805.67	100.00	980	100.00	161.69	100.00	54	100.00

Note: All weights are in grams and all materials are from 1/8-inch residuals. Data compiled from Erlandson, Rick, and Vellanoweth 2008.

5 percent by weight). Surprisingly, California mussels contributed only about 4 percent of the shell weight.

As with CA-SBA-72, the types of shellfish taxa identified in the four index unit collections are similar. For example, littleneck clam is the dominant shell type in CS 11 (25 percent by weight), unit 59 (27 percent by weight), and unit 98-25 (36 percent by weight). Venus clams are also relatively common, making up between 14 and 20 percent of the weight of shell from each unit. California mussel contributes about 13 percent of the weight of shell from unit 11 but only about 3 to 6 percent in units 98-25 and 59. In unit 22, shellfish remains were relatively poorly preserved, with only about eight shellfish types identified, 55 percent (by weight) of which are from undifferentiated clams. Of the eight shellfish types identified in collections from unit 22, Venus, Pismo, and littleneck clams are all relatively abundant (about 8 to 9 percent by weight). Collectively, the data from the four index units suggest that the shellfish in the northern and southern site areas are comparable, including rocky intertidal, estuary, and sandy beach taxa. The CA-SBA-73 shellfish assemblage is also similar to CA-SBA-72, demonstrating that people relied on shellfish from intertidal bay, estuary, rocky shore, and surf-swept sandy beach habitats.

Shellfish from CA-SBA-1674

In contrast to the relatively large samples from CA-SBA-72 and CA-SBA-73, only 161 g and a minimum of 54 individual shellfish were recovered from unit 4 and column sample 4 at CA-SBA-1674 (Table 8.2). Nineteen marine taxa were identified, but the assemblage is dominated by littleneck clams (18.9 percent by weight), undifferentiated clams (17.2 percent by weight), Pismo clams (16.7 percent by weight), oysters (15.4 percent by weight), Venus clams (10.3 percent by weight), and California mussels (9.1 percent by weight). This suite of shellfish remains from CA-SBA-1674 is generally similar to that of CA-SBA-72 and CA-SBA-73. These data suggest that shellfish were gathered in bay or estuary habitats, rocky intertidal areas, and surf-swept sandy beaches.

Vertebrate Remains from CA-SBA-72

Despite fairly high fragmentation and burning, a variety of fish, mammal, and reptile/amphibian bones were identified in the collection. Fish are the most abundant vertebrate category identified in the CA-SBA-72 samples, including at least 19 teleosts and 10 elasmobranchs in the three index unit collections (Table 8.3). The most common taxa by NISP are sardines or anchovies (clupeids; 47 percent), perch (16 percent of NISP), mackerels (10 percent of NISP), rockfish (9 percent of NISP), labrids (4 percent of NISP), and croakers (3 percent of NISP) (see also Johnson 1980). Making up less than 1 percent (NISP) of the assemblage are the remains of barracuda, yellowtail, and possible swordfish beak fragments. Elasmobranch remains, including shovelnose guitarfish, bat rays, and soupfin sharks, are also found in limited numbers (less than 1 to 2 percent of NISP). These data demonstrate that people who occupied CA-SBA-72 fished in bays or estuaries, rocky shores or shallow reefs, kelp beds, and surf-swept sandy beaches, and to a lesser extent offshore in boats. Although numerous shell fishhook fragments were found at CA-SBA-72, the fish represented in the samples suggest that people also used nets, spears, and harpoons.

A variety of mammals, birds, and reptiles/amphibians was also identified in the CA-SBA-72 assemblage (Table 8.4). About 25 percent of the bones by NISP were identifiable to at least general faunal categories, including birds such as cormorants, gulls, and murres (3 percent of total NISP), undifferentiated reptiles or amphibians (2 percent of NISP), deer (1 percent of NISP), dog (less than 1 percent of NISP), Guadalupe fur seals (less than 1 percent of NISP), and other marine and land mammals. Most of the nonfish remains are composed of undifferentiated sea mammal bones (44 percent), followed by large and medium mammals (18 and 19 percent of NISP, respectively) and small fauna (about 8 percent). Lawson et al. (1980) reported similar data from CA-SBA-72, with an assemblage dominated by sea mammals followed by large, medium, and small mammal remains.

The nonfish vertebrate remains from CA-SBA-72 suggest that people actively hunted or scavenged

Table 8.3. Late Holocene Fish Remains from SBA-72, SBA-73, and SBA-1674.

	SBA-72				**SBA-73**				**SBA-1674**			
	Weight (g)	**% Weight**	**NISP**	**% NISP**	**Weight (g)**	**% Weight**	**NISP**	**% NISP**	**Weight (g)**	**% Weight**	**NISP**	**% NISP**
Teleost												
Atherinidae (silversides)	.28	.05	13	.09	.75	.42	28	.56	-	-	-	-
Clinidae (kelpfish)	-	-	-	-	.36	.20	12	.24	-	-	-	-
Clupeidae (herring, sardine)	6.44	1.23	580	3.98	34.45	19.13	3,197	64.20	.57	23.65	6	30.00
Cottidae (sculpin)	.01	.00	1	.01	.28	.16	5	.10				
Embiotocidae (surfperch)	5.95	1.13	191	1.31	13.56	7.53	398	7.99	.17	7.05	2	10.00
Heterostichus rostratus (giant kelpfish)	.06	.01	1	.01	-	-	-	-	-	-	-	-
Hexagrammidae (greenling)	.03	.01	2	.01	.08	.04	5	.10	-	-	-	-
Labridae (senorita or wrasse)	.81	.15	48	.33	3.55	1.97	287	5.76	-	-	-	-
Mackerel undiff.	3.96	.75	125	.86	24.16	13.41	543	10.90	.86	35.68	7	35.00
Merluccius productus (Pacific hake)	.15	.03	1	.01	-	-	-	-	-	-	-	-
Mola mola (ocean sunfish)	-	-	-	-	1.81	1.00	3	.06	-	-	-	-
Ophiodon elongatus (lingcod)	-	-	-	-	.18	.10	1	.02	-	-	-	-
Paralabrax clathratus (kelp bass)	-	-	-	-	.10	.06	1	.02	-	-	-	-
Paralichthys californicus (California halibut)	1.20	.23	1	.01	1.22	.68	2	.04	-	-	-	-
Pleuronectiformes (flatfishes)	.12	.02	2	.01	.01	.01	1	.02	-	-	-	-
Porichthys sp. (midshipman)	.19	.04	6	.04	.42	.23	6	.12	-	-	-	-
Sarda chiliensis (Pacific bonito)	.21	.04	1	.01	3.26	1.81	10	.20	-	-	-	-
Sciaenidae (croaker)	.53	.10	34	.23	2.29	1.27	109	2.19	-	-	-	-
Scomber japonicus (chub mackerel)	.03	.01	1	.01	-	-	-	-	-	-	-	-
Scombridae (mackerel, tuna)	8.64	1.64	23	.16	7.47	4.15	18	.36	-	-	-	-
Sebastes sp. (rockfish)	7.84	1.49	105	.72	13.39	7.43	204	4.10	.15	6.22	1	5.00
Semicossyphus pulcher (California sheephead)	7.46	1.42	19	.13	13.69	7.60	35	.70	.62	25.73	3	15.00
Seriola lalandi (yellowtail)	13.64	2.60	8	.05	25.84	14.35	17	.34	-	-	-	-
Sphyraena argentea (barracuda)	6.02	1.15	12	.08	13.35	7.41	27	.54	-	-	-	-
Thunnus alalunga (albacore)	-	-	-	-	2.72	1.51	4	.08	-	-	-	-
Xiphias gladius (swordfish)	2.17	.41	6	.04	-	-	-	-	-	-	-	-
Teleost undifferentiated	440.98	83.94	13,201	90.58	1,167.91	-	34,722	-	10.25	-	169	-
Subtotal	506.72	96.45	13,035.77	89.45	1,330.88	-	39,638	-	12.62	-	188	940.00
Elasmobranch												
Batoidea (ray)	.05	.01	2	.01	-	-	-	-	-	-	-	-
Carcharinidae (requium sharks)	.47	.09	1	.01	9.11	5.06	15	.30	-	-	-	-
Galeorhinus galeus (soupfin shark)	.03	.01	2	.01	3.84	2.13	7	.14	-	-	-	-
Lamma ditropis (salmon shark)	.39	.07	1	.01	.22	.12	2	.04	-	-	-	-
Myliobatis californica (bat ray)	.55	.10	8	.05	3.06	1.70	22	.44	.04	1.66	1	5.00

Table 8.3. (cont.)

	SBA-72				SBA-73				SBA-1674			
	Weight (g)	% Weight	NISP	% NISP	Weight (g)	% Weight	NISP	% NISP	Weight (g)	% Weight	NISP	% NISP
Platyrhinoides triseriata (California thornback)	.11	.02	3	.02	.03	.02	3	.06	-	-	-	-
Prionace glauca (blue shark)	-	-	-	-	.16	.09	1	.02	-	-	-	-
Rajidae (thorn or skate)	.02	.00	1	.01	-	-	-	-	-	-	-	-
Rhinobatidae (shovelnose)	.08	.02	4	.03	-	-	-	-	-	-	-	-
Rhinobatos productus (shovelnose guitarfish)	1.13	.22	11	.08	.48	.27	8	.16	-	-	-	-
Squatina californica (angel shark)	.76	.14	4	.03	.18	.10	8	.16	-	-	-	-
Stingray	.01	.00	1	.01	-	-	-	-	-	-	-	-
Shark undiff.	.47	.09	13	.09	-	-	-	-	-	-	-	-
Triakididae (smoothhounds)	2.33	.44	6	.04	.08	.04	1	.02	-	-	-	-
Elasmobranch undiff.	12.24	2.33	135	.93	8.08	-	108	-	.37	-	2	-
Subtotal	18.64	3.55	192	1.32	25.21	-	172	-	.41	-	3	-
Total	525.36	100.00	14,574	100.00	1,356.09	-	39,810	-	13.03	-	191	-

Note: Percentages are based on specimens identified to family, genus, and species.

animals in a variety of habitats. This activity includes hunting, scavenging, or trading for deer and other land mammals, as well as sea mammals, including Guadalupe fur seals. The people of CA-SBA-72 also appear to have kept domesticated dogs for a variety of purposes, including hunting, security, and companionship. Although much of the sample appears to be cultural in origin, some of the bones, especially rodent, small fauna, and reptile or amphibian remains, may have been deposited naturally.

Vertebrate Remains from CA-SBA-73

Fish, mammal, bird, and reptile or amphibian bones are also relatively common in the four index unit collections from CA-SBA-73. Marine fishes are the most abundant vertebrates at CA-SBA-73, with 21 teleost and seven elasmobranch taxa identified from roughly 1.4 kg and nearly 40,000 bones (Table 8.3). Similar to the shellfish remains, most (77 percent of the NISP) of the fish bones are from unit 98-25. Clupeids were the most abundant fish taxon by NISP (64 percent), but mackerels (11 percent of NISP), surfperch (8 percent of NISP), labrids (6 percent of NISP), rockfish (4 percent of NISP), and croakers (2 percent of NISP) are also relatively common. Giant ocean sunfish, bonito and albacore tunas, yellowtail, and barracuda were also identified but generally constitute less than 1 percent of the NISP. Elasmobranchs, such as bat ray, blue shark, salmon shark, angel shark, and soupfin shark, were also found in small numbers (less than 1 percent of the NISP).

The fish remains are also relatively similar among the index unit collections, but the small size of the CS 11 and unit 22 samples from the northern site area make direct comparison to the fish remains from the southern site area (units 59 and 98-25) difficult. John Johnson (1980:219) also reported a small sample (21 g) of fish remains from CA-SBA-73N, including roughly 24 types of fishes (e.g., white croaker, mackerel, yellowtail, bonito, basking shark, bat ray, soupfin shark, and clupeids). Collectively, the samples from CA-SBA-73 suggest that people fished in kelp forest, rocky reef, sandy beach, bay and estuary, and offshore habitats. The types of fishes recovered suggest that people also used a variety of technologies, including hook and line, harpoons, and nets.

A number of other vertebrates were also identified in the CA-SBA-73 collections, including birds, marine mammals, and land mammals (Table 8.4). Most of these (64 percent of NISP) were found in

Table 8.4. Late Holocene Nonfish Vertebrate Remains from SBA-72, SBA-73, and SBA-1674.

	SBA-72				SBA-73				SBA-1674			
	Weight (g)	% Weight	NISP	% NISP	Weight (g)	% Weight	NISP	% NISP	Weight (g)	% Weight	NISP	% NISP
Artiodactyl	21.58	.45	9	.08	12.06	.50	2	.03	-	-	-	-
Odocoileus spp.	260.47	5.49	129	1.10	11.75	.48	11	.16	-	-	-	-
Canis spp.	28.77	.61	5	.04	-	-	-	-	-	-	-	-
Lepus spp.	3.98	.08	13	.11	1.63	.07	7	.10	-	-	-	-
Procyon lotor	1.94	.04	1	.01	-	-	-	-	-	-	-	-
Rodent	7.08	.15	79	.67	7.78	.32	120	1.74	-	-	-	-
Sea mammal	1,930.53	40.68	5,201	44.23	1,056.18	43.40	2,905	42.07	15.51	26.08	24	13.56
Pinniped	173.50	3.66	243	2.07	111.95	4.60	134	1.94	2.11	3.55	2	1.13
Otariid	426.66	8.99	149	1.27	133.36	5.48	56	.81	1.03	1.73	2	1.13
Phocid	-	-	-	-	.62	.03	1	.01	-	-	-	-
Arctocephalus townsendi	237.37	5.00	30	.26	56.84	2.34	8	.12	-	-	-	-
Callorhinus ursinus	6.31	.13	2	.02	-	-	-	-	-	-	-	-
Zalophus californianus	2.69	.06	1	.01	-	-	-	-	-	-	-	-
Phoca vitulina	18.09	.38	1	.01	-	-	-	-	-	-	-	-
Enhydra lutris	.66	.01	2	.02	-	-	-	-	-	-	-	-
Cetacean	29.76	.63	3	.03	25.24	1.04	3	.04	-	-	-	-
Large mammal	1,163.87	24.53	2,160	18.37	804.82	33.07	1,850	26.79	32.61	54.84	72	40.68
Medium mammal	330.54	6.97	2,255	19.18	160.11	6.58	1,112	16.10	4.94	8.31	31	17.51
Undiff. mammal	2.00	.04	5	.04	10.52	.43	3	.04	-	-	-	-
Rodent	-	-	-	-	-	-	-	-	.97	1.63	7	3.95
Reptile/amphibian	10.90	.23	222	1.89	-	-	-	-	.17	0.29	2	1.13
Turtle	5.54	.12	15	.13	-	-	-	-	-	-	-	-
Bird	29.92	.63	275	2.34	15.72	.65	174	2.52	-	-	-	-
Gavia spp.	-	-	-	-	.59	.02	1	.01	-	-	-	-
Larus spp.	.67	.01	1	.01	.61	.03	1	.01	-	-	-	-
Phalacrocorax spp.	4.44	.09	4	.03	-	-	-	-	-	-	-	-
Podiceps spp.	-	-	-	-	.42	.02	2	.03	-	-	-	-
Tytonidae	-	-	-	-	.58	.02	2	.03	-	-	-	-
Uria aalge	.21	.00	1	.01	-	-	-	-	-	-	-	-
Reptile/amphibian	-	-	-	-	1.77	.07	54	.78	-	-	-	-
Small fauna	47.79	1.01	952	8.10	21.29	.87	459	6.65	2.12	3.57	37	20.90
Undiff. tooth	14.81	-	135	-	.22	-	6	-	-	-	-	-
Undiff. bone	2,512.85	-	34,434	-	1,142.27	-	22,230	-	50.13	-	741	-
Total	7,272.93	-	46,327	-	3,576.33	-	29,141	-	109.59	-	918	-

Note: All weights are in grams and all materials are from 1/8-inch residuals. Data compiled from Erlandson et al. 2007.

unit 98-25 and were identifiable only to general animal categories (mammal, bird, etc.), although a few bones were identified to family, genus, or species. Marine mammal remains, including Guadalupe fur seal bones, eared seal bones, a true seal bone, and three cetacean bones, are found in small numbers (less than 1 percent of the nonfish vertebrate assemblages). Small amounts of deer, rabbit, and rodent bones, and numerous undifferentiated large, medium, and small mammal bones, were also identified. Bird bones, including the remains of a loon, gull, grebe, and owl, were also recovered. Reptile or amphibian bones are represented by 54 unidentified elements (less than 5 percent of the total nonfish vertebrate assemblage). Clearly, the Chumash people of CA-SBA-73 captured and processed a variety of land and sea mammals, birds, and other animals.

Vertebrate Remains from CA-SBA-1674

CA-SBA-1674 produced a much smaller assemblage of faunal remains than the other two sites, including just 191 fish bones from unit/CS 4 (Table 8.3). Among the identified specimens, mackerel (35 percent of NISP) and clupeid (30 percent of NISP) bones are most abundant, followed by California sheephead (15 percent of NISP), surfperch (10 percent of NISP), a rockfish (5 percent of NISP), and a bat ray (5 percent of NISP). These data are generally consistent with a small sample of fish remains analyzed by Johnson (1980:221), which included small amounts of clupeid, Pacific bonito, mackerel, kelp or sand bass, perch, and rockfish remains. The identified taxa could have been obtained from the surf zone, rocky shore, kelp forest, bays and estuaries, and offshore waters. Similar to those from CA-SBA-72 and CA-SBA-73, the fishes from CA-SBA-1674 could have been caught with a variety of technologies, including hooks and lines, nets, and spears.

Of the 918 fragments of other nonfish vertebrate remains recovered (Table 8.4), large and medium mammals (such as deer and dog) are most abundant (41 percent and 18 percent of NISP, respectively). Eared seal (sea lions and fur seals), undifferentiated pinnipeds, and sea mammal remains are also fairly abundant, comprising 23 percent of the sample. Rodents and small fauna are also present, but some of these may be of natural origin. Only two reptile or amphibian bones were identified. These remains are generally consistent with the materials reported for CA-SBA-72 and CA-SBA-73.

TAPHONOMY AND PRESERVATION OF THE TECOLOTE FAUNAL REMAINS

Despite the fragmentation and burning of the Tecolote faunal assemblage, a wide variety of invertebrate and vertebrate taxa were identified from the three archaeological sites. To quantify the potential biases created by the fragmentation of bone and shell, we created a fragmentation index that estimates the average weight/size of vertebrate remains, using a simple measure that entails dividing the total weight of specimens by the total NISP (see Lyman 2008; Reitz and Wing 1999:200; Zeder and Arter 1996). In this case, higher average specimen weights are a general approximation of lower fragmentation, and lower average specimen weights are an estimate of higher fragmentation. To provide an estimate of shellfish preservation, we divided the total weight by the total MNI for each of the major taxa. This is a measure of nonrepetitive elements used to calculate MNI, which serve as a general estimate of the total shellfish count.

These data are plotted in Figures 2–4 and compared to three comparably aged late-Holocene assemblages from San Miguel Island. These include CA-SMI-163, a Late-period and historic village site; CA-SMI-468, a late Middle- and Transitional-period site; and CA-SMI-481, a late Middle-period site (Rick 2007). Together, these represent some of the few late-Holocene northern Channel Island sites that have had detailed and relatively comprehensive data reported for sizable shellfish and vertebrate assemblages.

Archaeologists working on the Channel Islands and mainland coast of southern California have long contrasted the archaeological record of the two areas, noting a high degree of archaeological integrity and preservation on the islands and the opposite on the mainland. These assertions are generally based on qualitative observations by various researchers. The average specimen weight/size data from the Tecolote and island assemblages provide general quantitative confirmation of this trend, especially for vertebrate remains, but shellfish remains do not. For fish, average specimen sizes range from .09 to .13 g for the three San Miguel sites, while the values from the three Tecolote sites range from .03 to .07 g (Figure 8.2). The average specimen weight/sizes for the nonfish vertebrate remains range from .49 to 2.4 g on San Miguel Island to only .12 to .16 g on the mainland (Figure 8.3).

Shellfish presented a different variable, with the ratio of weight to MNI generally higher at CA-SBA-72 and CA-SBA-73 than at any of the island sites (Figure 8.4). This pattern is probably due to the relative abundance of large, thick, and hard-shelled Pismo, Venus, and littleneck clams in the Tecolote samples and the dearth or absence of these species in the San Miguel Island sites. These and several other mainland mollusk species have prominent hinges, spires, or other shell parts used to determine MNI that generally preserve well even in mainland sites. This trend is also somewhat

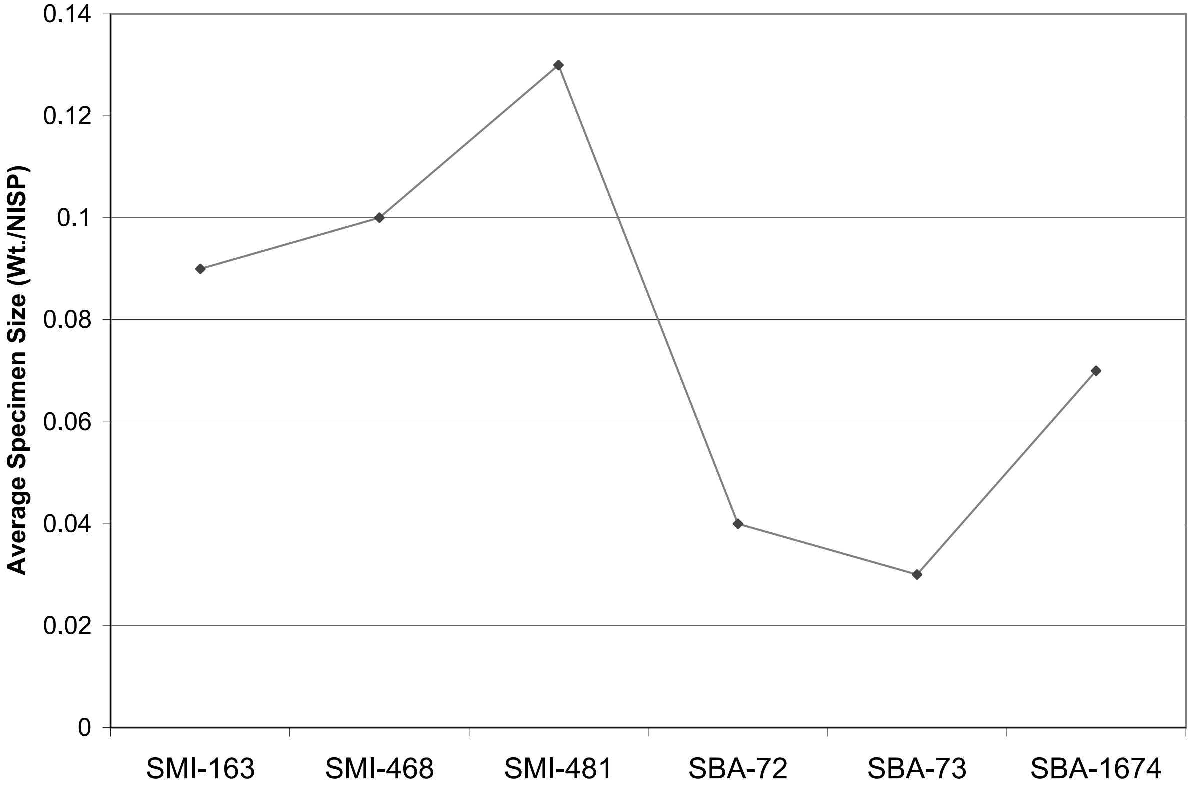


Figure 8.2. Fragmentation index for fish remains from Tecolote Canyon and San Miguel Island assemblages. Larger specimen sizes are assumed to represent lower fragmentation.

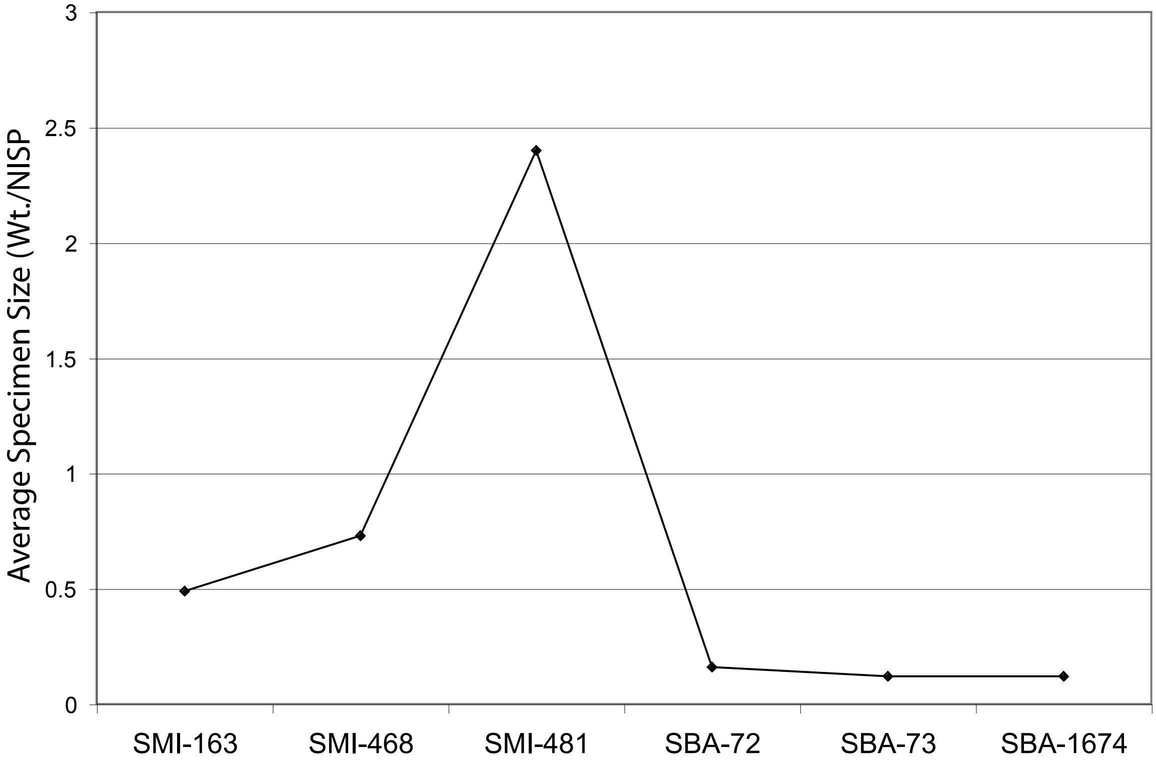


Figure 8.3. Fragmentation index for nonfish vertebrate remains from Tecolote Canyon and San Miguel Island assemblages. Larger specimen sizes are assumed to represent lower fragmentation.

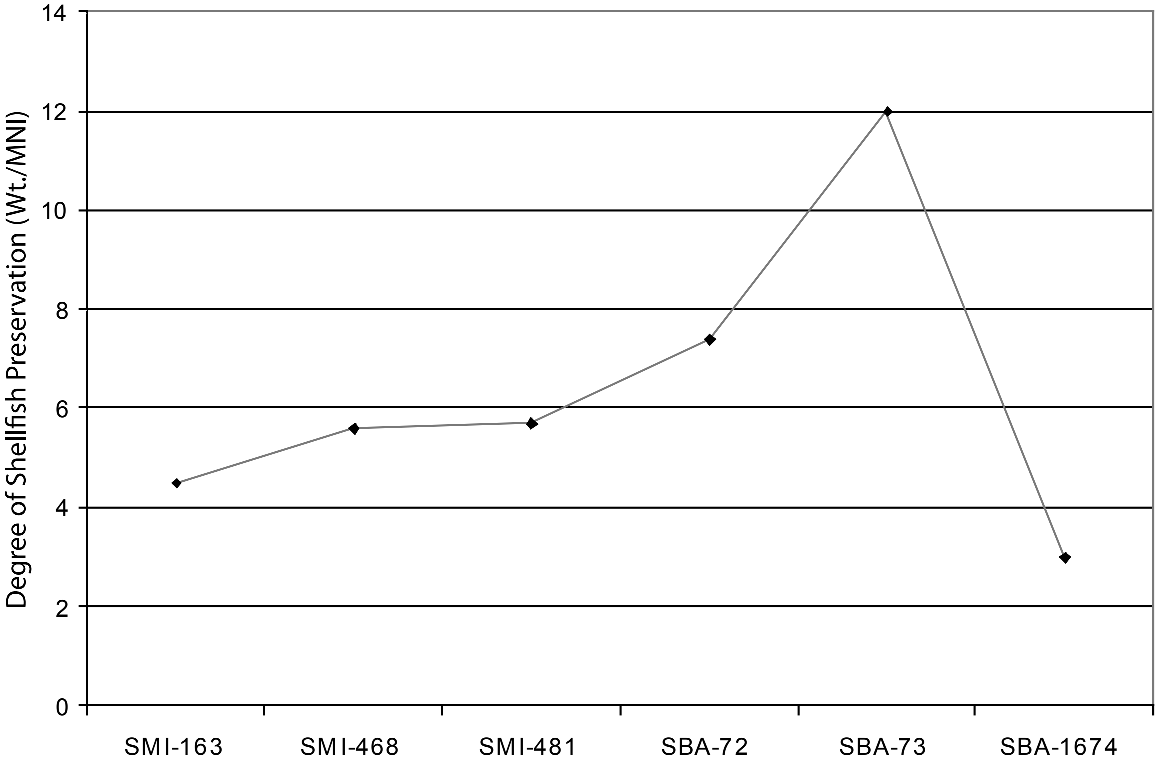


Figure 8.4. Relative preservation of shellfish remains from Tecolote Canyon and San Miguel Island assemblages as measured by weight/MNI. Larger values are assumed to represent lower fragmentation.

misleading because nearly 3,000 whole California mussel shells were measured from the three San Miguel Island sites (Rick 2007), while there were virtually no complete mussel shells found in any of the late Holocene Tecolote Canyon sites. These data suggest that the Tecolote vertebrate faunal assemblage was more fragmented than similarly aged assemblages from San Miguel Island but that there is variability in this trend, especially in the case of shellfish.

To investigate potential biases in the identification process, we also divided the total NISP of bones and weight of shellfish identified to family, genus, or species by the total number of bones or weight of shellfish from that class. This percentage provides an estimate of how many bones or shells were actually well preserved enough for more precise taxonomic identification. These data demonstrate that relatively small percentages of shellfish from either mainland or island contexts were classified as undifferentiated shell, with island sites over 99 percent (by weight), whereas the mainland sites were between about 93 and 96 percent (by weight) identified to lower taxonomic categories (Figure 8.5). For fish remains, again the island samples generally have a higher percentage of bones identified to more specific taxa, with about 12.5 to 25 percent (of NISP) identified, while in the mainland sites it is about 8.5 to 12.5 percent (of NISP). For the nonfish vertebrates, the differences are large, with values ranging from 3.2 to 12.6 percent (of NISP) identified to lower taxonomic categories for the islands and .4 to 1.3 percent (of NISP) for the mainland sites. These data suggest that site disturbances—plowing, animal burrowing, looting, and other processes that result in fragmentation—have a greater influence on the identification of faunal remains from mainland sites than island sites. This is less so for shellfish but generally more pronounced for vertebrate categories, perhaps due to their more delicate structure. There is variability within this trend, however, as the fish remains from CA-SBA-73 are relatively well preserved, a factor related primarily to the good preservation observed in unit 98-25.

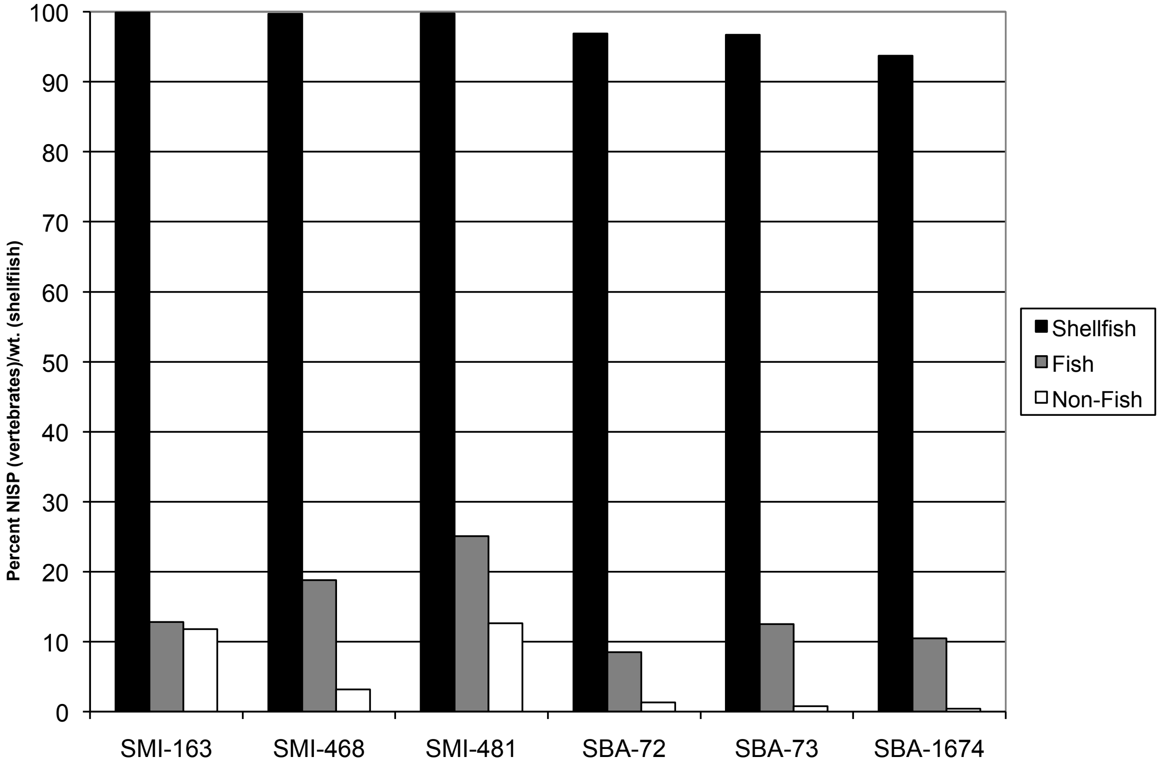


Figure 8.5. Percentage of each faunal category identified to family, genus, or species from Tecolote Canyon and San Miguel Island assemblages.

Fragmentation also appears to influence the taxonomic richness (total number of organisms identified to family, genus, or species) of the assemblages being studied. Because of the greater diversity within mainland compared to island ecosystems, taxonomic richness in the Tecolote assemblages should generally be higher than island assemblages. Shellfish richness at CA-SBA-72 (*n* = 41), CA-SBA-73 (*n* = 33), and CA-SBA-1674 (*n* = 19) is comparable to the island values from CA-SMI-163 (*n* = 40), CA-SMI-481 (*n* = 27), and CA-SMI-468 (*n* = 29). In this case, the values from the mainland sites should be higher considering the diverse array of shellfish available in bays and estuaries that were largely absent from the islands and the higher overall excavated volume at the Tecolote sites. For finfish, the values from CA-SBA-72 (*n* = 29), CA-SBA-73 (*n* = 28), and CA-SBA-1674 (*n* = 6) are generally higher than the values from CA-SMI-163 (*n* = 17), CA-SMI-481 (*n* = 17), and CA-SMI-468 (*n* = 19). The low richness at CA-SBA-1674 is a product of small sample size and the disturbed nature of this site. At the other sites, the higher finfish richness on the mainland reflects the greater taxonomic richness of mainland ecosystems. For mammals, the values between the mainland sites of CA-SBA-72 (*n* = 9), CA-SBA-73 (*n* = 4), and CA-SBA-1674 (*n* = 1) and island sites CA-SMI-163 (*n* = 5), CA-SMI-481 (*n* = 5), and CA-SMI-468 (*n* = 3) are comparable, a surprising result since island terrestrial communities are extremely diminished in mammals compared to the mainland. The Tecolote mammalian richness is likely reduced because of the high fragmentation and burning of the assemblage. Values for birds are low in both the mainland (*n* = 0 to 4 for the three sites) and island (*n* = 2 to 6 for the three sites) assemblages, probably reflecting an overall dearth of bird bones in most Santa Barbara Channel sites. Given the high degree of fragmentation of the overall assemblages, these Tecolote data probably underestimate the actual richness present in the Tecolote Canyon assemblages.

CONCLUSIONS

The late Holocene Tecolote Canyon sites contain a variety of fish, mammal, bird, shellfish, and other faunal remains. Historical land development, plowing, burrowing rodents, and looting have fragmented and mixed the constituents, however, resulting in relatively low chronological resolution and hindering the taxonomic identification of some of the faunal categories, especially vertebrates. Archaeologists have long recognized the qualitative differences in the preservation of island and mainland faunal assemblages, a pattern generally supported by the high stratigraphic integrity of many island sites (see Rick, Erlandson, and Vellanoweth 2006). Our comparisons of the Tecolote and San Miguel Island faunal remains provide quantitative support of this discrepancy, with island assemblages generally having lower fragmentation and a higher percentage of the assemblage with more precise taxonomic identification. The fragmentation and poorer preservation of the Tecolote assemblages also appear to influence the overall taxonomic richness of the assemblages, especially for mammals. These results are more pronounced for vertebrates than they are for shellfish remains, but this appears to be primarily the result of the abundance of large, hard-shelled clams in the Tecolote sites and the absence of these species in the San Miguel Island middens. The preservation of the Tecolote Canyon faunal materials was also affected by the high incidence of burning within the assemblage, from prehistoric and historic activities, which obscured or otherwise disturbed features useful for taxonomic identification.

These quantitative data underscore some of the methodological obstacles associated with working with the mainland assemblages, often from heavily disturbed deposits, but demonstrate that not all mainland assemblages are necessarily so fragmented or poorly preserved. This pattern is exemplified by the fish remains from CA-SBA-73, where preservation was generally good, and consequently a higher percentage of the bones could be identified. Many buried archaeological sites along the mainland coast have also been protected from bioturbation and other disturbance processes and may have preservation essentially equal to many island sites (Erlandson 2007; Rick and Erlandson 2000; Vellanoweth and Erlandson 2004). Although aspects of the Tecolote assemblages proved difficult for analysis, numerous invertebrate and vertebrate taxa were identified, providing important cultural and ecological information (Erlandson, Rick, and Vellanoweth 2008).

Our data suggest that calculating average specimen weights/sizes and noting the total percentage of bones or shells identified to more specific taxonomic categories can provide quantitative data on the potential biases taphonomic processes may have on interpretations of Santa Barbara Channel mainland and island faunal assemblages. Of course, this process requires that researchers count and report the often voluminous quantities of unidentified bone recovered during excavation. The potential biases illuminated by the fragmentation index are one reason to continue counting small bone fragments. Our data also underscore the need for researchers to use *and report* a range of zooarchaeological measures when quantifying faunal remains, especially primary data like NISP and weight, as well as MNI, MNE, and other secondary data. Each of these measures provides insight into the faunal assemblage being studied and allows for greater comparability between sites and assemblages. We believe this is well worth the effort, as it may help us improve our broader interpretation of southern California prehistory and historical ecology.

CHAPTER 9

Hunting versus Gathering:

Comparing Faunal and Artifactual Remains at CA-SMI-575NE, an 8,500-Year-Old San Miguel Island Shell Midden

JON M. ERLANDSON AND TODD BRAJE

For at least the last two decades, archaeologists have argued that early Holocene (ca. 11,000–7500 cal B.P.) peoples of the southern and central California coast relied heavily on shellfish and plant foods as dietary staples. Many early mainland sites contain abundant milling stones used to process plant foods but few hunting or fishing implements (see Erlandson 1994; Glassow et al. 1988). Such sites often contain some fish, mammal, and bird remains, but shellfish appear to have provided most of the edible meat represented. Due to their low fat and carbohydrate content, shellfish alone cannot support a human population (see Noli and Avery 1988), but Erlandson (1988b, 1991) argued that shellfish exploitation, when combined with the regular use of terrestrial plants, was an efficient way for early coastal peoples to make a living—plant foods providing most of their energy (calories), and shellfish most of the complete proteins needed for healthy growth, daily metabolism, and reproduction.

Throughout the Holocene, however, California's Channel Islands have contained an impoverished terrestrial fauna (domestic dogs, foxes, skunks, mice, and so on)—the larger of which may have been introduced to the islands by humans—and plant foods are considerably less diverse and abundant than along the mainland coast (Kennett 2005; Rick 2007; Rick et al. 2008, 2009). In contrast, the marine ecosystem is productive and diverse, fueled by the upwelling of nutrient-rich waters and extensive kelp forests (Schoenherr et al. 1999). With plant foods and terrestrial mammals more limited than on the mainland, early Channel Islanders probably relied more heavily on marine resources, including sea mammals that could have provided a rich source of fat and calories for island peoples (Glassow 1993a:89).

Archaeologists working on the Channel Islands have identified a remarkable record of early maritime activity, beginning about 13,000 years ago (cal B.P.) and including at least 5 terminal Pleistocene sites and roughly 40 more sites dated between about 10,000 and 7,500 years ago (Erlandson, Moss, and De Lauriers 2008; Rick et al. 2005). These sites include several of the earliest shell middens in the Americas, with evidence for early seafaring, fishing, and sea mammal hunting. Nonetheless, several recent studies suggest that early peoples of the Channel Islands relied heavily on shellfish gathering (e.g., Erlandson et al. 1999, Erlandson Rick and Batterson 2004). Such conclusions are based primarily on the analysis of faunal remains from relatively small excavation samples, however, and recent evidence from other early Channel Island sites suggests that marine fishing and hunting were more significant activities than previously believed

(Braje 2010; Erlandson, Braje et al. 2005, 2009; Rick et al. 2001).

In this chapter, we examine another case where a combination of subsurface testing and surface collections provides both faunal remains and artifacts from an early Holocene site on the northern Channel Islands. At CA-SMI-575NE, a recently identified 8,500-year-old shell midden on San Miguel Island, a combination of extensive erosion, excellent surface visibility, and patches of intact shell midden allowed us to use two separate lines of evidence to evaluate human subsistence. Our investigation of CA-SMI-575NE provided both faunal and technological evidence for early coastal subsistence practices, two data sets that lead to fundamentally different conclusions about the nature of early maritime activities at the site and on the island. In reconstructing the site's geographic location during the early Holocene, we also explore how site function and paleogeography may help explain discrepancies between the faunal and technological evidence from the site.

BACKGROUND

Although numerous sites older than 7500 cal B.P. have been identified on the northern Channel Islands, few of these have been extensively or systematically studied. At most of the excavated sites, sample sizes were limited by an emphasis on salvage from eroding sea cliff exposures, a heavy reliance on column samples (see Erlandson et al. 1999; Glassow 1980, 1993a; Kennett 2005), the relatively high density of faunal remains found in many early island sites, and a lack of motorized transport (San Miguel Island). Relying on comparatively small samples, archaeologists have sometimes projected mainland patterns onto early Channel Island sites (see Erlandson et al. 1999). This seemed reasonable given the stratigraphic integrity and excellent faunal preservation at many early island sites, where issues related to differential preservation or recovery, stratigraphic mixing, distinguishing natural versus cultural faunal remains (gophers and so on), and bone or shell weight loss due to chemical weathering are less problematic, especially when shellfish remains dominated most faunal assemblages.

On San Miguel Island, however, edible plants are limited in diversity and productivity, and early coastal economies may have been quite different than those of the mainland coast. The lack of Milling Stone sites on the island supports this idea, and the historic presence of more than 150,000 pinnipeds (DeLong and Melin 2000) suggests that marine mammals might have been important resources for early maritime peoples—although no faunal evidence currently supports a heavy early emphasis on pinniped hunting. Even at Daisy Cave, where thousands of fish bones (Rick et al. 2001) but much smaller numbers of sea mammal and bird bones were recovered from strata dated between about 10,200 and 8500 cal B.P., dietary reconstructions suggest that sea mammals played a minor economic role, a conclusion supported by the relatively small number of projectile points recovered from the early strata (Erlandson and Jew 2009). At other early Holocene sites on the northern Channel Islands for which quantified faunal data are available, shellfish dominate the recovered faunal remains, and dietary reconstructions suggest that shellfish provided most of the edible meat represented (Braje 2010; Erlandson et al. 1999; Erlandson, Braje et al. 2005; Glassow et al. 2008; Rick et al. 2005). At most of these sites, however, the size of the excavated samples and the number of recovered artifacts has been modest.

Recent technological evidence suggests that early subsistence on the Channel Islands was more diverse than once thought. In a 9,500-year-old component at CA-SMI-608, for instance, faunal remains are dominated by rocky shore shellfish, but a relatively large assemblage of artifacts includes bone gorges and chipped stone points and bifaces, suggesting that hunting and fishing were more significant activities than indicated by the faunal remains (Braje 2010; Erlandson, Braje et al. 2005). A similar pattern was recently identified at CA-SMI-507, a 9,000-year-old midden, where shellfish dominate the fauna but numerous bifaces and other stone tools were found (Erlandson et al. 2009). Three early sites located near chert sources at the east end of the island have also produced hundreds of bifaces, including numerous chipped stone crescents and stemmed Channel Island Barbed points that were almost certainly used in maritime hunting (Erlandson and Braje 2008).

Part of the problem in evaluating early subsistence patterns on San Miguel Island is that all these sites were located some distance from their contemporary coastline. Along with the fact that early sites located closer to submerged shorelines may have been lost to sea level rise and coastal erosion, the distance of sampled middens from the early Holocene coast may differentially affect the representation of various faunal classes transported to the sites. In such cases, carefully evaluating site function, paleogeographic context, and technological evidence may be crucial to a broader understanding of human subsistence patterns.

CA-SMI-575: CONTEXT, CHRONOLOGY, AND METHODS

CA-SMI-575 is a very large archaeological site situated on the bluffs overlooking Point Bennett near the west end of San Miguel Island (Figure 9.1). The site extends for roughly 1 km from northwest to southeast, capping a Pleistocene dune ridge extending from near the northwest coast of the island almost to the high cliffs overlooking the southwest coast. This ridge is located approximately 100 m above sea level, near the west end of a broad plateau. CA-SMI-575 contains numerous occupational loci, only a few of which have been dated, but ^{14}C dates from several loci show that it was occupied during the early, middle, and late Holocene, with dates ranging from about 9000 to 1000 cal B.P. (see Braje and Erlandson 2009; Braje et al. 2005). In January 2006, we identified the remnants of a thin shell midden embedded in the Simonton Soil, a late

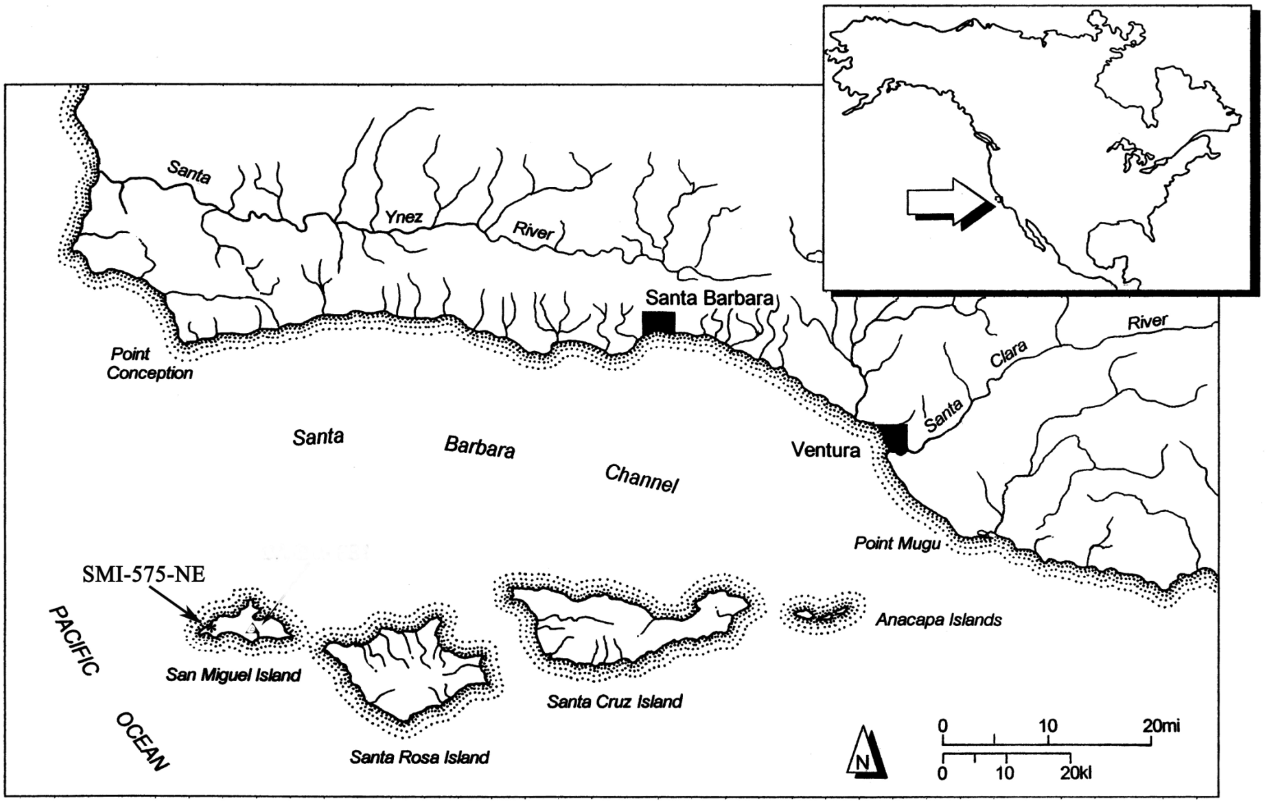


Figure 9.1. General location map for San Miguel Island and CA-SMI-575NE. Adapted from the original by R. van Rossman in Kennett (2005).

Pleistocene and early Holocene stratigraphic marker found across much of northwestern San Miguel (see Erlandson, Rick, and Peterson 2005). The youngest shell midden found embedded in this soil, which was sealed beneath extensive Holocene dunes, is approximately 6,500 years old.

Bordering CA-SMI-575 on the north, west, and south is a steep escarpment that drops to the modern coastline to the north and south, and to the broad lowland expanse of the Point Bennett area to the west. Point Bennett now shelters one of the largest pinniped rookeries in North America (DeLong and Melin 2000). Visiting the area today, it is easy to visualize this remarkable physical and biological landscape—including tens of thousands of barking pinnipeds from at least six different species—as a pristine and truly ancient phenomenon. Archaeological and geological evidence suggests, however, that both the geography and ecology of the modern landscape have changed dramatically over the last 10,000 years. Just 500 years ago, for instance, a large Chumash village existed in the midst of the modern rookery (Walker et al. 2002), and several shell middens in the vicinity dated between about 8000 and 10,000 cal B.P. have produced only small amounts of sea mammal remains (see Erlandson, Rick, and Batterson 2004; Rick et al. 2005). Significantly lower sea levels during the terminal Pleistocene and early Holocene also fundamentally changed the local geography (Figure 9.2).

Most of CA-SMI-575NE is heavily eroded, the result of decades of overgrazing by thousands of sheep and other livestock introduced by Euro-American ranchers from roughly A.D. 1850 to 1950 (Johnson 1980). Patches of soil remain intact, however, and contain numerous in situ shells (often with

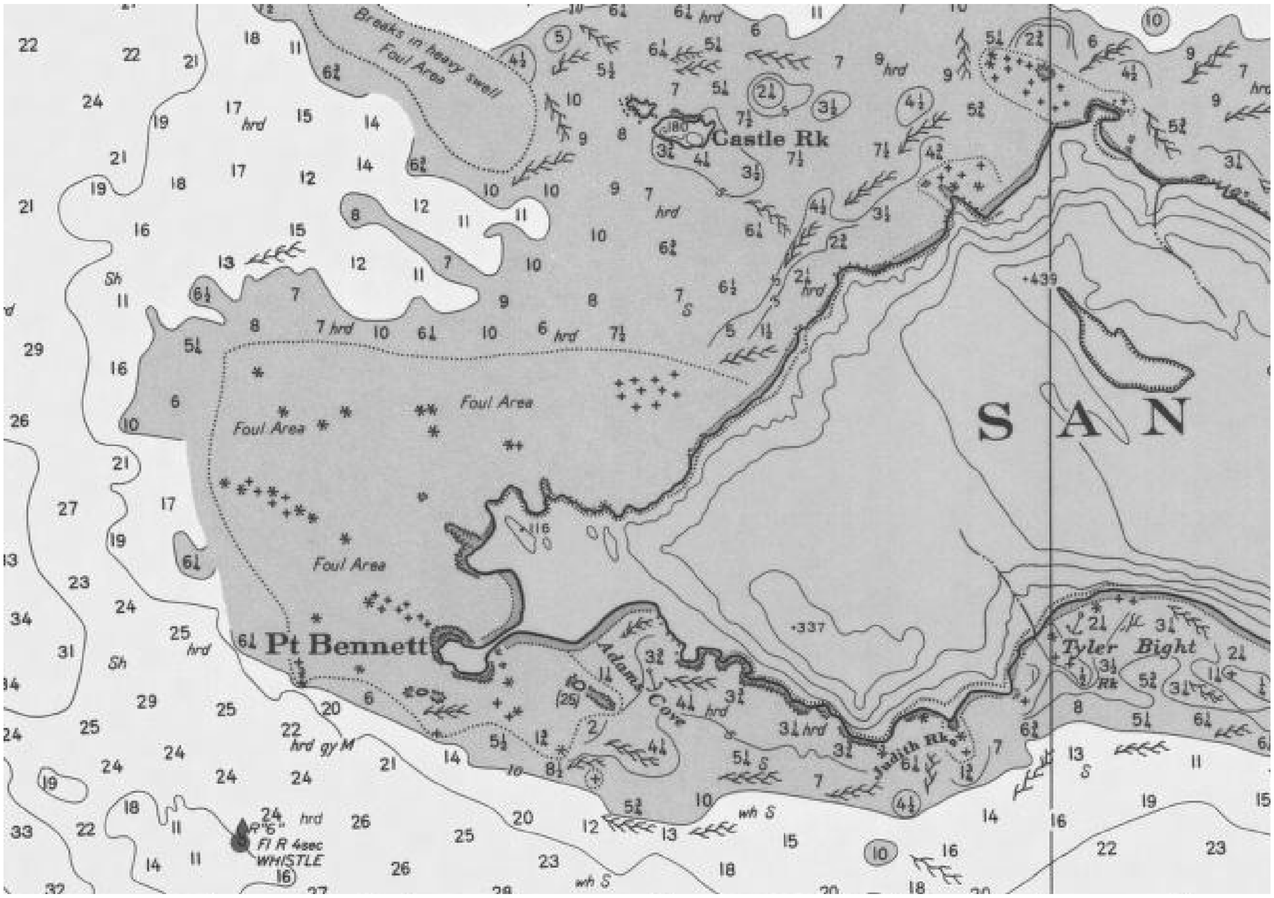


Figure 9.2. Local setting of CA-SMI-575NE, including shaded 10-fathom (about 18-m) isobath that approximates the location of the early Holocene shoreline. Adapted from 2004 *San Miguel Passage Nautical Chart* (1:40,000), National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Figure 9.3. Brendan Culleton examining 8,500-year-old shell midden (lower left) embedded in the Simonton Soil at CA-SMI-575NE. Channel Island Barbed points were scattered around this midden locality (photo by J. Erlandson).

articulated valves) of California mussels (*Mytilus californianus*) and other rocky intertidal mollusks (see below). Interspersed with these islands of intact soil are larger eroded areas where marine shells and occasional artifacts have been deflated onto a rugged caliche surface (Figure 9.3), as well as occasional patches of recent dunes that obscure portions of the site surface completely.

During a thorough reconnaissance, we found archaeological materials scattered over an area roughly 50 m long and 40 m wide. We surface-collected diagnostic artifacts from this area, collected several marine shells for radiocarbon (^{14}C) dating, and excavated a single 1-×-.5-m test pit in one of the denser intact shell midden features. In test unit 1, excavation of an intact midden averaging about 5–6 cm in thickness produced 27.5 liters of sediment, which was dry-screened over 1/16-inch mesh in the field. Screen residuals were bagged and returned to the laboratory, where they were wet-screened to remove any sediment adhering to the shells and other cultural constituents. After cleaning, screen residuals were sorted into broad categories of artifacts and botanical, invertebrate, vertebrate, and other archaeological remains. The faunal materials were identified to the most specific taxon possible, then quantified according to both weight and MNI. During our reconnaissance, we found only five diagnostic artifacts, observed no animal bone, and found only thin (about 5 cm thick) and relatively sparse shell midden deposits dominated by mussel shells. These characteristics suggested that CA-SMI-575NE was probably a campsite used relatively briefly by coastal foragers. Radiocarbon dating of a well-preserved California mussel shell found in situ in the Simonton Soil suggests that this occupation took place about 8,500 years ago, an age fully consistent with the site stratigraphy and the diagnostic artifacts found in the area.

Today CA-SMI-575NE is located about 550 m from Busted Balls Cove on San Miguel's northwest coast, but 8,500 years ago, sea levels were roughly 15 to 20 m lower than those currently along the southern California coast (Nardin et al. 1981). Comparing sea level curves with local bathymetric maps suggests that CA-SMI-575NE was located about 1.5 km (± 150 m) from the southwest coast and about 1.8 km (± 200 m) from the northwest coast at the time it was occupied, although coastal erosion, tectonic and isostatic adjustments, and offshore sedimentation add considerable uncertainty to such estimates. The considerable distance of the site from early Holocene coastal habitats is significant, because it may have limited the number of larger fish or sea mammal carcasses hauled to the location. Large animals may well have been butchered on or near the shoreline, with only the meat or primary cuts transported to the site. Intertidal shellfish, in contrast, are much smaller and can remain alive (and fresh) for several days after being collected. Because the site appears to have been occupied relatively briefly, it could also contain the remnants of a relatively limited and specialized range of subsistence activities, an idea that can be evaluated by analyzing both the recovered faunal remains and the artifacts.

FAUNAL REMAINS

Information on the faunal constituents at CA-SMI-575NE comes from two sources: surface observations and subsurface excavations. Heavy erosion of the soil in which the early Holocene shell midden is embedded has left an extensive scatter of marine shell fragments and chipped stone artifacts deflated on the site surface. Intact exposures of the midden deposits provide a narrower window on the site contents, however, and deflation of some site areas has concentrated cultural materials, allowing a broader assessment of the site economy. Examination of these extensive surface exposures suggested that the shell midden was composed primarily of California mussel shells of relatively large size. The complete lack of animal bone observed in surface exposures also suggests that the occupants consumed mostly shellfish while occupying the site.

To test this idea and collect a more representative sample of the midden constituents from the intact site remnants, we excavated the 50-×-100-cm test unit 1 through a shallow midden deposit preserved in an intact soil island. This test unit was excavated in the middle of a small but relatively dense concentration of shell midden embedded in the Simonton Soil (Figure 9.3). The midden in this area, similar to other intact site exposures, was relatively thin, reaching depths of only 5–6 cm below the current ground surface.

Similar to our observations from the site surface, the materials recovered from test unit 1 consist almost entirely of marine shellfish remains harvested from rocky intertidal habitats (Table 9.1). No bone or other vertebrate remains were recovered, but we collected over 3 kg of marine shell from this test unit, more than 99 percent of which was identifiable to at least general taxa. Only six discrete shellfish taxa were identified, however, suggesting that shellfish foraging was focused on a narrow range of species. Consistent with the dominance of mussel shells observed on the site surface, California mussel contributed almost 93 percent of the marine shell recovered in test unit 1 and over 38 percent of the MNI. The economic significance of mussels is underestimated by MNI values because the other shellfish represented in the assemblage consist almost entirely of small barnacles, limpets, gastropods, and other epifauna commonly associated with California mussel beds (Jones and Richman 1995). It is unlikely that these small (often tiny) shellfish represent food debris. A significant number of land snail (*Helminthoglypta ayresiana*) shells were also recovered in test unit 1, but these shells are ubiquitous in San Miguel Island soils, show no sign of modification or processing, and are almost certainly natural site constituents.

ARTIFACTS

Test unit 1 produced no artifacts and only small amounts of charcoal. Scattered on deflated surfaces

Table 9.1. Shellfish Remains from Test Unit 1 at CA-SMI-575NE.

Scientific and Common Names	**MNI**	**Weight (g)**	**MNI %**	**Weight %**
Mytilus californianus (California mussel)	84	2,803.5	38.5	92.7
Balanus spp. (acorn barnacle)	93	191.2	42.7	6.3
Serpulorbis spp. (worm shell)	1	1.4	0.5	< 0.1
Acmaeidae (limpets, small), undiff.	38	0.4	17.4	< 0.1
Pollicipes polymerus (leaf barnacle)	1	0.4	0.5	< 0.1
Gastropoda (marine snails, small), undiff.	1	0.1	0.5	< 01
Unidentified marine shell	-	28.2	-	0.9
Totals	218	3,025.2	100	100

Notes: All faunal remains came from the 0- to 10-cm level. Also recovered were 77.9 g (MNI 45) of land snail (*Helminthoglpytes ayresiana*) shell, probably of noncultural origin.

within and around the area of intact midden exposures at CA-SMI-575NE, however, we found five diagnostic projectile point fragments (Figure 9.4). All five fragments are from relatively small, stemmed, and barbed points, often referred to as Channel Island Barbed Points (Glassow et al. 2008; Justice 2002). Dozens of these distinctive and delicately flaked points have been identified from the Channel Islands over the years (see Heye 1921; Justice 2002), but they were only recently recognized as temporal markers of early Holocene and terminal Pleistocene assemblages dated between about 8,000 and 12,000 years ago. Glassow and his colleagues first found Channel Island Barbed points in a stratified and well-dated context at the Punta Arena site (CA-SCRI-109) on Santa Cruz Island, where three were found associated with a basal shell midden component dated to about 8400 cal B.P. (Glassow et al. 2008). A similar point was described by Rozaire (1978a) from one of the lower strata at Daisy Cave, but its antiquity and significance were recognized only after Glassow's discovery (Erlandson and Jew 2009). Because the early Holocene occupation of Daisy Cave appears to have ended about 8500 cal B.P., the Channel Island Barbed point from Daisy Cave is likely to be at least that old, but a careful reading of Rozaire's field notes suggests that it may have come from an earlier terminal Pleistocene component. More recently, a similar point was recovered from CA-SMI-608, a shell midden on the south coast of San Miguel Island dated between about 8700 and 9600 cal B.P.

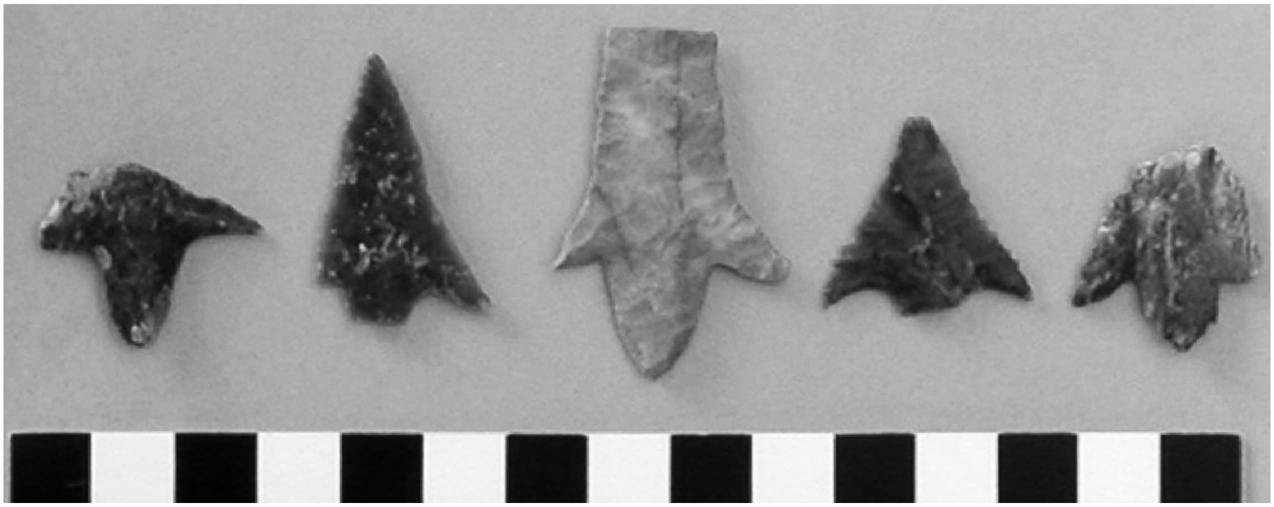


Figure 9.4. Five stemmed Channel Island Barbed (Arena) point fragments found on the surface of CA-SMI-575NE (scale in centimeters; photo by J. Erlandson).

(Braje 2010; Erlandson, Braje et al. 2005), and several others have been found in the Cardwell Bluffs area near the east end of the island (Erlandson and Braje 2008; Erlandson, Rick et al. 2011).

Glassow et al. (2008) described the Channel Island Barbed points from CA-SCRI-109 as small, thin, and delicately made, falling within the general range of arrow points rather than dart points. The CA-SMI-575NE specimens are consistent with this description, but the bow and arrow is generally regarded as having been introduced into coastal California only about 1,500 years ago. It seems likely, therefore, that these early Channel Island points were attached to the ends of darts thrown from atlatls. Glassow et al. (2008) suggested that Channel Island Barbed points may have been used in fishing, but they are rare at Daisy Cave, where over 27,000 fish bones were recovered from early Holocene strata (Rick et al. 2001). Erlandson and Braje (2008) proposed that they may have been utilized in hunting sea otters or pinnipeds, but very little sea mammal bone has been recovered from the early sites where they have been found. The lack of either fish or sea mammal remains recovered or observed at CA-SMI-575NE limits any conclusions about the function of the points found at the site. Use wear or residue analysis could potentially resolve some of these issues, but the projectile points found on the surface of CA-SMI-575NE show signs of abrasion from localized erosion and sandblasting resulting from the strong northwesterly winds that regularly batter the island. We can be sure they were not used in collecting or processing shellfish, however, so their presence clearly implies that the occupants of CA-SMI-575NE had a more diversified subsistence strategy than represented in the faunal remains identified at the site.

DISCUSSION

Archaeologists are trained to solve problems and test hypotheses using multiple lines of evidence, but most studies of early subsistence on the northern Channel Islands have relied on small samples of faunal remains without adequate comparison to the artifacts that provide an independent source of data on human subsistence. To some extent, this problem results from the low density of artifacts found in many early shell middens—especially those devoted primarily to shellfish collecting—but it is also a function of small sample size, including a heavy reliance on column or bulk samples. On the Channel Islands, it could also be related to the ability of early maritime people to scavenge sea mammal carcasses or capture seals and sea lions at rookeries onshore, where they can be dispatched with simple clubs or lances, strategies that might leave little in the way of technological evidence. Yet another problem in evaluating the importance of vertebrates in early maritime economies on the islands has to do with postglacial sea level rise and coastal dynamics, which have significantly altered the geographic context of many early Holocene sites.

At some early island sites, the apparent economic importance of shellfish seems well founded, even without technological evidence. At the largely deflated CA-SMI-606 in nearby Busted Balls Cove, Erlandson, Rick, and Batterson (2004) documented an early shell midden that contained large quantities of mussels and other marine shells, but almost no technology. At this site, where visibility and sample size were enhanced by deflation similar to that at CA-SMI-575NE, the dearth of technology supports the faunal evidence that shellfish collecting was the primary source of edible meat for the site occupants. At CA-SMI-507 and CA-SMI-608, in contrast, we recovered faunal assemblages dominated by marine shell, but artifact assemblages suggested that hunting was a significant activity (Braje 2010; Erlandson, Braje et al. 2005, Erlandson et al. 2009). The latter pattern seems to be present at CA-SMI-575NE, where vertebrate remains are rare but chipped stone points unlikely to be associated with shellfish gathering were relatively abundant.

At CA-SMI-575NE, probably a short-term campsite, the dichotomy between faunal remains and technological evidence may have a relatively simple explanation. Here, the Channel Island Barbed points may have been left behind during maintenance and retooling of hunting equipment after an unsuccessful hunting trip. Shellfish collecting may have made up for the lack of other meat brought back to the camp. Alternatively, the discrepancy between faunal and artifactual evidence at CA-SMI-575NE may have more to do with the distance of the camp from the contemporary coast and the differential processing of shellfish versus sea mammal or large fish carcasses. If the Channel Island Barbed points were used in hunting sea otters or seals, for instance, the animals may have been skinned and butchered near the beach, with only the prime cuts of meat and valuable skins/furs carried back to a residential site some distance from the coast. In contrast, mussels are smaller organisms that can stay alive and fresh in their shells for hours or even days. The meat of mussels is also generally small, messy, and much easier to process after cooking, so butchering them at the beach to carry the uncooked flesh to a home base makes much less sense. All this, combined with the fact that CA-SMI-575NE was probably located between 1.5 and 2.0 km from the coast 8,500 years ago, suggests that the "schlep effect" may have influenced the faunal constituents found in the midden. If so, the projectile points recovered from the site—similar to those from CA-SMI-608 and CA-SMI-507—may reflect an important component of early maritime economies on the islands that is poorly represented in faunal assemblages.

An early reliance on marine fishing and hunting on San Miguel Island is supported by the artifacts recovered from the early Holocene strata at Daisy Cave (numerous bone gorges, a Channel Island Barbed point, a chipped stone crescent, several other bifaces, abundant cordage, and so on), which also produced an eclectic array of marine animal remains, including pinnipeds, sea otters, seabirds, shellfish, and fish. It is also supported by the recent discovery of three large Paleocoastal lithic scatters (probably quarry/workshop sites) associated with chert sources at Cardwell Bluffs on eastern San Miguel, where hundreds of biface fragments—including numerous early stemmed points and crescents—suggest that manufacturing points, knives, and other hunting or butchering equipment was an important activity for early peoples on San Miguel (Erlandson and Braje 2008; Erlandson, Braje, and Rick 2008).

SUMMARY AND CONCLUSIONS

At CA-SMI-575NE, a relatively small and sparse 8,500-year-old shell midden on San Miguel Island, faunal remains include a narrow range of shellfish dominated by California mussels harvested from rocky shorelines located more than 1 km distant at the time. Although no vertebrate remains were found at the site, a small assemblage of formal artifacts found on the surface includes five Channel Island Barbed points. The dominance of shellfish at CA-SMI-575NE is consistent with data from several other early island and mainland sites, but the presence of a sophisticated hunting technology demonstrates that site occupants were engaged in maritime hunting or fishing activities that are not represented in the recovered faunal assemblage. Whether animals captured with this distinctive projectile technology were processed or eaten away from the site, or the occupants simply retooled their projectiles at the site after an unsuccessful day of hunting, is not clear. What is clear is that the faunal and artifact assemblages from the site each provide unique and very different types of information about the nature of the settlement and subsistence patterns of these early maritime peoples.

This is not an uncommon phenomenon in coastal archaeology, but it provides a valuable warning about an exclusive reliance on faunal remains to interpret human subsistence, site function, and historical ecology from shell middens. At times, zooarchaeologists are also asked to analyze faunal assemblages—or sometimes only portions (such as shellfish or fish remains) of an assemblage—with little knowledge of the artifacts recovered with the faunal samples. A more holistic approach to reconstructing subsistence is generally more productive. Finally, we note that coastal ecosystems around the world have changed dramatically since the end of the last glacial period, and archaeologists studying coastal sites dating to the terminal Pleistocene and early Holocene must carefully consider the ecological context (interior, coastal, pericoastal) of each site, its distance from the coast when it was occupied, the length and purpose of an occupation, the range of subsistence activities conducted from or at the site, and the potential effects of differential transport, preservation, or recovery on the assemblages we recover.

Archaeologists interested in reconstructing subsistence also need to carefully consider methodological issues related to sample size in assessing the representative nature of various faunal and artifactual assemblages. If shellfish remains and chipped stone debitage are abundant and relatively evenly distributed in a coastal shell midden, for instance, they may be well represented in small column or bulk samples. Mammal bones and projectile points may be comparatively rare and unevenly distributed in the same midden deposit, in contrast, and may be poorly represented in small samples (see Braje et al. 2007). Ultimately, to better understand the function of a site and the lives of the people who occupied it, archaeologists must develop sampling strategies that effectively recover both common and rarer objects, including faunal remains and artifacts that may provide very different views of ancient adaptations at a single site.

ACKNOWLEDGMENTS

We are indebted to Bob DeLong, Brendan Culleton, Kelly Minas, Ann Huston, Beverly Fernandes, and Nenette Paulson. Students in our Fundamentals of Archaeology (ANTH 340) class in spring 2006 did the preliminary sorting and identification of the CA-SMI-575NE materials under our supervision. Our research on San Miguel Island has been supported by the National Science Foundation (multiple awards), the National Parks Service, the Western National Parks Association, the Foundation for Exploration and Research on Cultural Origins, and a Knight Professorship from the University of Oregon. Finally, we are indebted to Mike Glassow and Terry Joslin for their patience and editorial help in the production and publication of this paper.

CHAPTER 10

Analytical Sampling Strategies for Marine Fish Remains:

Measuring Taxonomic Diversity and Abundance in Central California Middens

TERRY L. JOSLIN

Zooarchaeology researchers have clearly recognized that collection and processing techniques have a considerable effect on faunal analysis (Brewer 1992; Gordon 1993; Grayson 1978, 1981, 1984; James 1997; Lyman 1982; Shaffer 1992; Shaffer et al. 1994). The methods we employ to collect faunal remains impose constraints in the way data should be quantified and analyzed, and therefore require close consideration. Focusing on the analysis of fish (ichthyofaunal) remains, researchers have addressed many methodological considerations, such as sampling procedures (particularly the use of small 1/8- and 1/16-inch mesh screens), reliability and consistency of identifications, and taphonomy (Casteel 1972, 1976a, 1976b; Colley 1990; Gobalet 1989, 2000, 2001, 2005; Gobalet and Jones 1995). The study of fish remains, perhaps due to species diversity, variability in size and shape, and their fragile structure, requires fine-grained techniques and methods that are time-consuming to conduct and expensive to fund.

As a result, subsampling fish elements is a common approach used to analyze more manageable numbers (Clason and Prummel 1977) and infer subsistence trends associated with particular site occupations. Despite the attention on adequately sampling fish remains, the validity of subsampling methods (often in the form of column samples) has not been tested beyond Casteel's (1976a) initial experiment. Many published analyses of fish remains either depend exclusively on excavation units or exclusively on column samples, and little attention is given to strengths and weaknesses of each approach to collection and processing. Consequently, no research has addressed the issue of how many column samples and/or how many excavation units (that is, the volumes of each) are needed in particular analytical situations.

The principal goal of this paper is to examine how accurately two distinct sampling strategies—excavation units and smaller column samples—represent the ichthyofaunal assemblage. Of particular importance is how these sampling approaches affect use of two indices: the relative abundance or density of individual species and the taxonomic diversity of fish bone. This information is essential to addressing fundamental questions regarding diet composition and change through time. For the purposes of the current case study, relative abundance or relative density refers to the number of categories (identified fish taxa) as a percentage of the total within an assemblage (Grayson 1981:77), while diversity is the number of different categories of items present in an assemblage (Kintigh 1984:45).

Archaeological data for this analysis come from two sites: the White Rock site (CA-SLO-71) and the Prehistorics site (CA-SLO-115), located within the University of California Kenneth S. Norris Rancho Marino Reserve (UC Reserve), a 500-acre landholding near Cambria in northern San Luis Obispo County, California (Figure 10.1). Both sites are situated along a broad Pleistocene marine terrace overlooking the San Simeon Reef, a term developed by fishery biologists to describe the offshore rocky shelves, reefs, and associated kelp forests. In the context of this study, the San Simeon Reef refers to the distinctive environment that fostered unique coastal adaptations in this region of California (Joslin 2010).

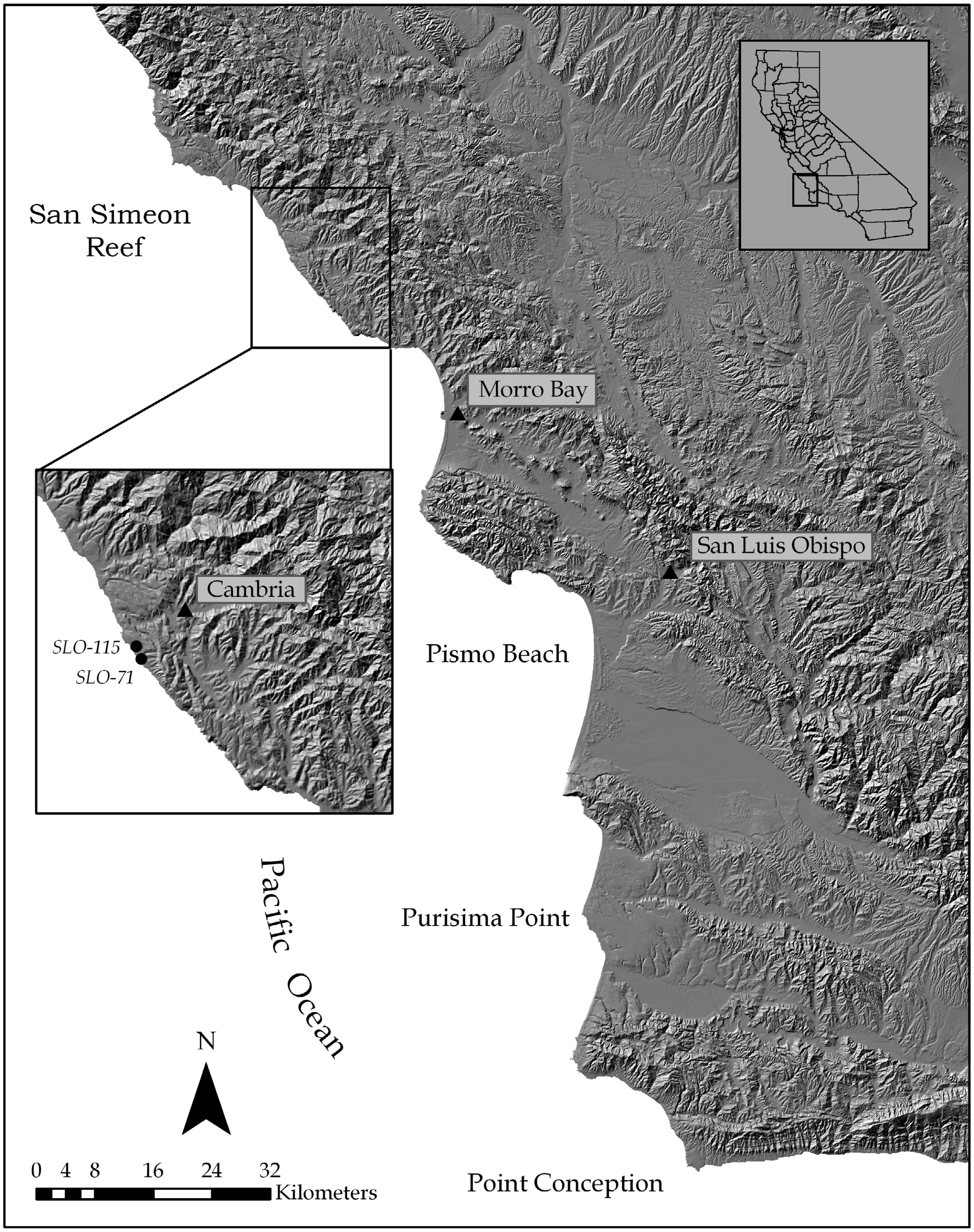


Figure 10.1. The central California coast region showing the location of the study sites.

Excavations at these sites identified contemporaneous deposits dating to a 300-year time span between about 700 and 400 cal B.P. (A.D. 1280 and 1540), falling within a time interval known as the Late Period (700 cal B.P. to Spanish contact) (Joslin 2006b). The samples provide an excellent opportunity to investigate temporal trends in prehistoric marine fisheries, as the problem of mixing from burrowing rodents has not contaminated earlier components. The assemblages contain a diverse artifact collection and rich faunal remains that suggest the sites were occupied as residential bases for part of the year. Unique to these sites are an abundance of fire-altered rocks (248 kg per cubic meter at White Rock and 668 kg per cubic meter at Prehistorics) and a high density of fish remains that suggests that occupants were processing marine fish, possibly for storage or transport to other residential bases. As Late-period adaptations along this portion of the California coastline are not well understood (Jones 1992, 1995; Jones and Ferneau 2002a, 2002b; Jones et al. 2007), the discovery of these new manifestations therefore requires detailed attention to the unusual abundance of fish remains, as it raises questions about the development of intensive marine fishing, a subsistence strategy associated with late Holocene adaptations along the Santa Barbara Channel (Glassow 1996; Landberg 1975; Pletka 2001; Rick 2007; Rick et al. 2001).

SITE SAMPLING AND ANALYTICAL METHODS

Excavations at the two sites were initiated to obtain baseline data for assessing the nature of the midden constituents and establishing the site chronology. In light of the exploratory nature of this research, sample sizes are relatively small, with initial results allowing for identification of baseline information on the deposits for future, more robust studies. Two excavation units were placed at each site (Table 10.1). At the White Rock site, a 1-×-1-m unit was excavated in the western site area, along a terrace edge that is in immediate danger of wave erosion, with a second 1-×-.5-m unit placed in the center of the site. The Prehistorics site excavation units were placed in the same manner, with one 1-×-.5-m unit located above the sea cliff edge and a second 1-×-1-m unit randomly located. At the completion of the four excavation units, one 20-×-20-cm column sample was taken from each unit wall. The excavation volume totals 2.32 m^3; 1.27 from White Rock and 1.05 from Prehistorics. It is import to recognize the distinctions in volume between the

Table 10.1. White Rock and Prehistorics Excavation Summary.

Site	Excavation Unit	Depth (cmbd)	Size (m)	Wet-Screen Mesh	Cubic Meters
White Rock	1 (S26/W13)	0–70	1 × 1	1/8"	.7
	2 (N2/E0)	0–100	1 × .50	1/8"	.5
Subtotal					1.2
Prehistorics	1 (S18/W27)	0–70	1 × 1	1/8"	.7
	2 (S21/W27)	0–60	1 × .50	1/8"	.3
Subtotal					1.0
Total unit volume					2.2
Column Samples					
White Rock	1 CS (east wall)	0–70	.20 × .20	1/16" / .4 mm	.028
	2 CS (east wall)	0–100	.20 × .20	1/16" / .4 mm	.040
Prehistorics	1 CS (north wall)	0–70	.20 × .20	1/16" / .4 mm	.028
	2 CS (west wall)	0–60	.20 × .20	1/16" / .4 mm	.024
Column sample volume					.12
Total cubic meters excavated					2.32

Notes: cmbd- = centimeters below unit datum; 1/8 inch correlates to 3-mm screen mesh, and 1/16 inch correlates to 1.5-mm screen mesh. Column samples were processed using the Flote-Tech flotation system.

two different sample types that Table 10.1 summarizes. Specifically, the volume from the two Prehistorics excavation units is 13 times that of the column sample volume, and at the White Rock site, the excavation unit volume is 17 times that of the column samples.

Collection and processing procedures of the excavation units and column samples from these two sites are identical to ensure compatibility of data between the sites and existing assemblages from other sites. The deposits removed from the excavation units were sifted in the field through 1/8-inch (3 mm) screen, and all materials retained in the screen were then bagged and labeled for transport to the UCSB Collections Processing Laboratory, where they were water-screened.

Midden soils in the four column samples were carefully collected in bulk and brought to the UCSB laboratory. In the laboratory, these materials were processed with a Flote-Tech machine-assisted flotation system. After removing the soil matrix from the column samples, the light fraction (organic remains) was captured in .4-mm nylon mesh, and all remaining materials (the heavy fraction) were washed and screened through 1/8-inch and 1/16-inch (1.5-mm) mesh screens. Once the samples were dry, the light fraction samples were weighed and cataloged without further processing. To recover a representative sample of the remains of smaller fishes, such as inshore-offshore migrators, fish vertebrae recovered from the 1/16-inch materials were sorted from the rest of the residues.[1]

Preliminary taxonomic identifications of fish remains in this study were made by the author using comparative skeletal collections at the Department of Anthropology Faunal Analysis Lab, UCSB, and the Santa Barbara Museum of Natural History. The fish elements were identified to the most specific taxon possible (including identification to order, family, genus, and species). The habitat information and conventions for defining taxonomic groupings used here follow Love (1996) and Humann (1996). After the initial identification of species, Kenneth Gobalet, Department of Biology, California State University, Bakersfield, then confirmed (and corrected) classifications to ensure the accuracy of reporting and the usefulness of the data generated (Gobalet 2001). According to the methods practiced by Gobalet (1997) and Gobalet and Jones (1995), identifications were conservative, made to the most specific taxon possible, except where distinctions were uncertain. For example, specific specimens are confidently assigned to the families Clupeidae (Pacific sardine and Pacific herring), Atherinidae (silversides including jacksmelt, topsmelt, and grunion), and Embiotocidae (surfperches), but not to species. Differentiating between the small prickleback remains in the sample also necessitated reporting the family name Stichaeidae in most cases, as the remains could represent various pricklebacks such as monkeyface prickleback (*Cebidichthys violaceus*), black prickleback (*Xiphister atropurpureus*), or rock prickleback (*Xiphister mucosus*). Conversely, certain elements and larger vertebrae are more diagnostic. Due to the degree of fragmentation, specimen decomposition, and limits within the comparative collections, precise taxonomic identification of many elements was not possible.

A total of 18 different elements were identified, but the most commonly recovered elements at both sites include the angular, dentary, maxilla, parasphenoid, premaxilla, quadrate, vertebra, and vomer. Vertebrae were by far the most frequent diagnostic element collected. At the White Rock site, however, numerous scales were recovered, particularly from unit 2 in the central site area. As with most faunal collections, many of the fragmentary bone specimens could be identified by element; however, these elements had features indicative of several different taxa of fish, unfortunately often from entirety different families. Again, taking the conservative approach, these ambiguous elements were identified as undifferentiated teleost elements and excluded from further analysis.

The fish remains were quantified in terms of NISP, MNI, and bone weight for each unit and level. Individually, these methods all have their shortcomings, particularly with regard to the analysis of fish elements (Casteel 1976b; Grayson 1984; Rick et al. 2001, 2002; Wheeler and Jones 1989). When used collectively, however, they offer a variety of measures to determine the relative importance or significance of faunal categories. Additionally, the methods also conform to those used by other faunal analysts in the region and therefore allow for greater comparability between sites and assemblages (for example, Hildebrandt et al. 2002; Jones and Ferneau 2002a). For this study, NISP is the total number of whole and fragmentary elements assigned to a particular taxon. MNI was calculated from the frequency of distinctive elements (for example, atlas or ultimate vertebra) or paired elements, such as premaxillae or dentaries. Although controversial, (Hildebrandt and Gifford-Gonzalez, this volume; Rick et al. 2001:559), the weight method was used to estimate the approximate meat yields to compare the general dietary significance of marine fish versus other faunal classes. Due to the small sample sizes and low MNI values, the following discussion will be based on NISP unless otherwise noted.

FISH REMAINS FROM THE WHITE ROCK AND PREHISTORICS SITES

The fish bone assemblage considered here is derived from the four hand-excavated units and the four column samples. A total of 197 g of fish bone (191.8 g from White Rock and 5.3 g from Prehistorics) was analyzed. Perhaps due to the sites' occupation later in prehistory, faunal preservation was relatively good (for example, fish scales and delicate bones from small fish were recovered) compared to other California open-air sites. The good preservation suggests that the samples discussed here are relatively representative.

The analysis of all faunal categories revealed a relatively high density of fish bone compared to terrestrial and marine mammal, bird, and reptile bone and marine shell. This implies that fish were of prime importance to the diet. Dietary reconstructions based on weight and NISP support this inference. Meat quantification suggests that fish (46.2 percent) account for the highest proportion of the consumed animal protein in the diet, followed by sea mammal (33.3 percent), land mammal (11.6 percent), and shellfish (7.8 percent). Fish bone density at the White Rock site is 7,100 elements or 152.2 g per cubic meter, while the sparse Prehistorics midden yielded only 319 elements or 5.5 g per cubic meter.

A total of 9,282 fish bone, teeth, and otolith elements was analyzed, with the highest proportion (96 percent) from the White Rock site (Table 10.2). Compared to mammal and bird elements, a fairly large percentage (25 percent) of the fishes was identified to taxa more specific than subclass, totaling 24 to families, genera, and species that occupy a variety of habitats. Excluding scales, most of the identified fishes from the two sites, including pricklebacks (*Xiphister* spp.), rockfish (*Sebastes* spp.), and cabezon (*Scorpaenichthys marmoratus)*, inhabit nearshore waters with a rocky substrate (80.4 percent of the total). Inshore-offshore migrators (11.6 percent of the total), including northern anchovy (*Engraulis mordax*), herring (Clupeidae), sardine (*Sardinops sagax)*, and smelt (Osmeridae), were also identified, as were a few taxa that typically inhabit nearshore waters, including sandy surf and mud bottom habitats (4.1 percent of the total). Nearshore taxa include surfperch (Embiotocidae), Pacific hake (*Merluccius productus*) from mid-depth waters (2.7 percent); and two species, señoritas (*Oxyjulis californica*) and giant kelpfish *(Heterostichus rostratus*), from kelp forest environments. However, if the White Rock site sample of 4.1 g of Atherinidae and Clupeidae scales is included in this total, then inshore-offshore migrators by NISP would comprise a larger proportion of the fish assemblage.

As noted above, the White Rock site produced a large and diverse fish bone assemblage, totaling 8,947 specimens, with 2,090 bones identified to family, genus, or species and 509 MNI (Table 10.2). Of the identified fish taxa, 22 were recognized during otolith analysis. As predicted, the identified elements are predominately rocky intertidal species. The collection is dominated by pricklebacks, which total 679 elements (36.3 percent of the total), followed by rockfishes (25 percent), rock or black pricklebacks (7.6 percent), surfperches (4.2 percent), and cabezon (3.4 percent). If the prickleback taxa, including monkeyfaces, are counted together (951 elements or 45.5 percent of the assemblage), they overwhelmingly dominate the collection. Inshore-offshore migrators account

Table 10.2. Ichthyofaunal Remains from White Rock and Prehistorics.

		CA-SLO-71		**CA-SLO-115**	
Screen Size		**1/8"**	**1/16"**	**1/8"**	**1/16"**
Common Name	**Scientific Name**				
Inshore-offshore Migrators*					
Herrings	Clupeidae	79	15	-	-
Pacific sardine	*Sardinops sagax*	4	-	-	-
Northern anchovy	*Engraulis mordax*	33	37	-	-
Smelt	Osmeridae	11	-	-	-
Silversides	Atherinidae	86	3	-	-
Rocky Intertidal					
Cabezon	*Scorpaenichthys marmoratus*	72	-	4	-
Clinids	Clinidae	40	2	-	-
Gobies	Gobiidae	5	-	-	-
Monkeyface prickleback	*Cebidichthys violaceus*	32	2	-	-
Pile perch	*Rhacochilus vacca*	29	1	-	-
Pricklebacks	Stichaeidae	679	80	15	1
Kelp greenlings	*Hexagrammos decagrammus*	15	-	-	-
Lingcod	*Ophioden elongatus*	3	-	-	-
Northern clingfish	*Gobiesox maeandricus*	1	-	-	-
Rockfishes	*Sebastes* spp.	513	10	16	-
Rock or black prickleback	*Xiphister* spp.	141	17	6	3
Sea bass	*Paralabrax* spp.	1	-	-	-
Striped kelpfish	*Gibbonsia metzi*	1	-	-	-
Sculpins	Cottidae	26	3	-	-
Wooly sculpin	*Clinocottus* spp.	1	-	-	-
Kelp Forests					
Giant Kelpfish	*Heterostichus rostatus*	2	-	-	-
Señorita	*Oxyjulis californica*	53	-	-	-
Mid-water					
Pacific Hake	*Merluccius productus*	5	-		-
Sandy Surf/Muddy Bottoms					
Surfperches	Embiotocidae	79	9	-	1
Ray-finned fishes	Actinopterygii	6,704	153	264	25
Total number of elements		8,615	332	305	30
MNI total		459	50	18	4

*Totals do not include 4.1 g/1,730 Atherinidae, Clupeidae, and other small fish scales.

for 11.9 percent of the assemblage. An inspection of the recovered fish scales reveals that most are Atherinopsids. Significantly, if the Atherinidae and Clupeidae scales in unit 2 were considered in the total fish elements, there would be 1,730 additional specimens in the inshore-offshore migrators category. Therefore, by habitat type, the migrators would surpass the rocky intertidal taxa, 51.1 and 44.4 percent, respectively. Although intermittently present throughout the units, the scales reach their highest concentration, 2.67 g, at a depth between 50 and 70 cm below datum, coinciding with the feature-1 ash lens. A total of 53 percent of the White Rock site fish assemblage exhibits heat alteration. Heat alteration was equally distributed through the depth of the midden.

A much smaller sample of fish remains (*n* = 335) was recovered from Prehistorics site. Teleostei (bony fish) dominates the remains, and no shark or ray (Elasmobranchi) elements were recovered. Unidentifiable Teleostei remains include a variety of body parts (221 elements), as well as 68 vertebrae. Of the identified fish remains, 92 percent of the elements exhibited evidence of heat alteration. Forty-six, or just 14 percent of the bones, were identified more specifically than family, resulting in an NISP of 46 and an MNI of only 22 (Table 10.2). These elements include equal proportions of rockfishes and pricklebacks (32.6 percent), followed by cabezon (19.5 percent), rock or black pricklebacks (13 percent), and a single surfperch. Of the individual remains that could be associated with a habitat, an overwhelming 97.8 percent typically inhabit nearshore waters above or on a rocky substrate, followed by a single representative of sandy surf, sand bottom, or mud bottom nearshore habitants.

MARINE FISH DENSITY IN COLUMN SAMPLE AND EXCAVATION UNITS

Based on the data derived from the fish bone assemblage, comparison may be made of elements recovered from the two different samples, starting with density. The relationship between the sample volume and the quantity of fish remains recovered is best represented with a series of portions and ratios (Table 10.3).

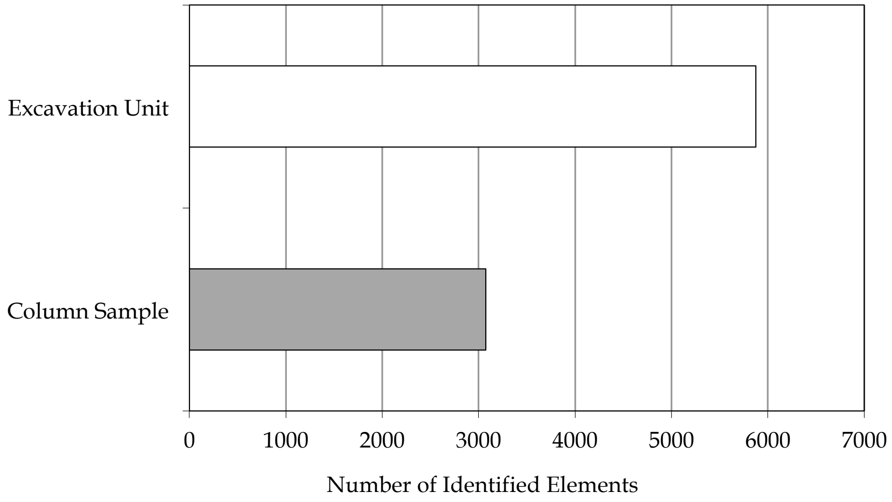
Undoubtedly a result of the larger sample size, a higher percentage of the overall fish elements analyzed was recovered from the excavation units (Figure 10.2). Based on NISP, 66 percent of the identified fish remains were recovered in the White Rock site excavation units, while 34 percent came from the column samples. The White Rock Site excavation units' volume is 17 times that of the column samples, with 5,875 elements collected from the units and 3,074 elements recovered from the smaller column samples. The results from the Prehistorics site are comparable, with 60 percent of all recovered fish constituents resulting from the units and 40 percent in the column samples. Although the Prehistorics site column sample volume is 1/13 the volume of the units, recovered data comprises 133 of the 335 elements of the total fish remains from the site.

However, when the fish bone quantities are converted to the number of specimens per cubic meters of deposits (density), column samples clearly yielded the highest density of elements (Figure 10.3). First, based on observed elements from all the recovery volume, the White Rock site yielded 7,100.8 elements, or 152.2 g of fish bone per cubic meter of deposits, while the Prehistorics site yielded 319 elements, or 5.5 g of fish bone per cubic meter. When considering just the excavation units, the White Rock Site unit samples have a density of 4,896 elements per cubic meter, while the column samples recovered nine times that amount, at 45,205 per cubic meter. A similar trend is apparent at the Prehistorics site, where units yielded a density of 335 elements per cubic meter, and the column samples recovered almost eight times that amount, at 2,558 per cubic meter.

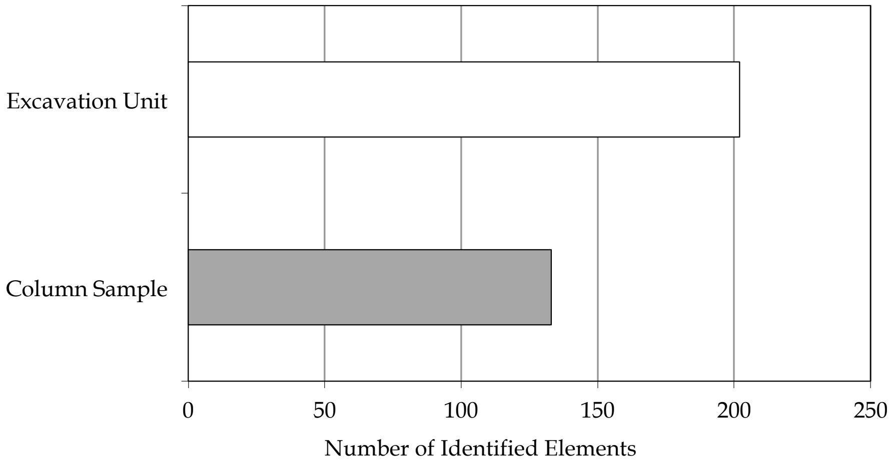
Table 10.3. Fish Bone and Otolith Density in Column Samples and Excavation Units.

	White Rock Site		**Prehistorics Site**	
	Column	**Excavation**	**Column**	**Excavation**
Proportion of identified fish elements	34%	66%	40%	60%
Fish elements per cubic meter	45,205	4,896	2,558	335
Ratio data (column:excavation)				
Observed	1:1.91		1:5.1	
Volumetrically corrected	9.2:1		7.6:1	

Note: = column samples; excavation = excavation units. Numbers of identified fish bone elements in the column samples include data from both 1/8- and 1/16-inch screen mesh.



White Rock, CA-SLO-71

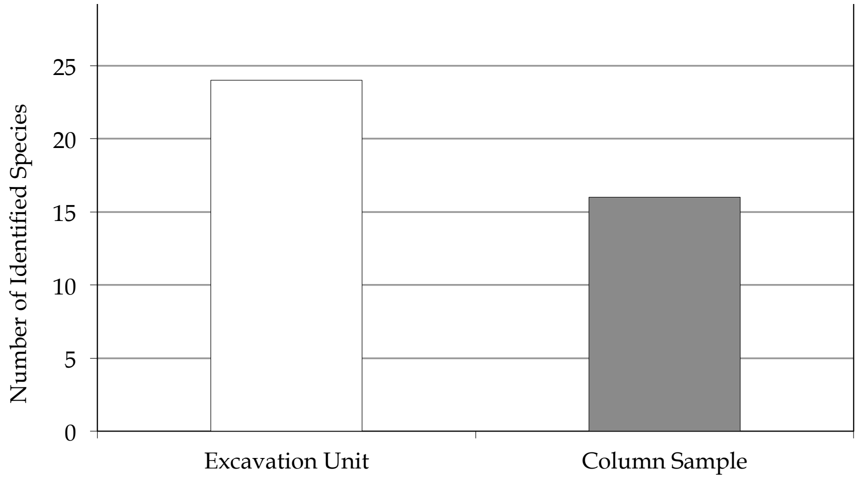


Prehistorics, CA-SLO-115

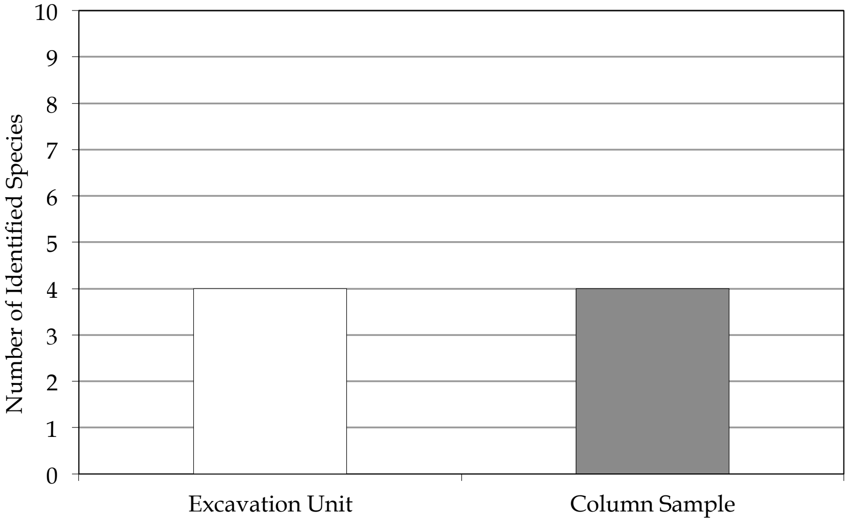
Figure 10.2. Density of marine fish elements per sample, based on NISP.

Illustrated as a series of ratios, the number of elements recovered in the two types of samples increases significantly when we compare the actual numbers of fish bone recovered to density (Table 10.3). For White Rock Site, the ratio of the number of recovered elements in the column samples to those in the excavation units is 1:2, but the ratio shifts to 9:1 when density is considered. A similar trend is seen in the ratios for the Prehistorics site, where the ratio between the numbers of recovered elements in the column samples to those in the excavation units is 1:5 but shifts to 8:1 when density is considered.

Although many archaeologists are aware of the difference between materials collected in excavation units and column samples, this exercise clearly demonstrates that column sample excavation and post-field laboratory processing result in a much higher density of fish remains than does unit excavation. Indeed, the higher column sample density



White Rock, CA-SLO-71



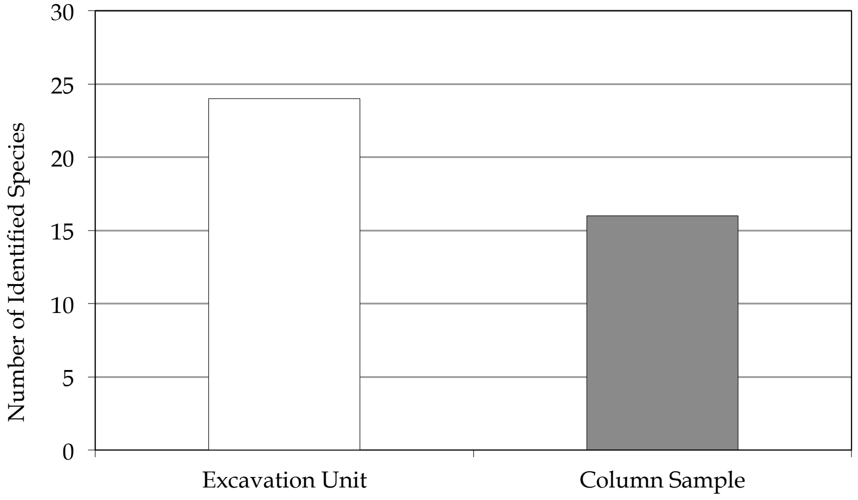
Prehistorics, CA-SLO-115

Figure 10.3. Density of marine fish elements per cubic meter of excavated deposits.

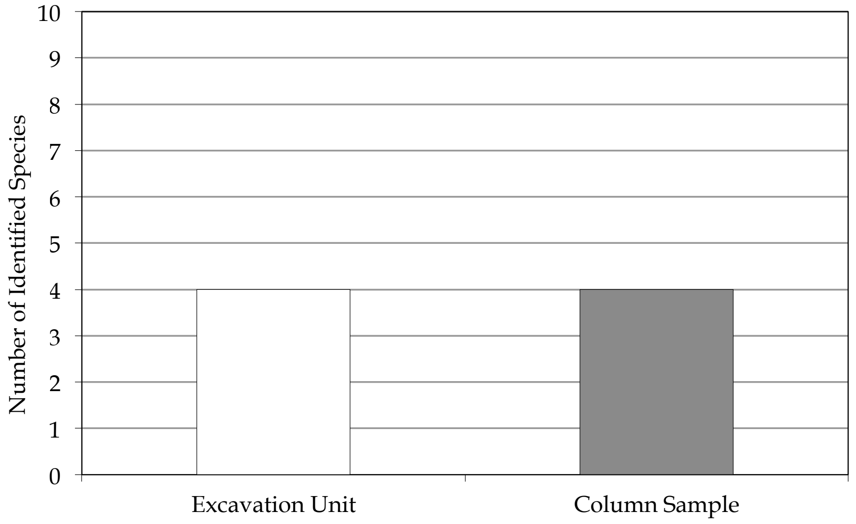
is not particularly surprising considering the more controlled post-field laboratory processing procedures and the smaller 1/16-inch mesh size employed during screening.

MARINE FISH DIVERSITY IN COLUMN SAMPLE AND EXCAVATION UNITS

Now that the abundance of fish elements using the two collection strategies has been considered, the variability in diversity of recovered fish using these two methods can be addressed. First, though the two study sites both contain fish species that occupy waters above rocky intertidal substrate, they contain different diversities of fish remains and taxa. In the individual collections, the White Rock site has 24 taxa represented in the fish assemblage, whereas at Prehistorics, only 5 are present. In the relatively large White Rock site fish assemblage, the elements from excavation units recovered all the taxa



White Rock, CA-SLO-71



Prehistorics, CA-SLO-115

Figure 10.4. Diversity of identified fish species in sampling units.

identified during site faunal analysis (Figure 10.4). Conversely, despite the detailed examination of the remains recovered from the White Rock site column samples, only 67 percent, or 16 of the 24 identified taxa, were recovered. The number of identifiable fish taxa at the Prehistorics site, which has a lower density of fish remains, is limited to five. Equal proportions of identifiable fish taxa, four of the overall total of five, or 80 percent, were recovered from each sample type. The single surfperch element was recovered from a column sample.

Based on a plot of the number of different taxa (diversity) against sample size (Figure 10.5), this trend suggests that diversity indices are typically correlated with sample size—as Grayson (1978, 1984) and Kintigh (1984) point out. The small

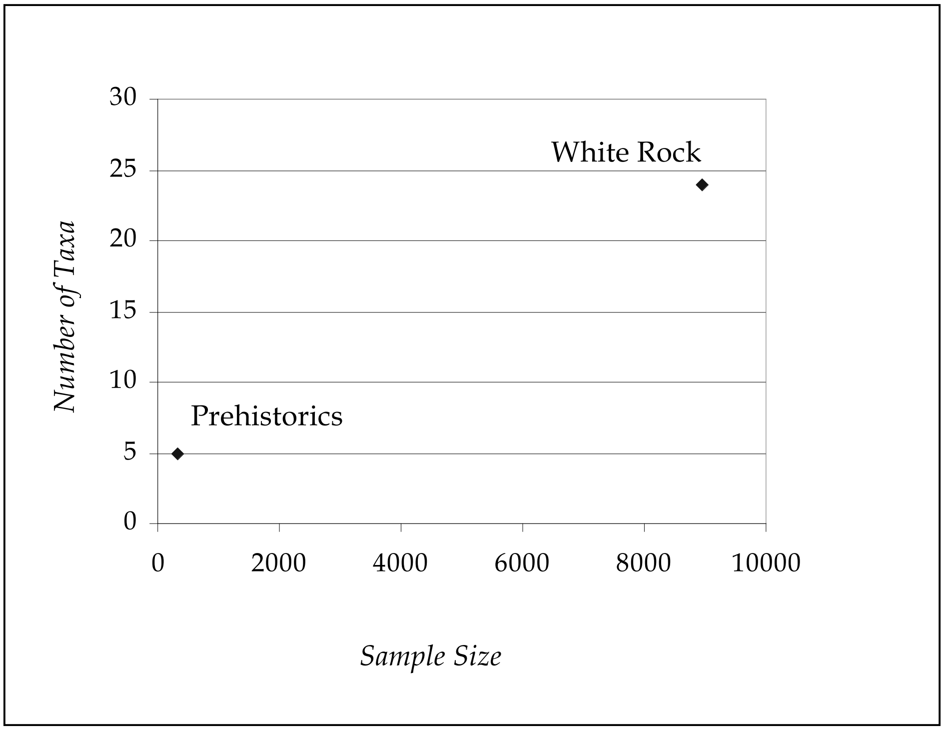


Figure 10.5. Observed fish class diversity indices.

assemblage at Prehistorics, equaling only 5 g of bone, clearly shows the effect of sample size on species diversity and illustrates how small samples influence interpretation of fish remains.

The results of this analysis demonstrate that the column samples identified the same important dietary contributors as the excavation units. These taxa include monkeyface, black pricklebacks, rock pricklebacks, rockfishes, and surfperches. However, the fish taxa occurring in lower density, which are those less important to the diet, were not represented in the smaller volumes of the column samples. These include Pacific sardine (*Sardinops sagax*), gobies (Gobiidae), sea bass (*Paralabrax* spp.), striped kelpfish (*Gibbonsia metzi*), wooly sculpin (*Clinocottus* spp.), and giant kelpfish *(Heterostichus rostratus*). This analysis revealed that the fish bones recovered from the excavation units had the greatest taxonomic diversity. The outcome of this exercise is also compelling in that, although the midden soils were initially screen-shifted in the field, large quantities of identifiable fish elements, including the delicate scales, were recovered from the excavation units. Careful recovery methods (using 1/8-inch screens) and post-field processing (wet-screening and sorting all the samples in the laboratory) obviously have an impact on the effectiveness of the ability to adequately collect fish remains.

SUMMARY AND CONCLUSIONS: EVALUATING THE VALIDITY OF MARINE FISH SAMPLING METHODS

This analysis of how sample type and recovery techniques affect fish species density and diversity provides one example of how our methods can affect data and, therefore, our interpretations of subsistence remains. Marine fish were often important to the diet of prehistoric inhabitants living along the central California coast, and accurate, reliable information derived from the study of their remains preserved in site deposits provides fundamental information on prehistoric hunter-gatherer-fisher subsistence and changes in the importance of specific food categories over time. The data acquired from samples of fish remains allows for inferences on the variety of technologies and methods of capture, as well as the social organization required for procurement, processing, and storage. Additionally, the recovery and identification of specific taxa and their density are fundamental not only to dietary analysis but also to environmental reconstruction of the habitats from which prehistoric occupants acquired food resources.

Consequently, the choices we make in utilizing a specific screen mesh size and the size of samples to be collected have significant impacts on the materials recovered from a deposit (Grayson 1984:168–169). Refinement of our excavation strategies and techniques through their evaluation enhances the possibility of generating accurate and representative information on faunal species represented, which then allows for intersite comparison of assemblage composition. In other words, an understanding of biases in our data resulting from the methods we use leads to confidence in our analytical conclusions. As Grayson (1981:77) suggests, "To ask whether a measure is valid is to ask whether it is measuring what we think it is."

The results of this study provide some intriguing insights that allow us to begin to evaluate the appropriateness of procedures for sampling marine fish remains. First, the results demonstrate that the techniques employed in collecting and processing the smaller-volume column samples resulted in higher density estimates of fish remains than the estimates derived from the excavation units. Column samples are needed if the relative dietary importance of fish is to be most appropriately estimated. However, the column samples appear to have underestimated taxonomic diversity, particularly of low-density taxa that may have been marginal to the diet but still procured. As a result, the variety of fish, and therefore inferences about the range of habitats exploited and technologies employed, may not be captured if column samples are used exclusively.

Because the coarser techniques associated with excavation units typically result in lower densities of fish bone, the resulting data are less reliable for developing inferences about relative abundance. In addition, recovery techniques used for these larger units also appear to result in underestimates of the importance of small migratory fish—obviously a result of the larger screen mesh size. As larger volumes of deposits are excavated, units are appropriate for demonstrating taxonomic richness. Excavation units are also necessary to understanding the relative importance of relatively rare but large fish taxa (for example, Elasmobranchii along the central California coast and swordfish [*Xiphias gladius*] in the Santa Barbara Channel vicinity). The analysis presented here demonstrates that archaeologists need to excavate samples larger than a few column samples to effectively evaluate faunal evidence for the dietary importance of the range of fish taxa actually represented in the deposits.

In light of this analysis of two common sampling methods, determining which one, or which combination of the two, to employ is primarily based on the research objectives, as well as the level of investigation—for example, initial testing or large-scale data recovery. Although useful for inferring the variety of species that site occupants were targeting, coarser-grained techniques for collecting and processing cannot provide data at the level of accuracy needed to answer fundamental research questions regarding diet, procurement strategies, and historic ecology. The data presented here clearly demonstrate that both excavation units and column samples are necessary for dietary reconstruction. The design of a research program depends not only on the research objectives but also on the character of the fish bone in the deposit: its density, degree of preservation, variation in size (that is, whole or fragmentary), and variation in distribution throughout the deposit. This evaluation of fish bone collection and processing strategies confirms the importance of careful selection of methods for acquiring data for the study of prehistoric coastal hunter-fisher-gatherers and demonstrates the significant effect different methods have on the information used for reconstructing prehistoric adaptations.

ACKNOWLEDGMENTS

The primary study sites for this research are located on the University of California Kenneth S. Norris Rancho Marino Reserve. I would like to extend my gratitude to the Natural Reserve System for both physically facilitating my research and providing partial funding via a 2002–2003 Mildred E. Mathias Graduate Student Research Grant. I am indebted to Dusty McKenzie for assisting me with initial fish identifications and to Ken Gobalet, who made a heroic effort to cross-check thousands of fish remains at an amazing speed. I thank Ethan Bertrando, Paula Carr, Ken Gobalet, and Mike Glassow for their support and encouragement during a detailed review that greatly improved this paper. Helpful comments also came from two anonymous reviewers. Finally, the ICAZ meetings in Mexico City provided an amazing opportunity to collaborate with fellow archaeologists who are also analyzing faunal remains, and I would like to acknowledge the council's role in cultivating such an environment.

NOTE

1. The CA-SLO-71 and CA-SLO-115 collections are now curated by the Repository for Archaeological and Ethnographic Collections, Department of Anthropology, University of California, Santa Barbara, under accession number 695.

CHAPTER 11

The Identification and Explanation of Intensified Fishing Practices

SCOTT PLETKA

One key issue in California midden analysis has been to identify and explain resource intensification (Arnold et al. 2004). Intensification refers to the input of greater amounts of labor per capita to procure resources. Intensification often entails not only working harder but also changing the manner by which procurement occurs (Johnson and Earle 2000). Groups sometimes intensify production under the auspices of new social institutions. Workers also frequently adopt new technologies to intensify production. The emergence of new institutions and technologies under these circumstances can have additional consequences (Johnson and Earle 2000). Such changes may foster increased integration within and among groups. The institutions and technologies that facilitate intensification may also promote the development of more hierarchical social organization. For these reasons, the role of intensification provides a recurring theme in accounts of hunter-gatherer social evolution in coastal California and elsewhere (e.g., Ames 1994; Jones 2002:8; Lourandos 1997). Procurement of fish, in particular, may have intensified in many places in California (Erlandson 2002:324). Prehistoric fishers of coastal California sometimes faced challenging environmental and economic circumstances, during which intensified subsistence practices might be expected to emerge. The identification and explanation of intensification requires both appropriate middle-level and high-level theory.

High-level theory provides expectations for the kind of behaviors that occurred in the past and thus for the kind of patterns that may be inferred from the archaeological record. The patterns develop from the aggregate of the individual decisions made by prehistoric fishers. Decision making by fishers depends, in part, on the costs and benefits to continuing the current strategy, the information available to these fishers, and the opportunity costs for conducting other activities.

Formal economic theories incorporate many of these variables. Optimal foraging theory, for example, provides a set of relevant models by which fishing strategies may be understood. Such models have provided insight into a number of different cases (e.g., Broughton 1997, 1999; Butler 2001; Nagaoka 2002). Models of technological intensification have also been developed (Bettinger et al. 2006; Ugan et al. 2003). The technological intensification models have been used to explain choices of fishing gear (Ugan et al. 2003) and hunting weapons (Bettinger et al. 2006). In addition to their power, as evidenced by their applicability to a wide variety of circumstances, these models have the virtue of simplicity. Explanations that have such qualities should be given preference over explanations that cover fewer cases or that are more complex (Fogelin 2007).

Complex theories and models still have a place. All theories, even simple ones, rely upon assumptions. For instance, many simple economic models assume that hunter-gatherers evaluate their environment with complete knowledge of the relevant costs and benefits of employing different strategies. Different models with different assumptions should be considered when the expectations derived from simpler models fail to conform to archeological patterns. Simple, formal economic models nevertheless provide a useful starting point for the explanation of such patterns (Kuhn 2004).

Middle-level theory is required to link archaeological data to the phenomenon of interest. What are the archaeological signatures of intensified fish procurement? Suggestive increases in the density of fish bone occurred during the late Holocene at many coastal Californian sites (e.g., Colten 2001; Jones, Porcasi, et al. 2008; Kennett and Conlee 2002; Kennett and Kennett 2000; Raab et al. 2002). Regardless of the prevalence of this phenomenon, a simple increase in the amount or diversity of faunal material does not necessarily imply intensification. Larger, denser, or more diverse deposits can be attributed to larger, longer, or repeated occupations. Many different factors determine the type and amount of faunal remains that become deposited in a midden. The issue of equifinality makes the analysis of fish remains from middens particularly difficult.

Variability among fish assemblages can be attributed in part to variability in climate, habitats exploited, technology used to take fish, and the organization of production. The identification of intensified fish procurement requires that the effects of such factors be isolated. The problems of middle-level theory will be addressed first, followed by a discussion of high-level theory as it applies to the choices made by prehistoric fishers.

MIDDLE-LEVEL THEORY AND THE IDENTIFICATION OF INTENSIFIED FISHING PRACTICES

The solution to the problems of middle-level theory is the same as the solution to many problems of archaeological analysis. Our goal is to identify the operation of a single process or related set of processes (Carr 1985; Read 1985). Attributes or assemblages that formed from a single process or set of processes should display unimodal variation in quantitative characteristics or bear one state of a discrete characteristic (Read 1985). For example, a spatially homogenous artifact assemblage would include all artifacts found clustered around a single locus of activity. Thus the analysis of intensification leads us to define homogenous fish assemblages, employing appropriate middle-level theory to identify the dimensions along which the assemblage should be homogenized. The resulting assemblages can then be used to evaluate models of intensification.

For purposes of identifying intensified fish procurement, we should divide the fish assemblage such that each subassemblage is homogenous with respect to the amount of labor required to obtain a given return, as measured in a currency like calories. Once we have created these subassemblages, we can track changes in the amount of labor invested in fishing through space and time from the size of the corresponding subassemblages. The most obvious way to create such homogenous assemblages would be to compile data on the return per amount of time committed for finding, capturing, and processing fish with a particular technology. These data could then be used to classify fish species by rate of return, grouping together fish with similar return rates. Along coastal California, however, fishers took dozens of different fish species from a variety of habitats, using a wide array of gear. No comprehensive set of ethnographic or experimental data from which we could estimate return rates exists. We will have to rely on qualitative means for evaluating the labor required to procure fish and for creating homogenous fish assemblages.

As mentioned previously, technological change comprises a key mechanism by which intensified production may be achieved (Johnson and Earle 2000). Some tools require a greater investment in labor to make, maintain, and use than other tools. Identification of the means used to catch fish may provide an indication of the amount of labor involved. Technologies available to prehistoric fishers of southern California, based on ethnohistoric and archaeological evidence, included spears and harpoons; bone gorges; composite hooks; circular shell fishhooks; various types of nets, such as dip nets and drag nets; tule reed rafts; and plank canoes (Hudson and Blackburn 1982). This gear varies in the fixed costs required to produce it.

Ethnographic evidence from the Great Basin indicates that hook-and-line and spears are much less expensive to produce than nets (Ugan et al. 2003). Manufacture of string used to weave nets may itself entail weeks of work (Hardy 2008). Increased use of nets thus represents an intensification of fishing practices.

Ethnohistoric and experimental evidence from southern California shows that plank canoes were more expensive to produce than tule reed rafts (Arnold 1995). Rafts and plank canoes, however, likely saw use in other activities besides fishing. For this reason, the cost of raft or plank canoe production should not necessarily be considered part of the cost of fishing. Subsequent analysis will focus strictly on the gear used to capture fish.

To create homogenous assemblages and track the investment of labor in fishing, fish assemblages should be subdivided to reflect differences in the gear used to exploit them. Having decided that fish assemblages should be so divided, the issue then becomes: How can we identify the gear used to capture fish? Answering this question requires middle-level theory that can link physical characteristics of the fish assemblage to gear type. Gear types differ in the sizes of fish captured by them (Wheeler and Jones 1989:168). Nets should capture a larger range of fish sizes than other gear, such as hook and line or spear. Hook and line or spears cannot effectively capture smaller species. Assemblages formed primarily from net-caught fish should have a larger proportion of small fish than assemblages formed from fish primarily caught by hook and line or spear. To verify this intuition, additional sources of data from which middle-level theory could be derived would be very helpful.

Baseline data on the size-frequency distribution of fish from the near-shore habitat in southern California, drawn from modern sources, could be compared to the size-frequency distribution of fish bone from archaeological assemblages. Prehistoric fishers presumably selected a portion of the natural range of variation in fish size through their use of particular fishing gear. Thus the comparison would facilitate the identification of such selection. Published modern data of this sort are surprisingly rare. None could be found for southern California. Beach seine netting around an estuary in Alaska produced fish assemblages whose size-frequency distributions were largely unimodal, with a long tail to the right (Robards et al. 1999). The size-frequency distribution of individual species varied from unimodal to multimodal, depending on the number of age classes present. The applicability of these data as an analogy to fish from southern California can obviously be questioned. The form taken by the Alaskan size-frequency distributions is probably not exceptional, however, and a consideration of the factors that produced these distributions may be useful.

Any near-shore habitat will likely contain a range of species, each represented by specimens from one or more age classes. Different species will vary in mean size within a particular age class. The aggregate of the individual size-frequency distributions is therefore likely to produce a highly variable unimodal distribution, particularly when individuals from many different species are represented. Assemblages formed from a mix of fish caught by net and fish caught by hook and line or spears should have a bimodal size-frequency distribution. The proportion of fish in each mode should reflect the emphasis placed on netting and other fishing gear. Variation in the size-frequency distribution among archaeological assemblages should provide some indication of variation in the techniques used to take fish.

Middle-level theory, however, must also verify that the size of fish bone reflects live fish size. In general, the size of particular animal parts reflects overall body size (Reitz and Wing 1999:68–71, Table 3.24). Previous studies of a number of species have demonstrated a strong, positive relationship between vertebra size and fish size (e.g., Casteel 1976b; Granadeiro and Silva 2000), allowing inferences to be made regarding the original size of a fish based on vertebra size. The exact nature of this relationship varies by species and by the specific vertebra measured.

Other fish bones, including various jawbones and otoliths, have also been employed to estimate fish size (e.g., Broughton 1999; Leach and Davidson 2001; Longenecker 2008). For analysis of California midden assemblages, vertebrae seem to be a useful bone type on which to focus. Vertebrae are generally the most well-represented bone type among all species likely to occur in these midden assemblages. Vertebrae will therefore be most likely to provide adequate sample sizes for further analysis.

Ideally, we should obtain multiple specimens for each species represented in the middens and develop functions relating bone size to fish body size. Such a project requires large collections, spanning dozens of species and including a range of sizes for each species. Most faunal analysts probably do not have access to collections of this scope.

A preliminary analysis using a variety of common species from southern California demonstrated that a positive relationship between vertebra size and fish size exists among many species of bony fish (teleosts) (Table 11.1 and Figure 11.1). The individuals

Table 11.1. Live Weight and Vertebra Characteristics.

Taxa	**Accession**	**Live Weight (g)**	**Abdominal Height (mm)**	**Caudal Length (mm)**	**Caudal Width (mm)**	**Caudal Height (mm)**	**Caudal Weight (g)**
Amphistichus argenteus	510	42.5	2.2	2.3	2.2	2.1	0.10
Anchoa compressa	975	16.1	1.3	2.1	1.7	1.6	0.00
Atherinops affinis	1,062	83.4	2.0	3.1	2.8	2.4	0.02
Atherinopsis californiensis	353	190.2	2.7	3.9	3.5	3.3	0.03
Chromis punctipinnis	1,222	314.0	3.9	6.3	4.1	3.9	0.10
Embiotica jacksoni	1,187	453.3	4.7	4.6	5.2	4.7	0.14
Engraulis mordax	1,048	12.2	1.3	1.9	1.4	1.6	0.00
Genyonemus lineatus	909	228.3	4.2	6.5	4.7	4.1	0.07
Girella nigricans	951	527.9	4.9	6.5	5.3	5.4	0.29
Heterostichus rostratus	343	47.6	2.2	2.5	2.4	2.6	0.10
Hyperprosopon argenteum	1,190	58.2	2.7	2.9	2.8	2.7	0.03
Hypsops rubicundis	1,226	259.3	3.4	4.8	3.8	3.7	0.12
Oxyjulius californica	1,119	140.5	3.2	5.8	3.7	3.5	0.70
Paralabrax clathratus	344	98.2	3.1	5.2	3.2	3.0	0.04
Paralabrax clathratus	953	1278.1	7.6	10.6	9.5	8.3	N/A
Paralabrax nebulifer	1,101	188.0	5.5	7.9	5.1	5.0	0.15
Paralabrax nebulifer	1,105	1,128.5	7.4	10.5	7.4	6.9	0.43
Paralichthys californicus	932	683.7	7.0	7.9	8.0	8.5	0.41
Porichthys myriaster	1,059	298.5	4.9	5.4	5.0	5.2	0.09
Rhacochilus toxotes	N/A	131.9	3.2	3.4	3.2	3.1	0.04
Rhacochilus toxotes	1,215	209.9	3.9	3.7	3.9	3.9	0.06
Rhacochilus vacca	1,218	444.4	4.8	4.5	4.7	4.7	0.14
Scomber japonicus	1,143	378.5	3.9	7.4	4.8	4.0	0.08
Sebastes hopkinsi	1,344	423.9	4.9	7.6	5.6	5.4	0.17
Sebastes miniatus	1,345	310.1	4.2	5.8	4.6	4.6	0.12
Sebastes saxicola	1,293	19.5	2.2	3.0	2.0	2.0	0.10
Semicossyphus pulcher	303	1360.0	6.6	8.7	7.6	6.9	0.51
Seriphus politus	904	28.1	2.2	3.4	2.0	2.2	0.01
Thunnus albacares	340	2,143.1	7.2	9.2	8.6	8.7	0.32
Xenistius californicus	1,120	41.6	2.2	2.5	2.5	2.4	0.02

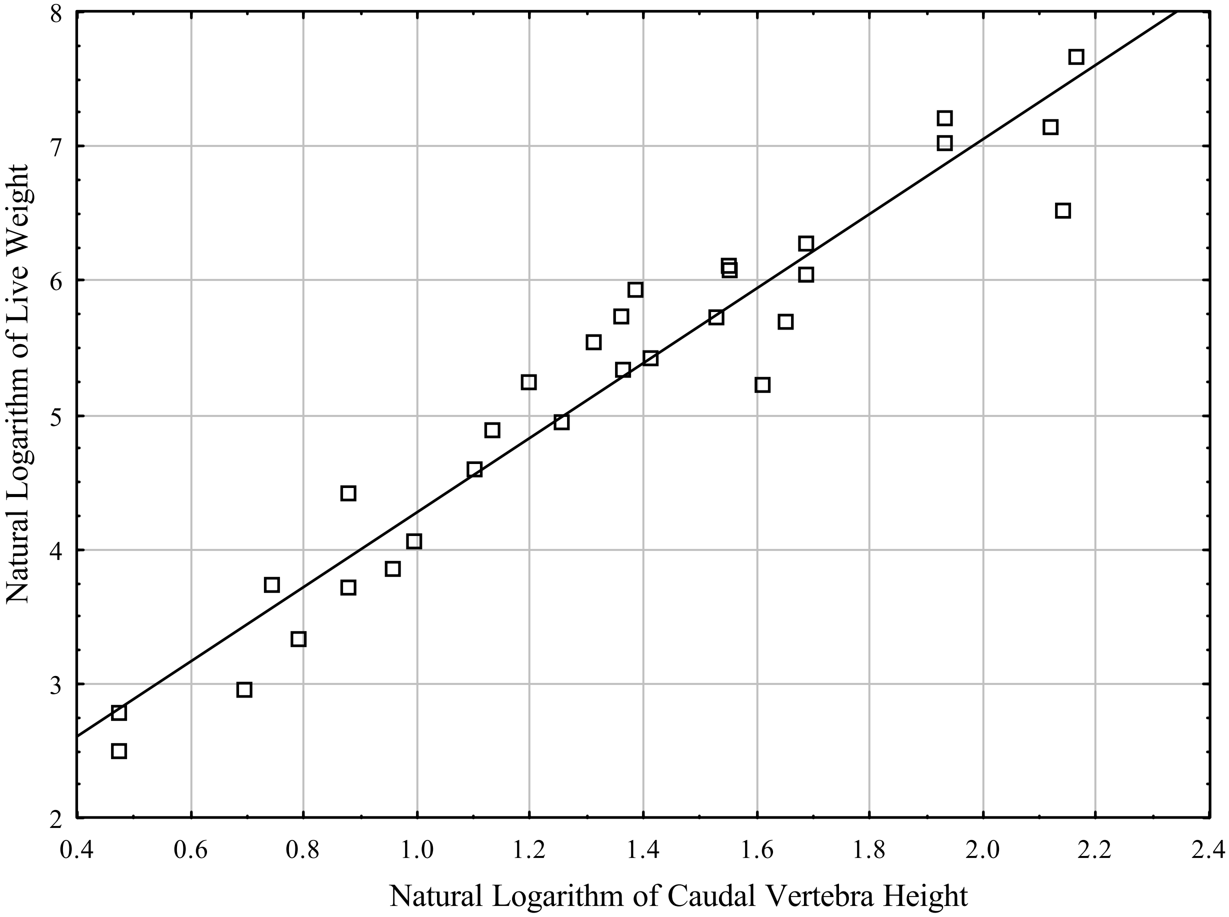


Figure 11.1. Scatter plot of the natural logarithm of caudal vertebra height and the natural logarithm of fish live weight.

used in the analysis derived from an unsystematic sample of specimens from UCLA's Zooarchaeology Laboratory for which live weight had been recorded. The analysis showed that a positive, linear relationship obtains between the logarithm of vertebra size and the logarithm of live weight for the specimens in this sample. This relationship appears to be an instance of allometric scaling.

Many animal species exhibit a power-law relationship between the scale of particular traits and overall body size (Reitz and Wing 1999:69–71). Let y equal body size and x equal the size of a particular trait. Then: $y = ax^b$, where a and b are both constants and the parameters to be estimated from the data. Note that a logarithmic transformation of this relationship results in the following linear equation:

$$\log(y) = \log(a) + b\log(x)$$

This equation produces a straight line with the y intercept at $\log(a)$ and a slope of b. The logarithmic transformation of the data illustrated in Figure 11.1 shows this kind of line.

For my sample of fish, I evaluated the relationship between the logarithm of fish live weight and the logarithm of caudal vertebra size using a linear regression analysis. The estimates for the sample are $a = 4.54$ and $b = 2.77$. The 95 percent confidence interval for a ranges from 3.05 to 6.76, while the 95 percent confidence interval for b ranges from 2.49 to 3.05. For this analysis, $r^2 = 0.93$, and the p-values for both parameters are less than 0.001. The low p-values indicate that the sample size was sufficiently large. Vertebra height thus provides a reliable predictor of live weight within the range of sizes represented in the sample.

The sample of fish for this analysis should be expanded. Nevertheless, it supports the commonsense notion that fish bone size reflects the overall size of fish. The data that corroborate this middle-level theory are not comprehensive, but they provide sufficient justification to proceed. Caudal vertebra height will be used as a measure of fish size in subsequent analyses.

The use of vertebrae introduces an additional issue of quantification that requires resolution. Bony fish have two main types of vertebra: abdominal and caudal. Predictable variation in form occurs among the abdominal and caudal vertebrae in the vertebral column of an individual fish. Despite this predictability, an undifferentiated pile of fish vertebrae is usually just separated into these main types because the variation can be subtle. Multiple specimens of a single vertebra type (like caudal vertebrae) from a particular species thus could be attributable to a single individual or multiple individuals. Many statistical tests, however, require that each observation be independent of the others. This assumption is particularly critical for the analysis of size-frequency distributions. The assumption of independent observations would be violated if multiple bone specimens derived from the same individual. This violation could dramatically affect inferences regarding the shape of that distribution. Some method must be used to eliminate potentially redundant specimens.

Two criteria can be used to identify vertebrae from separate individuals. First, the size of vertebrae within an individual bony fish (excluding the length of the centrum) typically varies only a little. The vertebral centra of sharks, skates, and rays (elasmobranchs) seem to vary to a much greater extent within individuals. Subsequent analysis focused on bony fish for this reason. Second, each species of bony fish has a characteristic number of abdominal and caudal vertebrae, and this number varies modestly among individuals (e.g., Clothier 1950). A small number of caudal vertebrae within a narrow size range from a particular taxon, for example, may well have come from a single specimen. Vertebrae from a particular taxon that span a large size range or that occur in large numbers within a small size range are likely to have derived from multiple specimens.

In the sample of fish specimens from UCLA's Zooarchaeology Laboratory, when comparing abdominal and caudal vertebrae, vertebra height typically varied less than .3 mm. The amount of variation in vertebra size within individuals could be a function of the overall size of those fish. Size differences between the abdominal and caudal vertebrae within an individual might be expected to be greater for larger individuals. For this reason, I examined the relationship between abdominal/caudal vertebra size differences within individuals and the size of those individuals' caudal vertebrae. In an initial inspection of the data, two large fish appeared to be outliers. I removed the outliers prior to further analysis. With these two cases omitted, a simple linear regression estimated the y intercept to be .044 and the slope of the regression line to be .055, while r^2 equaled .21 and p equaled .01. The size difference within individuals was not strongly correlated with the overall size of the caudal vertebra. This rule of thumb may therefore be widely applicable. When the number of caudal vertebrae within a .3-mm size interval exceeds the typical number for that taxon, more than one individual from that size range may be represented. Additional work should be undertaken, using a larger sample of fish, to confirm and refine this observation. In the interim, the foregoing principles and observations will be used to calculate the minimum number of individuals represented and to determine their size.

Analysis of archaeological assemblages should begin with the identification of modes in the distribution of fish size—modes that should reflect the use of different fishing gear. The mode of smaller fish represents fish taken by net, and the mode of larger fish reflects fish taken by hook and line or by spear. The identification of these modes may not be straightforward, since netting may capture large fish as well as small fish. In assemblages where net-caught fish predominate, the prevalence of net-caught fish may obscure any mode in the fish size distribution formed by fish caught with other gear.

Fortunately, statistical techniques can help distinguish separate populations that are mixed together in a single distribution. Finite mixture distributions model such situations (Monchot 1999). Mixture models can be fit to data using the maximum likelihood method (Bolker 2008:169–221). To use this method, probability distributions that are appropriate for the variability in the data have to be selected.

For caudal vertebra size-frequency data, a mixture model comprising two lognormal distributions seems suitable. This model has five unique parameters: the proportion of fish in one of the two distributions, the mean and standard deviation of the first lognormal distribution, and the mean and standard deviation of the second lognormal distribution. Under certain values for the standard deviation, lognormal distributions may have a short tail to the left and a long tail to the right. Distributions with this form reflect the presence of some cases that are much larger than the rest. Other values of the standard deviation can cause the lognormal distribution to resemble a normal distribution. The lognormal probability distribution is thus sufficiently flexible to model the type of fish caught by different gear. The parameter values estimated by the mixture model should provide further clues to the type of gear used to catch fish.

The maximum likelihood method finds the parameter values that make the observed data most likely to occur, given the assumed probability distributions. Likelihood values derive from the product of the probability of observing each case in the data at a particular set of parameter values. For continuous probability distributions, the calculations employ the probability density rather than the probability. Likelihood calculations, in practice, typically use the logarithm of the likelihood (log-likelihood), because logarithms can be summed. Calculating the product of many small numbers can be computationally more difficult than summing the logarithm of those numbers. The best parameter estimates have the highest likelihood value or the lowest negative log-likelihood value.

Mixture distributions can be analyzed using the mixdist package for the R statistical program (Du 2002). This package uses special algorithms to search the space of parameter values, calculate likelihood values, and find the best parameter estimates. The package allows the parameters of the contributing populations, including the proportion of each population represented in the distribution and the mean vertebra size in each separate population, to be estimated.

Direct search of the parameter space provides another straightforward approach to finding the maximum likelihood estimates (Bolker 2008:223–225). In a direct search, likelihood values are calculated for each combination of parameter values within a specified range of those parameter values. The likelihood values are then compared to each other to find the maximum likelihood estimates.

Having fit the models, another issue must be resolved: Do these models provide an appropriate fit to the data? A simpler model might also explain the observed patterns. A simpler model than the mixture model of two lognormal distributions is a single lognormal distribution. Models with many parameters generally fit data better than models with fewer parameters. Models with fewer parameters, however, should generally be preferred to models with more parameters, following the principle that simpler explanations are better than complex explanations (Fogelin 2007). Models with many parameters may also be worse at predicting variability in new data sets (Bolker 2008:203–204). In essence, more complex models may be finely tuned to match the particular, unique combination of factors that affected one data set. The next data set will have been affected by these factors differently. A simpler model that does not try to "explain" all variation may therefore do better at predicting variability in additional data sets. Such models focus on the deterministic factors that pattern variation. There are formal tests by which complex and simpler models may be evaluated.

The likelihood ratio test provides a way to compare nested models (Bolker 2008:204–209). Models are nested when complex models can be reduced to simpler models by setting parameters to particular values. Mixture models of two lognormal distributions reduce to single lognormal distributions by setting the proportion of cases in the first lognormal distribution to zero or one. As the name implies, the likelihood ratio test compares the likelihood values of a complex model and a simpler model. The ratio of these values has a chi-square distribution. This chi-square distribution has degrees of freedom equal to the difference in the number of parameters between the two models being compared. If the observed ratio attests to a sufficiently significant increase in a complex model's fit to the data compared to a simpler model, that model's complexity can be justified. The likelihood ratio test would support the intuition that archaeological fish assemblages formed from the use of several fishing gear types if the mixture models provide a significantly better fit to the data than single lognormal distributions. The mixture model parameters can then be used to quantify the number of fish taken by nets and by other gear. Archaeological analysis should not just end with this estimate, however.

The overall contribution to the diet of fish caught by nets in comparison to fish caught by other gear is of particular interest. Smaller fish produce a lower return on the work invested in fishing, all other things being equal. Many small fish might have to be caught to provide the contribution to the diet that a single, large fish would provide. The proportion of net-caught or hook/spear-caught fish bone in an assemblage thus does not by itself accurately reflect that return. This contribution can be determined by calculating the total live weight of fish represented by the modeled distributions of net-caught fish and fish caught with other gear. The total live weight of fish in an assemblage has a more obvious relationship to the potential dietary contribution of the fish than the count of those fish. The positive correlation between caudal vertebra height and fish live weight allows these amounts to be inferred using a simple transformation of the data.

The total live weight of net-caught and hook/spear-caught fish may be calculated from the mixture model results. The mixture model provides parameters that can be employed to create an idealized size-frequency distribution for each population. These distributions are scaled using the inferred number of fish from each population and the live weight equation. The scaled distributions are then integrated over the range of observed vertebra heights to obtain the total weight of fish. Once this mathematical operation has been completed for both populations that comprise the mixture distribution, assemblages can be compared for patterns in the amount of fish caught by net and by other gear.

The mixture model results and their transformation into the weights represented by each distribution may be manipulated further to evaluate fishing strategies and their environmental context. The total weight of fish in each distribution can be divided by the estimated number of individuals from each distribution to produce the average fish size. Fish size should respond to local environmental conditions and the level of exploitation to which local fish were subject. Changes in regional climatic conditions are correlated with variability in the growth of fish (e.g., Black et al. 2005; Leach and Davidson 2001). Modern fishing practices have also decreased fish size among many species, as larger fish are preferentially taken (Hsieh et al. 2006; Hutchings and Baum 2005). Extensive fishing in the past conceivably could have affected local fish populations in a similar fashion. These predicted relationships will be explored further in the next section.

HIGH-LEVEL THEORY FOR THE INTERPRETATION OF PATTERNS IN FISHING INTENSITY

Formal economic theory provides expectations for the relationships among fish size, net use, and environmental conditions. Many different kinds of formal economic theory exist, and some of this diversity will be explored in the following paragraphs. I begin with a discussion of a technological intensification model. This model is both simple and directly relevant for understanding the decisions made by fishers faced with a choice of gear to use.

Recall that nets are more expensive to produce than other types of fishing gear (Ugan et al. 2003), and these fixed costs affect the circumstances under which different gear is employed (Bettinger et al. 2006; Ugan et al. 2003). This insight can be formalized in a model for technological intensification, following Bettinger et al. (2006:541). Let r_i equal the return rate for using a particular type of gear *i*, such as nets or spears (in kcal per hour); *p* equal the hours spent procuring fish; and m_i equal the hours required to manufacture the *i*th gear type.

Assume that nets are more expensive to produce than another type of gear ($m_{nets} > m_{other}$) and that nets provide a greater rate of return ($r_{nets} > r_{other}$). Nets would never be adopted if they were both more expensive and had a lower return rate. Under these assumptions, fishers will adopt nets when:

$$\frac{r_{nets}}{m_{nets} + p} > \frac{r_{other}}{m_{other} + p}$$

The foregoing equation can be used to derive the length of time fishers would have to be engaged in procurement for nets to produce better returns than another gear type. This threshold is given by the following equation:

$$p = \frac{(r_{other} \times m_{nets}) - (r_{nets} \times m_{other})}{r_{nets} - r_{other}}$$

Some useful insights can be derived from the model. Because nets are expensive to make or acquire, they have to be used extensively for the benefits to outweigh the costs. Fishers should prefer to use nets once some threshold level of fishing effort has been reached. The model cannot explain why fishers might choose to fish extensively, however. Declining environmental conditions would seem a plausible reason to redouble fishing efforts. Despite the plausibility of this intuition, any drop in environmental productivity that affects the return rates of different gear types to the same extent does not alter the threshold value of fishing effort. Any constant that changes the value of return rates equally can be divided out of the model. The model was not intended to evaluate the effects of such factors on investment in technology.

The model also assumes that the costs of finding, chasing, and processing fish are constant across gear types (Bettinger et al. 2006:541), so it does not include them. Like return rates, the values of these variables are likely to be affected by environmental changes. The technological investment model can be revised to incorporate search and pursuit costs.

This revision will allow variability in the abundance of fish to be evaluated. To extend the model, let *o* equal the hours spent searching and pursuing prey. With this addition to the original model, the condition under which fishers would adopt nets is:

$$\frac{r_{nets}}{m_{nets} + p + o} > \frac{r_{other}}{m_{other} + p + o}$$

The threshold number of hours spent in procurement at which the return rate of nets is the same as another gear type is thus given by:

$$p = \frac{[r_{other} \times (m_{nets} + o)] - [r_{nets} \times (m_{other} + o)]}{r_{nets} - r_{other}}$$

The revised model does not have qualitatively different implications for the adoption of different gear types. The revised model does show that an increase in the hours spent searching for fish would reduce the time at which nets would be preferred relative to another gear type, given the assumption that nets have a higher return rate. An environmental change that altered the abundance of fish, increasing search times, could lead to greater use of nets.

Poor conditions may have other observable effects on archaeological fish assemblages. Recall that fish size may be sensitive to climate (Black et al. 2005; Leach and Davidson 2001) and to predation (Hsieh et al. 2006; Hutchings and Baum 2005). The prey choice model speaks to the relationship between fish size and fishing practices. This model may therefore provide a better context for understanding net use.

Prey choice models show that foragers who seek to optimize their returns should preferentially take certain kinds of prey (see reviews in Bettinger 1991; Bird and O'Connell 2006; Lupo 2007). All other things being equal, fishers using hook and line or spears should focus their efforts on prey that is large, readily caught, and easily processed. Such prey provides a greater return for the effort expended. Archaeological applications of prey choice models typically assume that larger prey is preferred to smaller prey. In these applications, the cost of handling and processing larger prey is presumed not to be commensurately larger as well. When large prey is abundant, fishers will forgo opportunities to catch other types of fish. Fishers will become less selective as the density of preferred prey decreases, however.

Thus fishers should target large fish, unless such fish become scarce due to overexploitation, reduction in favorable habitat, poor marine productivity, or other circumstances. Fishers will still take large fish whenever they are available, even as those fish become less abundant. They should just be more willing to take smaller fish in the face of scarcity. The average weight among fish caught by hook or by spear may thus serve as an index of environmental conditions. Fish size should also be correlated with other environmental indices.

The discussion of the prey choice and technological intensification models can now be integrated to provide additional predictions. Nets provide better returns than other gear only if fishing effort exceeds a threshold number of hours to offset the high costs of making those nets. The threshold number of hours is the same for all fishers, so fishers should respond identically when faced with changes in search costs or gear production costs. Shifts in environmental conditions that decrease fish abundance and increase search costs will lower the threshold number of hours for all fishers. The frequency of net use may change (but change rapidly) only when environmental perturbations have altered this threshold value sufficiently. Using average fish weight among hook- and spear-caught fish as an index of environmental conditions, net use may change only when the average fish weight has reached certain levels. Net use may predominate when average fish weight reaches a particularly low value, and it may be rare when average fish weight attains a particularly high value.

In practice, however, individuals may vary in return rates and opportunity costs in using various types of gear (e.g., Bird and Bleige Bird 2000). Children, for example, may be better suited for simple hook and line fishing than for the production and use of large nets. This variability may engender a more gradual response to changing conditions among fishers. Some fishers may be quite sensitive to environmental changes and quickly switch technologies, while other individuals may not be so sensitive. Average weight among hook- and spear-caught fish, again serving as an index of environmental conditions, may therefore be negatively correlated with net use, provided that the assumptions of these models hold true.

The technological intensification and prey choice models employ a number of assumptions. The models assume, for example, that individuals possess perfect information about their environment and the return rates to fishing with various gear types. The models also assume that the relevant currency is the nutrients that prey would provide upon consumption. To the extent that these models fail to fit particular real-world cases, other models that use different assumptions should be explored.

Suppose, for example, that fish are valuable to fishers as a good to be exchanged for other products. The value of fish would thus be a function of both their return rate and the demand for fish among consumers. To the extent that fishers have a comparative advantage in fish procurement and demand for fish is relatively strong, net fishing may be worthwhile, even if it is costly. Under these circumstances, the high cost of fish procurement would be offset by the goods received in exchange.

Specialized fishing need not have developed for fishing to be affected by the emergence of exchange systems. Fishing and the specialized production of other goods could be alternative strategies for the acquisition of desirable products. Under this scenario, fishing poses an opportunity cost to other specialized production. Fishers may therefore be less inclined to spend large amounts of time fishing if they can more easily satisfy their needs through the production and exchange of other goods. While the microeconomic theory underlying both of these proposals is well established, archaeological evidence for the operation of such processes may be less obvious.

If fishing develops into a specialized activity, the total amount of fish caught ought to be positively correlated with other evidence for the importance of specialized production and exchange. Net use may increase dramatically once some threshold level of specialized production and exchange has been reached, as the number of hours spent fishing increases to the point at which net use becomes viable. Alternatively, net use may increase more gradually as exchange grows in significance due to variability among fishers regarding the threshold value at which they would adopt nets.

If fishing is a lesser alternative to the specialized production of other goods, net use may be negatively correlated with evidence for the importance of specialized production and exchange. Net use may then drop precipitously once a threshold level of specialized production and exchange has been attained. Of course, net use may decline more gradually due to the same variability among fishers regarding the threshold level of effort that has been discussed previously.

Like the technological intensification and prey choice models, these microeconomic models of net use assume that fishers have perfect information about return rates, environmental conditions, and demand for fish. Assumptions of this sort may be appropriate as an approximation for simple adaptive problems. Information may be very difficult to gather or evaluate, however (Henrich 2002). Return rates for the use of different gear types and search costs may be difficult to estimate, for example. Experimental studies, ethnographic evidence, and theoretical considerations suggest that individuals acquire relatively few norms through their own trial-and-error learning (Boyd and Richerson 1985; Henrich 2002).

Models of cultural transmission allow the effects of imperfect information to be incorporated. Individuals acquire much of their norms through a mechanism of cultural transmission that includes some type of imitation (Boyd and Richerson 1985; Henrich 2002). Most fishers may prefer to take their cues about the type of gear to employ from someone else, like a particularly successful fisher. Transmission rules of this sort can lead to the spread of adaptive norms (Boyd and Richerson 1985).

The utility of explicit models of cultural transmission often lies in their ability to account for cases where culture change appears maladaptive (e.g., Henrich 2004) or unrelated to adaptation (e.g., Neiman 1995). Simpler economic models may provide an adequate account of shifts in adaptive norms when such changes have obvious adaptive consequences (Bettinger et al. 1996), as may be the case with many changes in subsistence. Models like the prey choice and technological intensification models usefully draw connections between key variables such as diet breadth and environmental conditions. They do not address the processes by which norms regarding subsistence behavior change. The details of these processes can be significant for understanding changes with less obvious adaptive consequences.

Cultural transmission models may therefore provide insight to cases where change in subsistence does not conform to the predictions of the prey choice or technological intensification models. In many cultural transmission models, random factors like sampling effects and imperfect copying work alongside more focused imitation processes to elevate (or decrease) the popularity of particular cultural traits (e.g., Henrich 2004; Pletka 2004). Individuals may select a subset of the available population before choosing the "best" model or set of models to copy, for instance. These random factors work most powerfully among small groups. Sampling effects within small groups can eventually cause a particular variant to predominate within the group (Pletka 2004). Such changes typically occur only after many false starts, with substantial swings in the frequency of the trait within the population (Bettinger et al. 1996; Pletka 2004). The operation of sampling effects may thus be identifiable as a pattern of gradual change that does not closely correspond to other environmental or economic trends.

Other effects resulting from the mechanics of cultural transmission are possible. Cultural transmission processes may sometimes lead to the development of exaggerated cultural traits featured in prestige competition or to within-group homogeneity and among-group heterogeneity in certain characteristics (Bettinger et al. 1996; Boyd and Richerson 1985). The applicability of alternative models depends on the details of a particular case. Discussion of a case study seems appropriate to illustrate these points and many of the issues that were raised previously.

CASE STUDY

The resolution of these issues of high-level and middle-level theory will be illustrated by an examination of fish assemblages from an archaeological site—designated CA-SCRI-191—located on Santa Cruz Island, California. The Fowler Museum of Cultural History at UCLA now houses these assemblages. I identified fish bones from the site using collections from the Los Angeles County Museum of Natural History and the Zooarchaeology Laboratory at UCLA. As I have discussed previously (Pletka 2001), fish assemblages from Santa Cruz Island are quite well preserved. The excavation techniques were adequate to ensure that the importance of small fish species can be evaluated (Pletka 2001). Those techniques remained consistent among all the assemblages. The proportion of small fish should therefore reflect the behaviors of interest rather than taphonomic factors or recovery techniques.

Located at the western end of Santa Cruz Island, CA-SCRI-191 is one of the few sites on the island to have been occupied from the late Middle through the Late period (Arnold 2001). The poor environmental conditions of the intervening Transitional period (A.D. 1150 to 1300) disrupted settlement at many other island sites. Extended drought affected much of the American Southwest during this period (Jones et al. 1999). Occupation on Santa Cruz Island persisted at the few sites, such as CA-SCRI-191, where freshwater occurred. The site lies near the mouth of Cañada Cervada Creek, an important source of freshwater.

Marine productivity may also have declined during the Transitional period (Arnold and Tissot 1993; Kennett and Kennett 2000). Paleoenvironmental data regarding ocean conditions are complex and not entirely consistent (Arnold and Tissot 1993; Kennett and Kennett 2000). Proxy data derived directly from Santa Cruz Island midden deposits, however, shows that sea surface temperatures during the Transitional period were unusually high (Arnold and Tissot 1993). These conditions may have affected the distribution and abundance of fish (see review in Pletka 2001).

A variety of social and economic responses to the challenges of the Transitional period have already been documented (Arnold 1992, 2001). The specialized production and exchange of various items emerged throughout the Chumash world (Arnold and Munns 1994). Specialized microlithic drill production, for example, developed near suitable sources of chert on the eastern end of Santa Cruz Island (Arnold 1987). Economic specialization in shell bead production arose at CA-SCRI-191 during this period. In exchange for beads, these specialized bead producers presumably received food and other goods. Fishers at the site may have responded by changing their fishing strategies. The number of fish caught by the site's inhabitants seems to peak late in the Transitional period before declining (see Figure 11.2 and Table 11.2).

This observation is consistent with other faunal analyses (e.g., Colten 2001), but it could be attributable to a number of different factors. The peak in density of fish remains could be due to changes in the rate of sedimentation. It could be ascribed to an increase in population at the site during the Transitional period. CA-SCRI-191 may have served as a refuge for groups from elsewhere on the island in this period, since fresh water was more readily available there. The increase in the density of fish remains could reflect a more widespread emphasis on fishing by the site's inhabitants as other foods normally taken by them became less abundant. It could be attributable to increased economic specialization. Fish may have subsidized on-site bead production. Workers at CA-SCRI-191 may have specialized in both bead production and fish procurement, as the local inhabitants had comparative advantages in these activities and exchanged beads and fish for other goods. The greater density of fish could also be due to some quirk of cultural transmission, as fishers made choices about the appropriate gear to use and effort to undertake based on the work being done by their neighbors. A more detailed examination of the data allowed these possibilities to be distinguished.

Histograms show that the distribution of caudal vertebra height varies from bimodal to unimodal among the assemblages (Figure 11.2). The distribution of vertebra height seems to have formed from two separate populations, each of which appears to

Table 11.2. Results of the Mixture Distribution Analysis.

Level	Period	*n*	Likelihood Ratio Test *p*-Value	Mode	Proportion	Proportion Confidence Interval	Log Mean	Log Mean Confidence Interval	Log Standard Deviation	Weight (g)	Proportion by Weight
15-20 cm	Late	41 (3)	0.28	Small	0.75	0.03-0.98	1.06	0.58-1.76	0.27	3,132.47	0.33
				Large	0.25	0.02-0.97	1.59	0.58-1.76	0.12	6,462.64	0.67
20-25 cm	Late	33 (1)	0.16	Small	0.72	0.17-0.94	0.99	0.62-1.14	0.29	2,061.23	0.41
				Large	0.28	0.06-0.83	1.50	1.23-1.62	0.10	3,020.60	0.59
25-30 cm	Late	66 (2)	0.12	Small	0.63	0.25-0.97	1.00	0.80-1.24	0.26	3,767.13	0.55
				Large	0.37	0.03-0.75	1.59	1.35-1.85	0.18	11,154.06	0.45
30-35 cm	Late	87 (10)	0.06	Small	0.76	0.45-0.91	1.07	0.91-1.18	0.28	6,868.12	0.19
				Large	0.24	0.09-0.55	1.66	1.46-1.73	0.13	28,553.29	0.81
35-40 cm	Transitional-Late	100 (6)	0.05	Small	0.71	0.11-0.93	1.20	0.75-1.31	0.31	11,355.03	0.28
				Large	0.29	0.07-0.89	1.67	1.41-1.80	0.14	29,534.52	0.72
40-45 cm	Transitional	79 (3)	0.01	Small	0.70	0.49-0.88	1.12	1.00-1.24	0.25	6,747.65	0.26
				Large	0.30	0.12-0.51	1.65	1.54-1.73	0.11	19,401.44	0.74
45-50 cm	Transitional	80 (3)	0.10	Small	0.74	0.11-0.94	0.99	0.60-1.12	0.29	5,452.52	0.22
				Large	0.26	0.06-0.89	1.59	1.21-1.76	0.16	18,853.45	0.78
50-55 cm	Middle	53 (2)	0.05	Small	0.53	0.26-0.84	1.07	0.89-1.26	0.26	3,113.33	0.18
				Large	0.47	0.16-0.74	1.55	1.44-1.64	0.14	13,926.05	0.82

Notes: The n column includes both the minimum number of individuals and (in parentheses) the number of specimens removed as outliers prior to the mixture model analyses. The confidence intervals are 90 percent confidence intervals. The reported weight of large fish also includes those large fish that were removed as outliers prior to analysis of the mixture models.

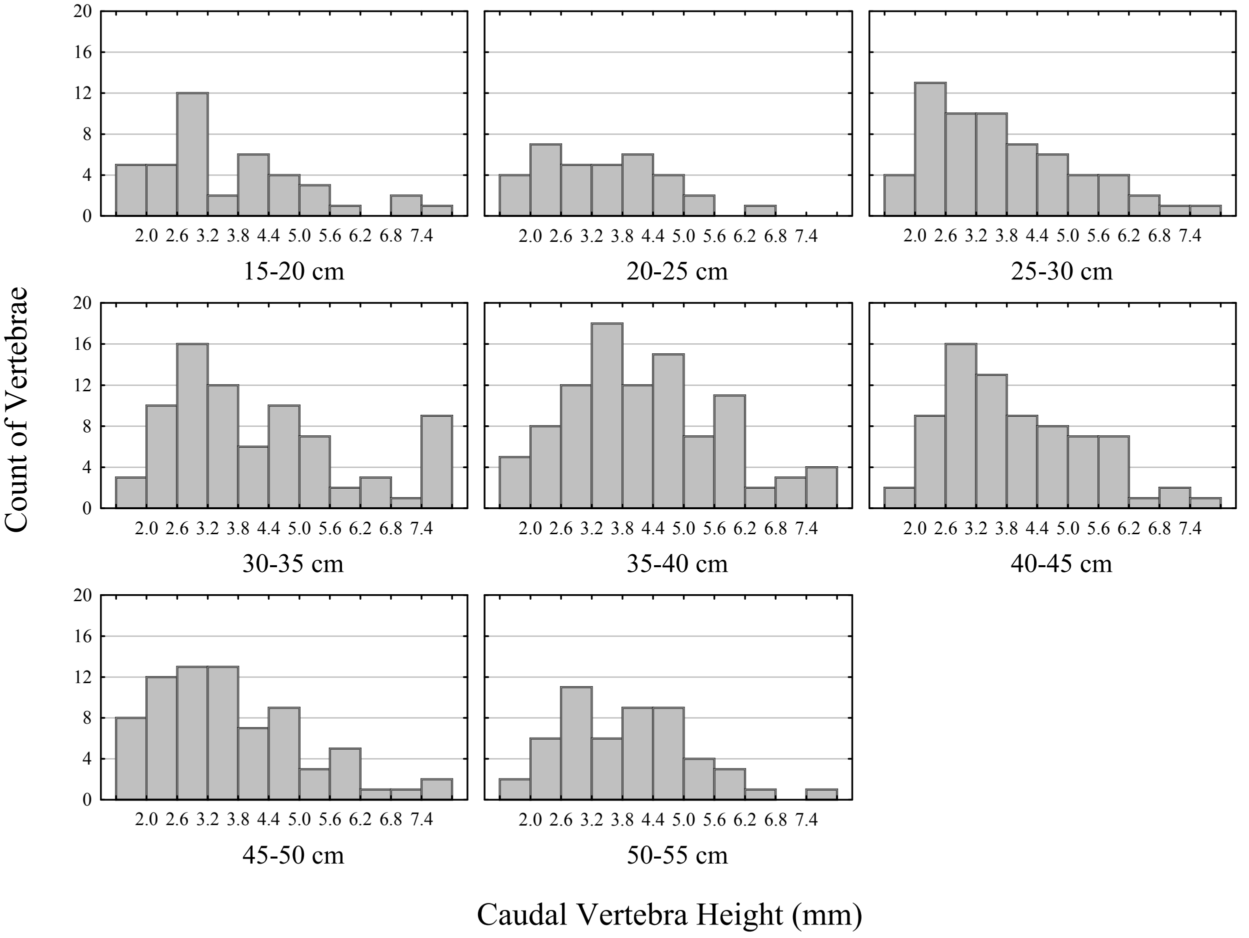


Figure 11.2. Histograms of caudal vertebra height by level from CA-SCRI-191.

have a lognormal distribution. The two modes are particularly evident in the assemblages from the 50 to 55 cm level, 30 to 35 cm level, and 15 to 20 cm level. The histogram for the 30 to 35 cm level also displays a third mode of very large fish. The first two modes among all these assemblages likely reflect the capture of fish by nets and by other gear types, while the third mode of the 30 to 35 cm level might represent the use of some additional technique.

Analysis using the maximum likelihood method and the direct search approach supported these observations. The observed size-frequency distribution was modeled as the combination of two populations with lognormal distributions (Figure 11.3 and Table 11.2), as previously discussed. The mixture model analysis excluded a few outliers from each assemblage, including the third mode in the 30 to 35 cm level. For each assemblage, I also fit a single lognormal distribution to the data. I then compared the fit of the mixture model to the single lognormal distribution using the likelihood ratio test (Bolker 2008:204–209). The likelihood ratio test *p*-value column in Table 11.2 shows the outcome of this comparison.

The mixture models provided significantly better fits to the data than the single lognormal distributions. Many of the *p*-values for the likelihood ratio tests, however, exceed the arbitrary .05 value commonly employed in studies. Notice that the *p*-values are generally lower when the sample size is higher. *P*-values often reflect such sample size effects. In addition, there is no universal threshold at which a *p*-value can be said to be truly "significant." The differences between the mean values of the lognormal distributions that comprise the mixture distributions are nontrivial. The standard deviations of the distributions of smaller fish are also consistently larger than the standard deviations of the distributions of larger fish. Such differences would be expected if the distribution of smaller fish derived from net fishing and the distribution of larger fish derived from the use of other techniques. Some fish are too small to be caught with hook or spear, but nets may catch both small and large fish. The mixture models thus appear to capture meaningful variation. For these reasons, I am comfortable applying the mixture models to all my assemblages, despite their greater complexity.

The analysis indicates that two separate populations formed the size-frequency distribution of each assemblage. The relative importance of these two populations varied only a little through time. The proportion of netted fish among the assemblages stayed consistently above 50 percent (Figure 11.4 and Table 11.2). The mixture models produced large confidence intervals for the estimates of proportion due to the relatively small sample sizes employed in the models (Table 11.2 and Figure 11.4). Much of the observable variation in proportion of netted fish may reflect sampling error. The prevalence of net use at the site, however, accords with the results of an earlier analysis using a different approach (Pletka 2001).

The use of nets and other fishing tackle may be further evaluated using the log mean and log standard deviation parameters for the individual lognormal distributions generated by the mixture model analysis. I used these parameters to calculate the weight of fish represented by the individual distributions (Table 11.2). As discussed in the methods section, the model parameters define idealized size-frequency distributions for each separate population that comprises the mixture distribution. The area under the curve of these idealized size-frequency distributions provides the probability that vertebrae in a population occur within any particular discrete interval of caudal vertebra height. These size-frequency distributions were scaled by the inferred number of fish from each population and the live weight equation and integrated over the range of observed caudal vertebra height to determine the total live weight of fish obtained using the two sets of gear. While this approach generated an estimate of the weight of the fish included in the mixture models, the models omitted some outliers.

The outliers also need to be considered. Because the omitted vertebrae are large, their contribution to the total weight of fish in each level is potentially substantial. I therefore calculated the weight of these fish directly from the live weight equation. This amount was added to the mode of larger fish. Table 11.2 reflects the results of this analysis in the

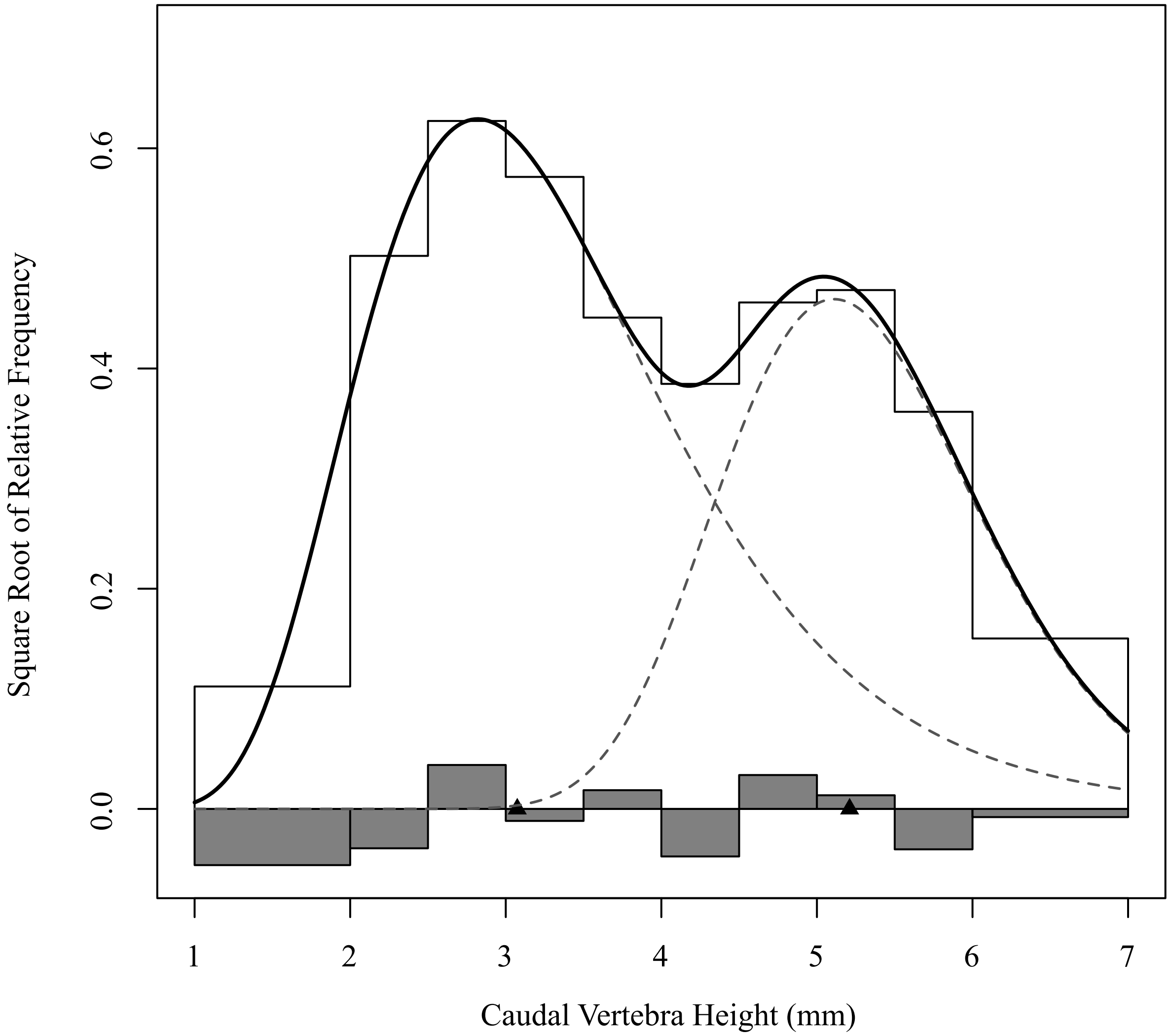


Figure 11.3. Example of mixture model results for the 40 to 45 cm level. The graph shows the histogram of the original data, the combined modeled distribution, and the individual size-frequency distributions. The triangles mark the means of the individual distributions, while the gray bars show deviations of the model from the observed distribution. The scale of the deviations is depicted in relative terms. Also note that the histogram interval differs from that used in Figure 2 and that three large outliers were removed prior to analysis.

"Weight" and "Proportion by Weight" columns. The inclusion of these outliers may reduce the homogeneity of the corresponding subassemblages. Fishers likely used several different techniques to catch such large fish. The distribution of smaller fish, however, should include only those fish caught with nets, allowing the proportion of net-caught fish, by weight, to be readily calculated.

The proportion of netted fish, by weight, in each level provides a better indication of the emphasis placed on fishing with that gear than the proportion of netted fish by count of vertebrae. Unsurprisingly, the proportion of netted fish by weight is consistently lower than the proportion of netted fish by count (Figure 11.5). The proportion of netted fish by weight varies modestly through time, and this proportion is higher during the later periods. The increased importance of netted fish during this time perhaps reflects the emergence of specialization at the site. Some fishers may have procured

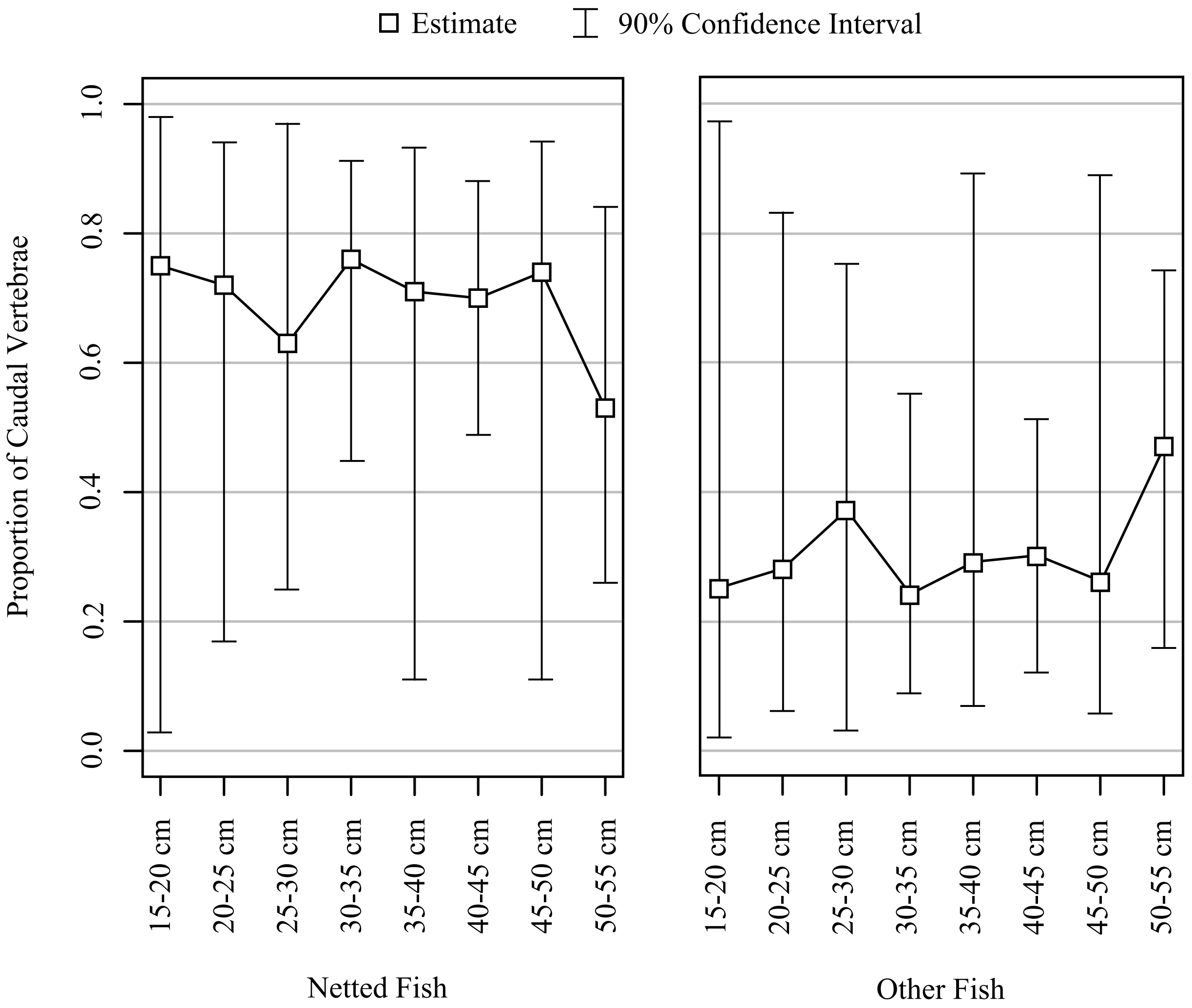


Figure 11.4. Proportion of caudal vertebrae from the "netted fish" and "other fish" populations by level.

fish in exchange for other goods. The proportion of netted fish by weight can be compared to measures of environmental productivity and economic specialization to confirm, refute, or refine this interpretation.

The average size of hook- and spear-caught fish ought to reflect environmental conditions, since fishers should always prefer to take the largest fish possible. For each level, I calculated the average size of hook- and spear-caught fish in the following manner. I divided the total weight of fish in the distribution of larger fish by the sum of two numbers. The first number is the mixture model's estimate for the number of fish in that distribution. The second number is the number of large vertebrae omitted from the mixture model. This procedure provides an estimate for the average size of hook- and spear-caught fish in grams.

The proportion of netted fish by weight does not, however, bear an obvious relationship to the average size of hook- and spear-caught fish (Figure 11.6). A Spearman rank-order correlation analysis found little correlation between these variables ($R = -.48$; $p = 0.24$). Note that the average size of hook- and spear-caught fish is highest in the levels ranging from 50 to 30 cm in depth. These levels were deposited during the Transitional period and the beginning of the Late period. The size of hook- and

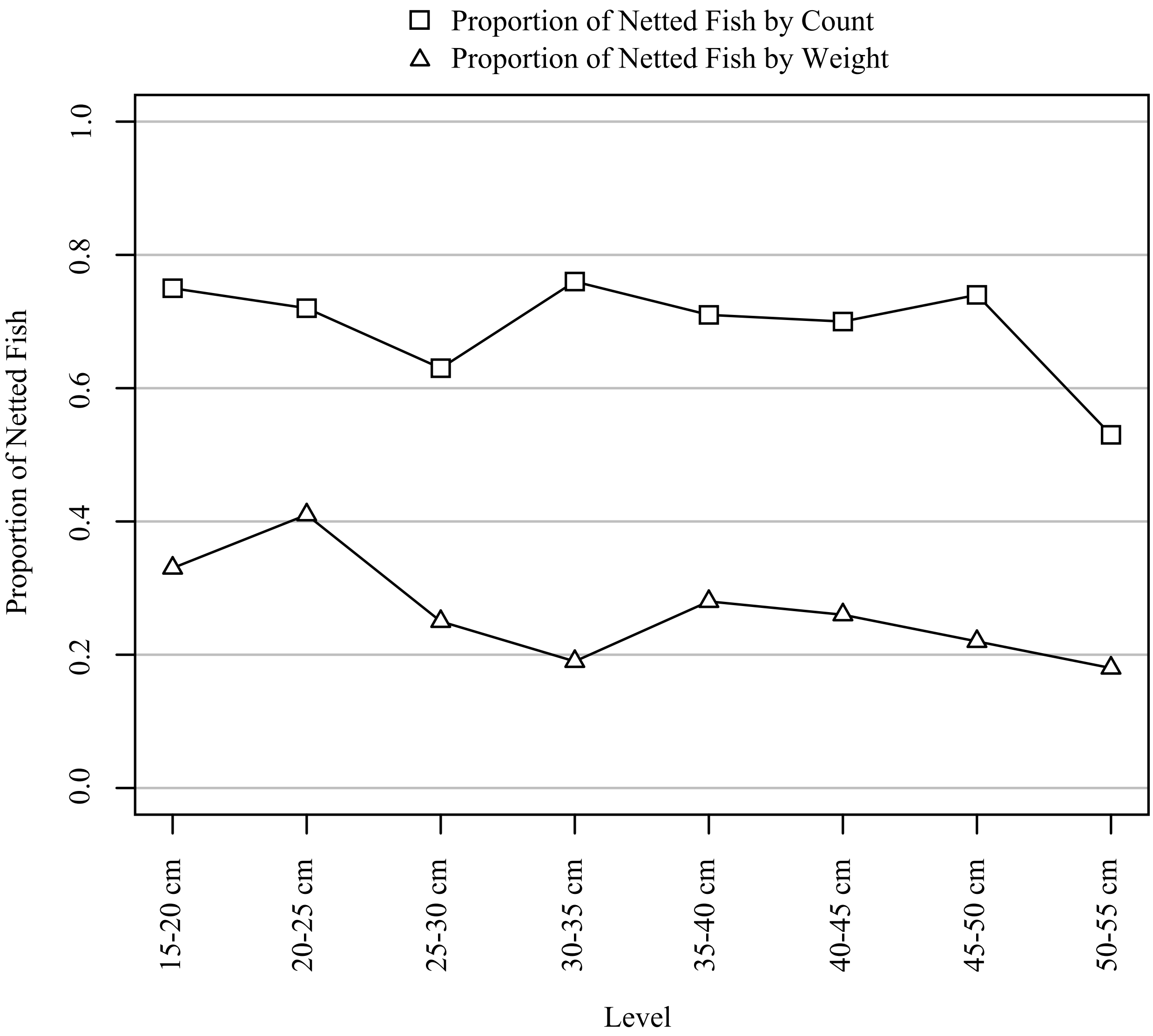


Figure 11.5. Plot of the proportion of netted fish by count and by weight for all levels.

spear-caught fish was much smaller in the earlier and later phases of occupation. Proxy environmental data from CA-SCRI-191 indicate that sea surface temperatures peaked in the time span represented by the deposits from the 35 to 45 cm levels (Arnold and Tissot 1993). As noted, the conditions of this period led to many changes, including the development of craft specialization and exchange among villages.

The relationship between specialized bead production and net fishing is obviously of interest, but the extent of specialized bead production and exchange at CA-SCRI-191 needs to be quantified. In particular, I wanted to find a measure of intensification that was appropriate for bead production. A series of changes characterize the development of specialized bead production at CA-SCRI-191 (Arnold and Graesch 2001; Arnold and Munns 1994). Both the scale of production and the types of beads that were made changed.

The greatest increases in the scale of bead production occurred prior to the late Middle period, so these increases took place before the deposition of the levels analyzed in this study (Arnold and Graesch 2001:78–79). The density of shell detritus and unfinished beads was quite high in all levels

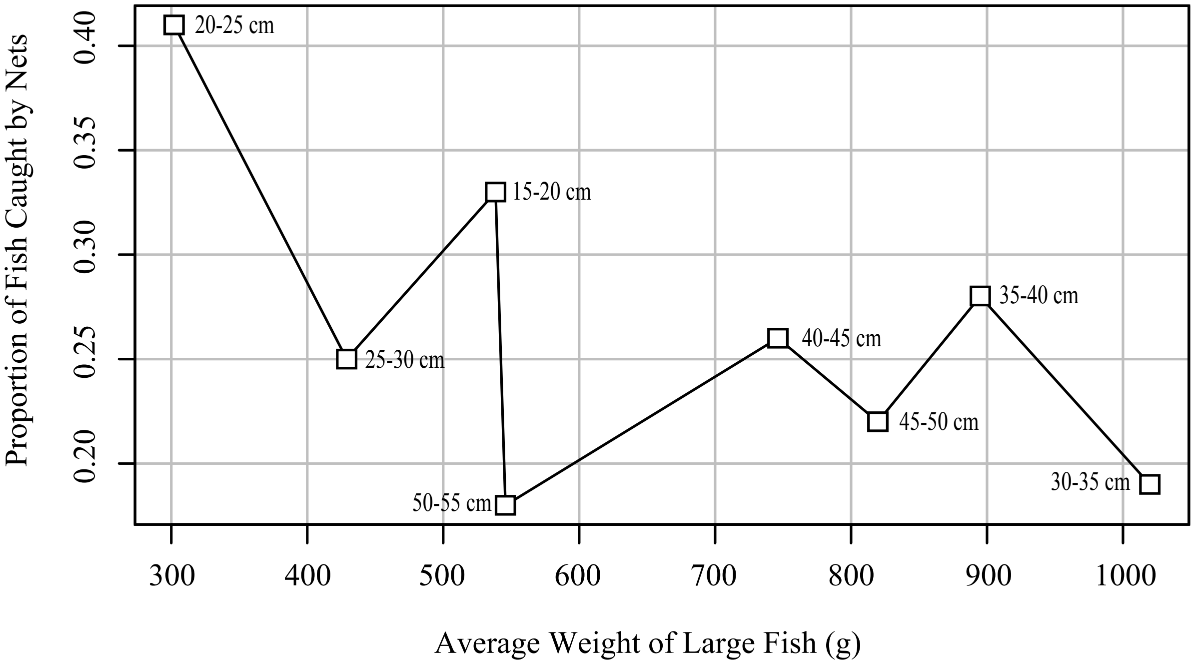


Figure 11.6. Plot of the average weight of large fish and the proportion of fish caught by nets.

that I analyzed, although some variation occurred. Variation in the intensity of bead production in these levels could be attributable to changes in sedimentation or to changes in population rather than to shifts in the intensity of production. A different aspect of bead production was therefore used to quantify changes in production and exchange.

The proportion of *Olivella* beads made from the callus portion of the shell is a better measure of the intensification of specialized production. Bead makers at CA-SCRI-191 and elsewhere began to make beads from the callus portion of the *Olivella* shell—rather than the wall portion—during the Transitional period (Arnold and Graesch 2001:81; Arnold and Munns 1994; Pletka 2004). The reasons for this shift are not entirely clear, but a demand for these beads clearly existed (Pletka 2004). In any case, the ratio of callus beads to wall beads increased steadily during the Transitional and Late periods (e.g., Pletka 2004:80–81). The shift did not occur because callus beads are easier to make. The callus portion of the *Olivella* shell is small and thick. An *Olivella* shell can produce more wall beads than callus beads. Callus beads are also harder to drill. Callus beads thus require more labor to produce than wall beads. For these reasons, the proportion of *Olivella* beads made from the callus portion of the shell served as an index of the intensification of bead production.

Based on a Spearman rank-order correlation analysis ($R = .74$ and $p = .05$), the proportion of netted fish has a strong, positive correlation to the proportion of callus beads (Figure 11.7). Note that one case, the 30 to 35 cm level, appears to be an outlier in this analysis. With the outlier removed, the correlation improves ($R = .89$ and $p = .01$). Fishing with nets does not seem to have posed an opportunity cost to the specialized production of beads. The occupants of CA-SCRI-191 intensified both activities.

Specialized bead production and net fishing apparently complemented each other. The intensification of these activities changed in response to similar microeconomic forces. Growing demand for

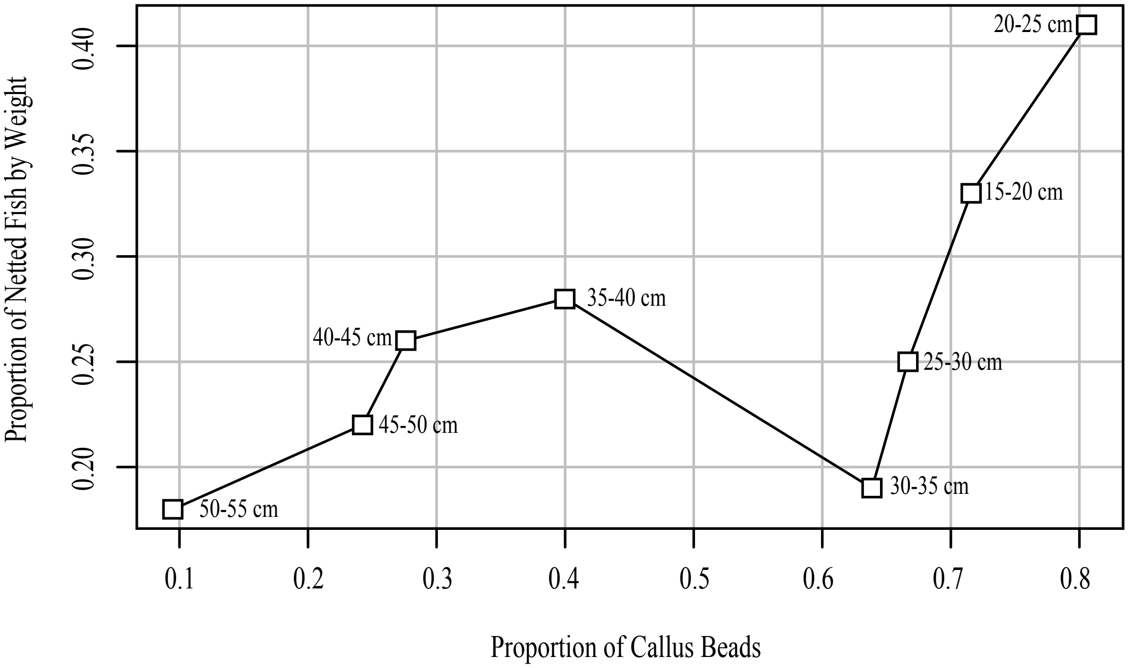


Figure 11.7. Plot of the proportion of netted fish by weight and the proportion of *Olivella* beads made from the callus portion of the shell.

callus beads probably led to the intensified production of this bead type (Pletka 2004). Specialized bead makers worked at CA-SCRI-191 and at other sites on Santa Cruz Island (Arnold and Graesch 2001). Fishers at CA-SCRI-191 likely provisioned such specialists. The site's inhabitants probably intensified these two particular activities because they possessed a comparative advantage in bead making and net fishing relative to the inhabitants of other sites.

The outlier in this interpretation is notable. The 30 to 35 cm deposit, dating to early in the Late period, provides evidence of extensive specialized production of beads but relatively little evidence of net fishing. The average weight of large fish, however, is highest in this deposit. As the discussion of the technological investment and prey choice models suggested, an abundance of large prey should increase the threshold number of hours that fishers would have to work for net use to be preferred. Fishers may have been induced to use hook and line or spears during this time because large fish were so readily available.

The data from CA-SCRI-191 thus support two interpretations. First, intensive fishing through the use of nets was another specialized activity, like the specialized production and exchange of beads. As reliance on specialized bead production and exchange increased, villagers at CA-SCRI-191 devoted a commensurate amount of time to fishing. Fishers may have supplied specialized bead makers in exchange for other goods. Second, environmental productivity varied sufficiently that people undertook both hook and line and spear fishing, and specialized bead production and exchange, during a portion of the Late period. Conditions may have been so favorable then that most fishers abandoned their expensive nets, as time spent searching for desirable fish dropped below a threshold level. The technological intensification and microeconomic models for net use are not mutually exclusive, and they explain different aspects of the variability in net use. The invocation of cultural transmission processes does not seem necessary to explain the variability.

CONCLUSION

This analysis has demonstrated that the intensification of subsistence practices can be evaluated even in the absence of detailed information regarding procurement return rates. Intensification can be identified from increased dependence on gear that is expensive to produce. For fishing practices, a greater reliance on nets should represent an intensification of fishing. The use of different fishing gear can be recognized as modes in a bone size-frequency distribution. Patterns in the use of nets can be related to the ecological and economic circumstances in which those patterns formed. Formal economic theory, taken from a variety of sources, provided useful interpretations of the patterns. While not all the high-level theory examined here was applicable to the case study, several theories were applicable and explained different aspects of variability in fishing intensification. The consideration of multiple explanations may also be beneficial in other cases.

ACKNOWLEDGMENTS

I would like to thank Mike Glassow and Terry Joslin for the invitation to contribute this paper and for their subsequent encouragement throughout its development. Jeanne Arnold provided access to the assemblages analyzed in this study and to other data from her work on Santa Cruz Island. Tom Wake allowed me to use space and comparative materials at UCLA's Zooarchaeology Laboratory. Robert Lavenberg provided similar access to the ichthyological collections at the Los Angeles County Museum of Natural History during my initial analysis of Santa Cruz Island fish bone. The paper benefited from the comments of the two anonymous reviewers and from comments by Roger Colten.

CHAPTER 12

Identifying Fishing Techniques from the Skeletal Remains of Fish

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Ichthyofaunal assemblages present unique challenges to the archaeologist in comparison to terrestrial faunal remains. The lack of morphological distinctiveness in most piscine postcranial elements impedes precise taxonomic identification and reduces the likelihood of recognizing high species diversity when present. Furthermore, the smaller and more fragile nature of fish bone threatens to leave these types of remains underrepresented in archaeological deposits and underconsidered in archaeological research. Nonetheless, appreciation of the role of fisheries as a resource in the development of human society in California is gaining momentum in prehistoric research (Jones 1992; McKenzie 2007; Pletka 2001; Raab et al. 1995).

Identification of fishing techniques in a prehistoric context is commonly achieved through recovery of particular types of fishing implements, such as hooks, weights, or harpoons. When these artifacts are not available, conclusions are based on speculations derived from contemporary fishing information and known fish behavior. These approaches may be flawed in some cases because of differential preservation, recovery techniques, and sample size, not to mention the assumptions of the researcher. Nonetheless, they do allow indirect inference of fishing techniques.

Our first objective in this paper is to evaluate various recovery procedures to understand better any biases that may emerge in the assemblage before analysis begins. In particular, we consider screen mesh size and sample size. Understanding the influence of recovery procedures on our ability to infer fishing techniques and their change through time is a critical component in the elucidation of culture change in coastal California. The second objective is development of an approach for inferring fishing techniques proposed previously, based on the argument that ichthyofaunal assemblages produced from hook and line as opposed to netting should be manifest in growth profiles. Rick and Erlandson (2000) argued that an early Holocene assemblage recovered from site CA-SBA-2057 contains evidence that netting was an important fishing technique. Their argument is based on the abundance of small clupeids (sardines, *Sardinops sagax*; and herrings, *Clupea pallas*) and surfperch (Embiotocidae) found at the site. Using ethnographic data and common sense, they conclude that these small fish were procured through some form of netting, despite no physical evidence of nets from the site. We evaluate the potential of Rick and Erlandson's approach by comparing various archaeological assemblages from what we consider baseline site types. The focus on vertebrae in our evaluation is intentional because of their superior preservation compared to other skeletal elements. The simple metrical data we use result in fish size profiles that directly reflect specific fishing techniques.

Before proceeding with our analysis, we must point out that even the most experienced contemporary anglers have difficultly predicting the outcome of fishing expeditions. Beyond the difficulties of predicting success rates of a particular fishing event, projecting what species will be caught is fraught with challenges, and tackle choice cannot eliminate catching fish of varying taxa that are not desired or anticipated. Rockfish (*Sebastes* spp.), for example, are generally caught while fishing in rocky reef/kelp bed environments. However, these fish occasionally are caught in muddy-bottom estuaries or in the surf zone over sandy bottoms. With this caveat in mind, lures, weirs, nets, and other gear can be employed with the anticipation of procuring a particular fish, but random chance always plays a role in any fishing endeavor. Consequently, we seek to predict only a likelihood, not an absolute outcome.

The setting for this research is the south-central coast of California, particularly within northern San Luis Obispo County (Figure 12.1). The tribal territories that overlap our study area are associated with the northern Chumash and coastal Salinan groups. The coastline here encompasses a variety of marine habitats, including estuarine, sandy beach, rocky near-shore, reef, and kelp forest habitats. Consequently, piscine diversity is great, and the methods Native Californians employed to exploit these fisheries were equally diverse and effective. The faunal assemblages used in this study were selected to represent this range of habitats and thus provide good test populations for assessing recovery and analytical methods for inferring prehistoric fishing strategies from osteological remains.

METHODS

Today, archaeologists working along coastal California employ a variety of techniques for collecting information related to fishing. Developed to overcome shortfalls in archaeological recovery in the past, microsampling, flotation, column sampling, and fine-mesh screening, among other techniques, have been applied in California to obtain a more balanced and accurate view of the constituents of deposits. Sifting through screens with smaller mesh sizes continues to be the most effective approach for recovering remains of small fish. Examples presented in this study were collected from deposits using 6-mm, 3-mm, and 1.5-mm mesh. The excavation units from which the assemblages came all measured 1 m^2 in area. The smallest mesh, 1.5 mm, was used to process the smaller column samples, which were typically 20-×-20 cm in area. Due primarily to extensive bioturbation in California coastal middens, archaeological excavation in the study area is generally conducted in arbitrary levels that are 10 cm thick. Individual level volumes of the column samples discussed here are .004 m^3.

Methods developed to identify fish size from skeletal remains are also important to this study. Early research relied on the simple fact that larger bones are derived from larger fish. While this approach is generally valid, it is overly simplistic and prone to inaccuracies. Efforts to overcome this shortcoming by focusing on particular elements, such as otoliths, have produced improvements (Balme 1983). Recent studies have found that even more accurate approaches may be used to estimate fish size from bone size based on logarithmic equations that more closely reflect the growth rates of fish (Carpenter 2002). As discussed below, our efforts focus more on relative measures, such as distinguishing large fish from small fish, rather than absolute measures that would equate to fixed values, such as weight or caloric value.

The methods developed for this study are based on previous investigations by Casteel (1974:96), who found a linear relationship between vertebral size and live fish weight. More specifically, Casteel demonstrated that the size of a fish may be ascertained from measuring the maximum width of the posterior face of one of its vertebra. The size profiles we produced in this study allow comparison of the range of small, medium, and large fish of

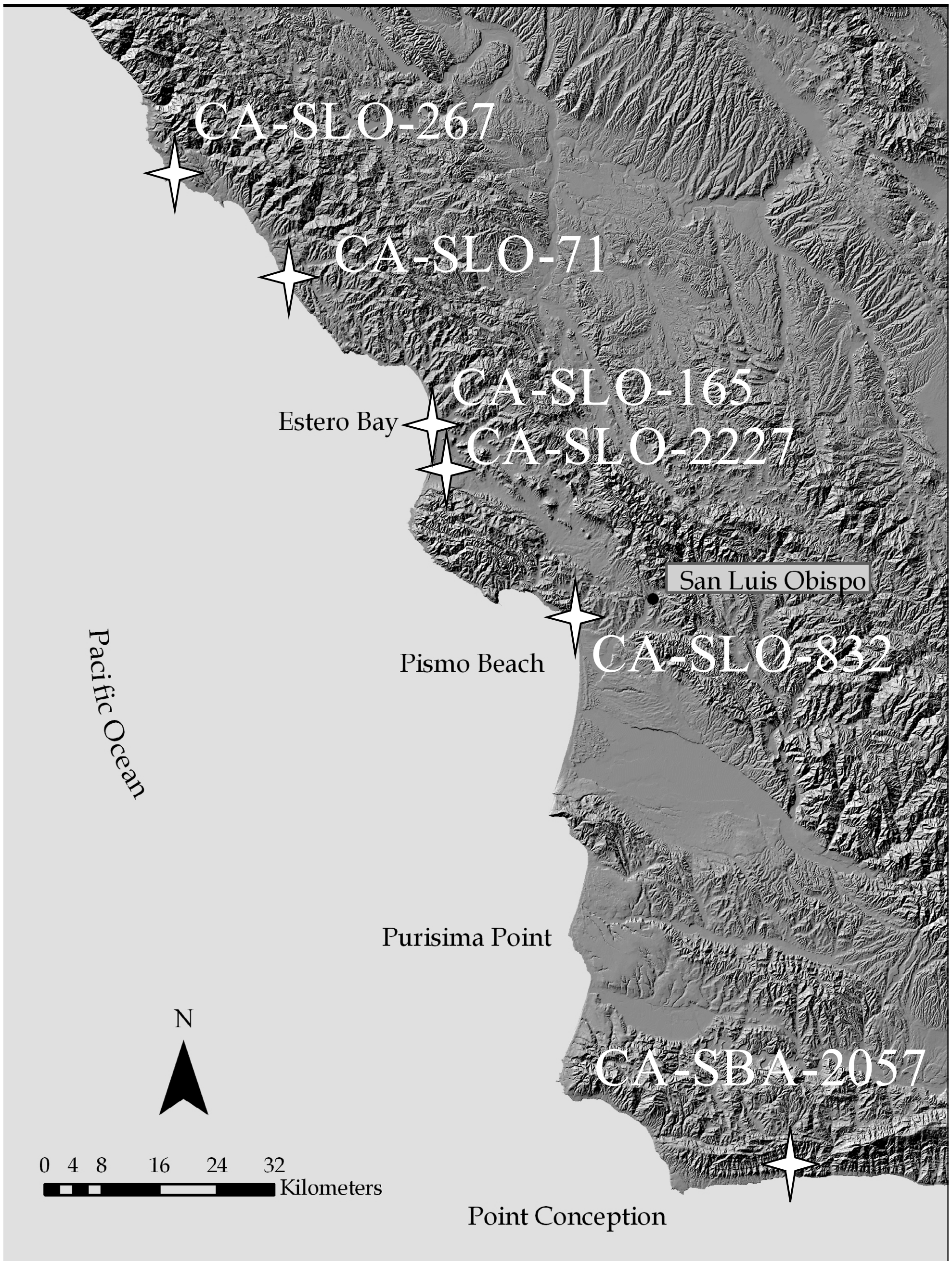

Figure 12.1. Research area showing sites mentioned in the study.

particular taxa as a meaningful proxy of the fishing techniques used to acquire them. Future efforts to equate these relative measures to absolute ones may be possible with the collection of additional data. Assigning absolute values would certainly carry this research much further and make it more relevant to evaluating optimal foraging models.

PREHISTORIC FISHING TECHNIQUES IN CENTRAL CALIFORNIA

Native Californians employed a wide variety of methods to procure fish. Within our study area, more than two dozen fishing-related technological components have been identified (Table 12.1). However, four broad fishing strategies may be

Table 12.1. Fishing Techniques and Associated Tackle for the Central Coast.

Technique	**Material Cultural Remains**	**Related Marine Habitat**	**Primary Targets**
Netting	Weir trap Dip net Drag net Seine net Gill net Net weights	Rivers and streams Estuaries Calm sandy beaches Open ocean	Small to medium sized schooling fish Seasonal migrators
Hook and line	Shell fishhook Cactus fishhook Abalone lures Fishing pole Bone gorges Line weights	Sandy beaches Kelp forests Rocky intertidal Offshore reefs	Aggressive predatory fish Large-mouthed species Medium to large size
Spearing	Harpoon arrow Simple fish spear Harpoons	Open ocean Kelp forest Rocky intertidal Estuaries	Large pelagic fish Large near-surface fish Small tide pool fish
Nontechnological	Fish poisoning Simple hand grab	Small closed bodies of water Pools Tide pools Beach spawners	Small tide pool fish Grunion Anadromous spawners

Note: From Hudson and Blackburn 1981.

defined: netting, spearing, hook and line, and nontechnological approaches such as hand capture. Hudson and Blackburn (1982) describe all known fishing techniques used in Chumash territory. However, fishing techniques were more restricted on the central coast north of Point Conception, due in part to *tomols*, or plank canoes, not being used. As a result, open-ocean fishing appears to have been a very infrequent activity, in contrast to the Santa Barbara Channel area, where it was quite common. Therefore, for purposes of our analysis, we eliminated several of the fishing techniques listed in Table 12.1, such as fish poisoning and use of cactus-spine fishhooks and harpoons.

Our first objective is to identify the baseline taxa of fish that would have been predominantly caught by either hook and line or netting (Table 12.1). The distinction between the two groups of fish taxa was derived primarily from the ethnohistoric record but also relied upon modern fishing information, replication studies (experimental archaeology), and biological information regarding the behavior of different fish. We suggest the following associations between particular economically important fish and fishing techniques.

In broad terms, hook-and-line technologies are most effective for large-mouthed, aggressive predators that utilize a "ram/suction" feeding technique, as defined by Horn and Ferry-Graham (2006). Rockfish and cabezon (*Scorpaenichthys marmoratus*) are examples of ram/suction feeders commonly identified in archaeological sites within the study area. In contrast, sardines, anchovies, and other small schooling fish can be effectively captured only using some form of net, weir, or sieve. Larger schooling fish, in particular surfperches, can be acquired successfully by both hook and line and netting, although their "grazing" approach to predation, rather than ram/suction, makes them less suitable for hook-and-line techniques (Horn and Ferry-Graham 2006). Cartilaginous fish, such as sharks and rays, have a mouth structure that limits the effectiveness of hook-and-line fishing (McKenzie 2007). Pricklebacks (Stichaeidae) have been identified in archaeological deposits throughout central California. Members of this family are commonly found in crevices and under rocks in the upper intertidal zone (Humann 1996:82–83). Smaller members of this family, including the black prickleback (*Xiphister atropurpureus*) and rock prickleback (*Xiphister mucosus*), were most likely captured by hand, as their diminutive size and their habitat would preclude the use of hooks or nets. Monkeyface pricklebacks (Cebidichthys violaceus) may have also been captured by hand, although their larger average size makes them available using hook-and-line methods as well. Modern anglers frequently catch monkeyface pricklebacks by poke poling along rocky shorelines (Love 1996:294). It is presently unclear if prehistoric fishers on the central coast employed poke poling to extract shallow-water fishes. In addition to the direct relationship between particular fish and particular fishing strategies, there is an equally clear relationship between fishing technique and marine environment (Table 12.2).

The Archaeology of Net Fishing

Netting is a fishing technique with a long history of use, extending back to the Pleistocene in the Old World (Balme 1983). In California, remains of fiber cordage from Daisy Cave on San Miguel Island, in association with evidence of a marine-based economy dating between 10,000 and 8000 B.P., may speak to the antiquity of this approach on the Pacific coast (Erlandson et al. 1996). Despite great antiquity, the archaeological record holds very little direct evidence of this method of fishing. Nevertheless, fishers worldwide have used netting technology. More importantly, when employed in a proper way in an appropriate setting, it can be an exceptionally efficient and effective approach with respect to energetic return rates.

The species we place in the netting category are small schooling fish. Their large aggregate numbers make netting an effective means of capture. Typically, these fish occur in such large numbers that they can provide a substantial amount of food when available. Because of the small size of these fish, other methods of catching them, such as hook and line or spearing, are generally ineffective. Netting is most successfully used in closed-water settings, such as in estuaries or off sandy beaches during periods of low surf. Calm waters and a lack of underwater structure facilitate use of nets, and small schooling fish often favor these types of environments. It is worth noting that Strudwick (1986) observed a decrease in the frequency of shell fishhooks in coastal archaeological sites where sandy beaches and estuaries are the predominant marine habitats, indirectly supporting the importance of netting in these types of settings.

The Archaeology of Hook and Line Fishing

In central California fishhooks first appear around 3000 B.P., although earlier examples may occur (Des Lauries 2006; Parker 2004; Rick and Erlandson 1999; Strudwick 1986). Bone gorges appear to have been the primary hook-and-line fishing technology used in southern and central California prior to the introduction of shell fishhooks (Tartaglia 1976). The widespread replacement of bone gorges with hooks seems to be related to the superior effectiveness of shell fishhooks (McKenzie 2007). Both of these implements target relatively large fish with large mouths capable of swallowing the tackle.

Recent archaeological experiments have shown that aboriginal hook-and-line technology has differential success in capturing specific types of fish (McKenzie 2007). These experiments involved prehistoric fishing simulations that employed replicated incurving shell fishhooks in multiple marine environments along the central coast of California and the Channel Islands. Both replicated bone gorges and shell fishhooks were used for equal periods of time in kelp beds, near-shore rocky reefs, and sandy beach/surf zones. Results of these experiments indicate that shell fishhooks are well designed to capture large-bodied aggressive feeders that employ a ram/suction feeding method, such as like cabezon and rockfish (Horn and Ferry-Grahm 2006). These

Table 12.2. Primary Fishing Strategies and Proposed Associated Fish Species.

Fishing Method	Predominant Associated Species	Predominant Marine Environment
Hook and line	Rock fish (40+ species) Cabezon Lingcod Halibut (2 species)	Primarily offshore reefs and kelp forests
Netting	Pacific sardine Northern anchovy Herring	Primarily open shore sandy beaches and estuaries
Both	Surfperch (10+ species) Silversides Mackerel	Kelp forests, open ocean, and sandy beaches

same hooks function poorly, however, when targeting smaller, less aggressive fish that employ a grazing feeding method, such as surfperch (Horn and Ferry-Grahm 2006). The population of fish captured during the fishing experiments illustrates this difference. While fishing with shell fishhooks, 21 cabezon and 14 rockfish were caught in rocky reef/kelp forest environments, but only four surfperch were captured in the sandy beach/surf zone (McKenzie 2007). Based in part on these findings, we suggest that reefs and kelp forests are the habitats best suited to hook-and-line fishing.

The Archaeology of Spear Fishing

Although complicated by deep water, turbidity, and other factors, spearing is essentially an adaptation of a land-based hunting approach to a marine environment. This technique is most effective when large targets are available in proximity to the fisher or in a closed setting. Sharks and rays exemplify the characteristics of fish most effectively recovered by this method, although smaller fish in tidal pools can also be acquired in this manner. In addition, the unique mouth morphology of elasmobranchs reduces the likelihood of capture with incurving shell fishhooks (McKenzie 2007). Differences between cartilaginous and bony fish in taphonomy, fishing techniques, and processing of the carcass make integration of elasmobranchs in these studies problematic. For these and other reasons, most of the comparisons in our study will focus on netting versus hook-and-line methods of fish capture.

CASE STUDIES

We present four case studies that consider how sample size, recovery method, and metrical studies may influence our ability to infer fishing techniques from ichthyofaunal remains. To demonstrate how recovery methods influence our ability to identify fishing strategies, the case studies evaluate mesh size and sample size. Data derived from these case studies are then compared across time and space to provide meaningful information. Finally, we present a method of predicting fishing strategies by measuring the diameter of particular fish vertebrae.

Case Study 1: Effects of Screen Mesh Size on Identifying Fishing Techniques

It has already been demonstrated that screen mesh size is known to affect the recovery of fish elements from an archaeological site (Gobalet 2005; Gobalet and Jones 1995; Gordon 1993; James 1997; Joslin 2006a; Nagoaka 1994; Zohar and Belmaker 2005). Building on this, we seek to determine if mesh size and subsequent recovery of fish remains will affect how fishing techniques may be interpreted from an assemblage. To investigate this question, we present a case study from Morro Bay involving employment of various mesh sizes. The samples were processed differently based on excavation type; 1-×-1-m units were processed with 6- and 3-mm screen, while smaller column samples were processed through 1.5- and .6-mm screen.

As Table 12.3 demonstrates, as mesh size becomes finer, netted fish species compose a larger percentage of the sample. The inverse trend is noted for hook-and-line species. Interestingly, species that fall within both categories (such as Embiotocidae) show a pattern where use of the finer mesh results in the inference that netting was more important and productive than is indicated by use of the larger mesh. The anomalous pattern appearing for the spear/harpoon category is due to the taxa present; they are all cartilaginous fish and are identified by teeth and dermal denticles as often as centra, which would be

Table 12.3. Results of Mesh Size Effects on Interpreting Fishing Strategies from CA-SLO-165.

Mesh Size (mm)	Average Meat Weight of Fish (kg)	Spear/Harpoon Species (e.g., Elasmobranchs) %	Hook and Line Fish %	Netted Fish %	Net or Hook %
6	5.6875	27	45	9	18
3	3.4253	40	26	13	20
1.5	2.4737	33	16	25	25
0.6	0.7800	0	0	50	50

recovered only with much smaller mesh sizes. This anomaly illustrates the problem of comparing bony and cartilaginous fish, as discussed above.

Case Study 2: Effects of Sample Size on Identifying Fishing Techniques

In this case study we evaluate the effects of sample size on identifying fishing techniques. Identical excavation sample sizes, 1-×-1-m units and 20-×-20-cm column samples were used at the two sites from which datasets for comparison were obtained. The processing approaches used for acquiring samples of fish remains also were the same at both sites. The fact that the smaller samples were processed through 1.5-mm mesh should favor the recovery of netted species. This inherent bias is taken into consideration in the final analysis. The two sites were occupied contemporaneously, but one rests on a dune next to an estuary and the other is perched on a sea cliff overlooking reefs and kelp beds.

CA-SLO-2227 is located along what was once the inland margin of the Morro Bay estuary and exhibits clear evidence of intensive exploitation of estuarine resources. Fish bones are the dominant remains among vertebrates, but no artifacts related to fishing techniques (such as fishhooks or line weights) have been recovered. The assemblage recovered from both the 3-mm and the 1.5-mm mesh screening indicates that netting was the principal method used to procure fish. These findings are not surprising, as estuaries are most effectively exploited by netting because of the large number of small schooling fish and calm water conditions relative to the open ocean.

The overall pattern at CA-SLO-2227 is clear. Netting is the primary fishing approach inferred to have been practiced at this site (Table 12.4). If perch and silversides represent fish that were netted, as is argued below, then netted fish compose 96 percent of the unit sample and 97 percent in the

Table 12.4. Ichthyofaunal Assemblage from CA-SLO-2227.

Species	Number of Vertebrae in the Unit (3-mm mesh)	Percentage in the Unit	Number of Vertebrae in the Co1umn Sample (1.5-mm mesh)	Percentage in the Column Sample	Predominant Fishing Technique
Northern anchovy *Engraulis mordax*	0	0	16	7	Netting
Herring Clupeidae	161	11	41	19	Netting
Silversides Atherinidae	809	53	77	36	Both
Surfperch Embiotocidae	478	32	75	35	Both
Lingcod *Ophioden elongates*	4	0.2	0	0	Hook and line
Cabezon *Scorpaenichthys marmoratus*	2	0.1	0	0	Hook and line
Rockfish *Sebastes* spp.	22	1	1	0.5	Hook and line
Bat ray *Myliobatis californica*	28	2	0	0	Spearing
Thornback *Platyrhinoidis triseriata*	2	0.1	0	0	Spearing
Smoothhound *Mustelus* sp.	8	0.4	0	0	Spearing
Prickleback Stichaeidae	5	0.3	0	0	Other
Pacific staghorn sculpin *Leptocottus armatus*	0	0	5	2	Unknown
Giant kelpfish *Heterostichus rostatus*	0	0	1	0.5	Unknown
Total	1,519	100.1	216	100	

much smaller column sample (Figure 12.2). The slightly greater representation of netted species in the column sample is probably due to the finer mesh used to process it. As a result, identification of fishing techniques at sites such as CA-SLO-2227 does not seem to be especially affected by varying sample size.

Located just south of the town of Cambria, the second site, CA-SLO-71, is perched on an ocean terrace overlooking a vast stretch of rocky coastline, reefs, and kelp forests. The site was occupied by people who focused on collecting and processing marine resources, particularly fish and shellfish, although evidence of sea mammal, pelagic bird, and kelp harvesting is also evident. Excavation techniques were identical to those used at CA-SLO-2227, including a 1-×-1-m unit whose deposits were sifted through 3-mm mesh and a column sample sifted through 1.5-mm mesh, the data from which we use for this study.

In this example, when the two types of samples are compared, we find some dramatic differences in fishing techniques (Figure 12.3). Fishing techniques represented at CA-SLO-71 are far more diverse (Table 12.5). Identification of netting increases from 6.2 percent to 32 percent when the smaller-meshed column sample is compared to the unit. Conversely, evidence of hook-and-line fishing declines from 36.2 percent to 9 percent in the column sample. Interestingly, some of the value lost from hook-and-line fishing may be regained if some fish in the "both" category are included. This would not be unreasonable, as we demonstrate below, but including this category would not be enough to make up for the greater discrepancy that appears between netted fish and those caught by hook and line, as they are represented in both sample sizes.

The results of this study are surprising. Sample size apparently had little effect on samples from the estuarine site but a significant effect on those from the rocky shore site. The explanation probably has less to do with location and more to do with the variety of fishing techniques used. Netting appears to be the dominant, perhaps only, fishing technique used at CA-SLO-2227. On the other hand, occupants at CA-SLO-71 focused on hook-and-line fishing but also relied on netting, spearing, and hand collection (including perhaps poke poles in tidal pools). This greater diversity in fishing techniques at CA-SLO-71 may have left the assemblage more prone to conflicting patterns in the ichthyofaunal assemblage. Similar site assemblages with diverse fishing approaches represented may be equally susceptible to conflicting interpretations based on variation in sample sizes. Not to be overlooked is the effect of the smaller mesh used for the column samples. This also had an effect on the results, favoring the recovery of netted species from this site.

Case Study 3: Comparing Fish Remains and Fishing Techniques through Time

Based on our expectations concerning how fishing techniques are reflected in species profiles, a simple exercise of applying this model back through time may be used to assess its effectiveness to some degree. The five coastal midden sites considered here span a time interval from the Millingstone to the Late period—that is, from approximately 9000 to 400 B.P. (Table 12.6). They include three sites located next to estuaries, CA-SLO-832 (Pismo Beach), CA-SLO-165 (Morro Bay), and CA-SLO-2227 (Morro Bay); and two overlooking rocky shores, CA-SLO-71 (Cambria) and CA-SLO-267 (San Simeon) (Bertrando 2009; Jones and Ferneau 2002b; Jones et al. 2002; Joslin 2006b; Mikkelsen et al 2000). When viewed through time, the relative frequencies of exploited fish species, as indicated by the ichthyofaunal data, remain fairly constant (Figure 12.4). With regard to fishing techniques, it is clear that netting was by far the most important procurement method extending back to the early Holocene. This pattern may also be seen at early Holocene sites in the Santa Barbara Channel region (Rick and Erlandson 2000).

The findings here support the idea that the hook and line did not appear, or at least did not have an economic impact, until relatively late in prehistory. As noted earlier, the shell fishhook did not appear in the local area until about 3000 B.P. The ichthyofaunal data derived from the rocky shore sites demonstrate that the hook and line did not

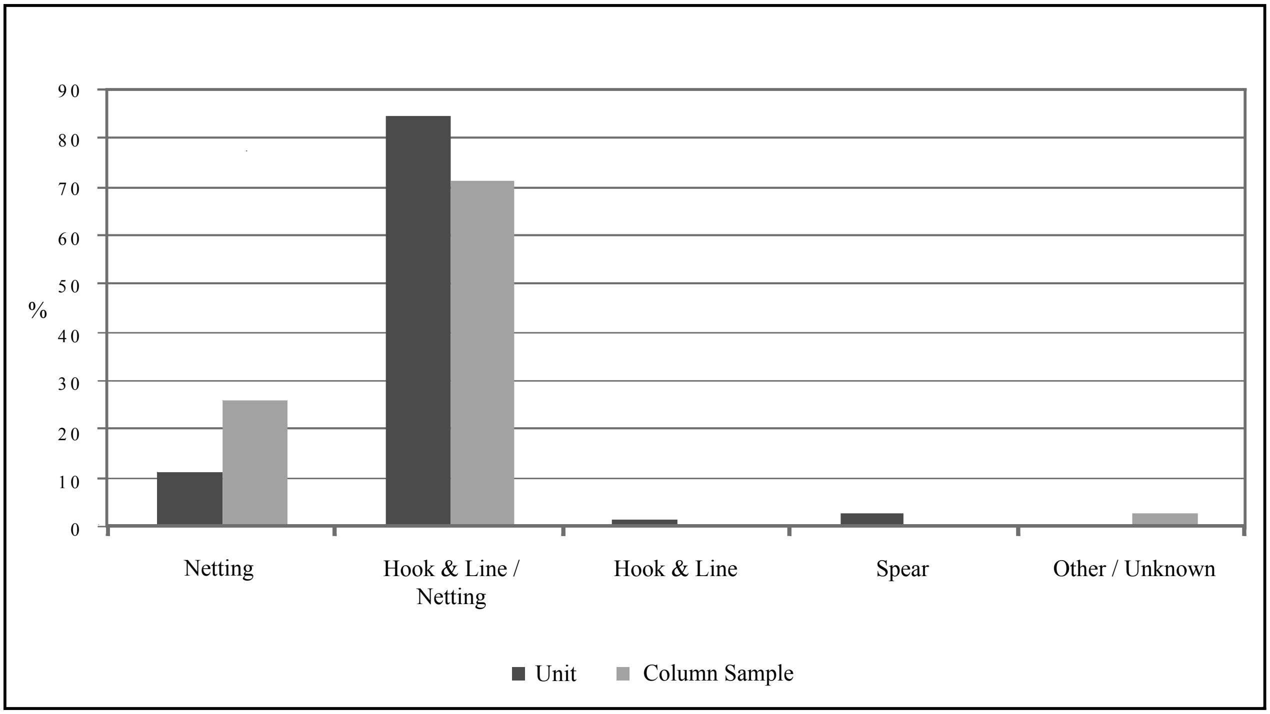

Figure 12.2. Sample size comparison: CA-SLO-2227.

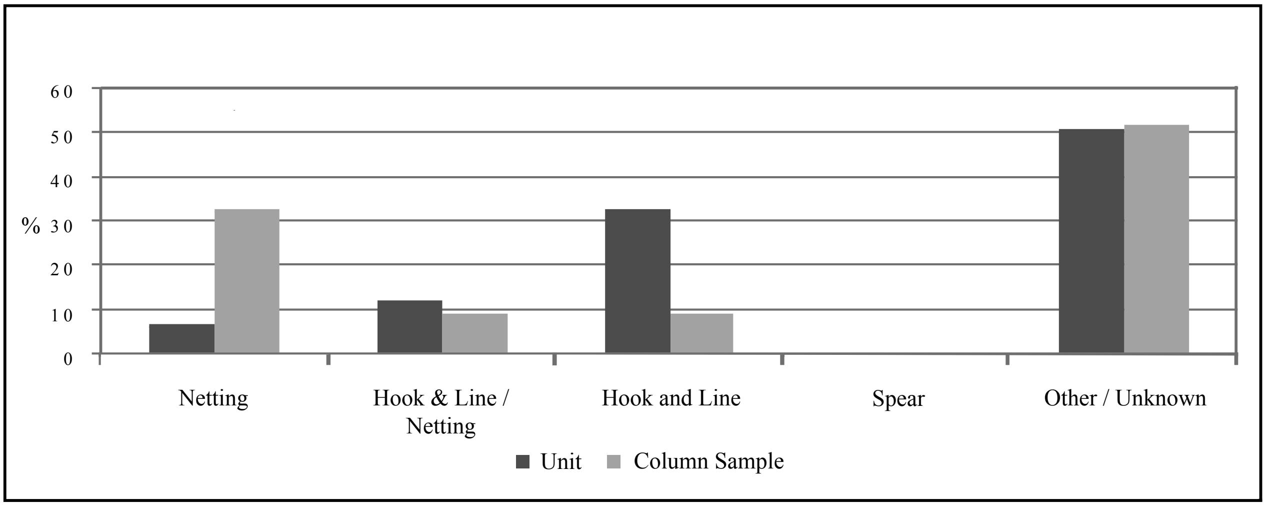

Figure 12.3. Sample size comparison: CA-SLO-71.

Table 12.5. Ichthyofaunal Assemblage of Primary Species from CA-SLO-71.

Species	**Number of Elements in the Unit (3-mm Mesh)**	**Percentage in the Unit**	**Number of Elements in the Column Sample (1.5-mm Mesh)**	**Percentage in the Column Sample**	**Predominant Fishing Technique**
Northern anchovy *Engraulis mordax*	33	2.0	37	23.0	Netting
Herrings Clupeidae	79	4.0	15	9.0	Netting
Pacific sardine *Sardinops sagax*	4	0.2	0	0.0	Netting
Cabezon *Scorpaenichthys marmoratus*	72	4.0	4	3.0	Hook and Line
Lingcod *Ophioden elongates*	3	0.1	0	0.0	Hook and Line
Rockfish *Sebastes* spp.	513	28.0	10	6.0	Hook and Line
Pile perch *Racochilus vacca*	29	2.0	1	0.6	Both
Smelt Osmeridae	11	0.6	0	0.0	Both
Silversides Atherinidae	86	5.0	3	2.0	Both
Surfperch Embiotocidae	79	4.0	9	6.0	Both
Pricklebacks Stichaeidae	852	47.0	82	51.0	Other
Senorita *Oxyjulis californica*	53	3.0	0	0.0	Unknown
Giant Kelpfish *Heterostichus rostatus*	2	0.1	0	0.0	Unknown
Total	1,816	100.0	161	100.6	

Table 12.6. Culture History for the Research Area.

Period	**Temporal Span**
Early Millingstone, Paleoindian	8500–6500 B.C.
Millingstone	6500–3500 B.C.
Early	3500–600 B.C.
Middle	600 B.C.–A.D. 1000
Middle/late transition	A.D. 1000–1250
Late	A.D. 1250–1769

have a dramatic impact on the Native economies of the mainland until the Late period (Figure 12.5). Even the estuarine sites show some evidence of this in the increase in the "both hooks and nets" category, implying that hook-and-line fishing may have increased slightly during the Late period.

In this study, our correlation between fish remains and fishing strategies provides a data source informing on fishing techniques that is an alternative to considering tackle-related artifacts alone. There are deeper implications, however, in that estuarine fishing shows greater continuity and probably experienced less change in technology than fishing in the more challenging waters of the rocky reefs and kelp forest. Further consideration of these topics must await future research.

Case Study 4: Identifying Fishing Techniques from Metrical Studies of Skeletal Elements

Metrical studies of ichthyofaunal remains can provide data leading directly to recognizing prehistoric fishing techniques. Such data are especially important in the absence of artifactual evidence. This case study hinges on two general assumptions discussed earlier. The first is that the size of archaeological remains of a fish is directly related to the size of the living specimen. In other words, larger fish have larger bones. The second is that fish size had a direct effect on the selection and efficiency of prehistoric procurement methods. For example, the small size of northern anchovies would have precluded the use of shell fishhooks in their acquisition. As noted above, Casteel (1974) reported a linear

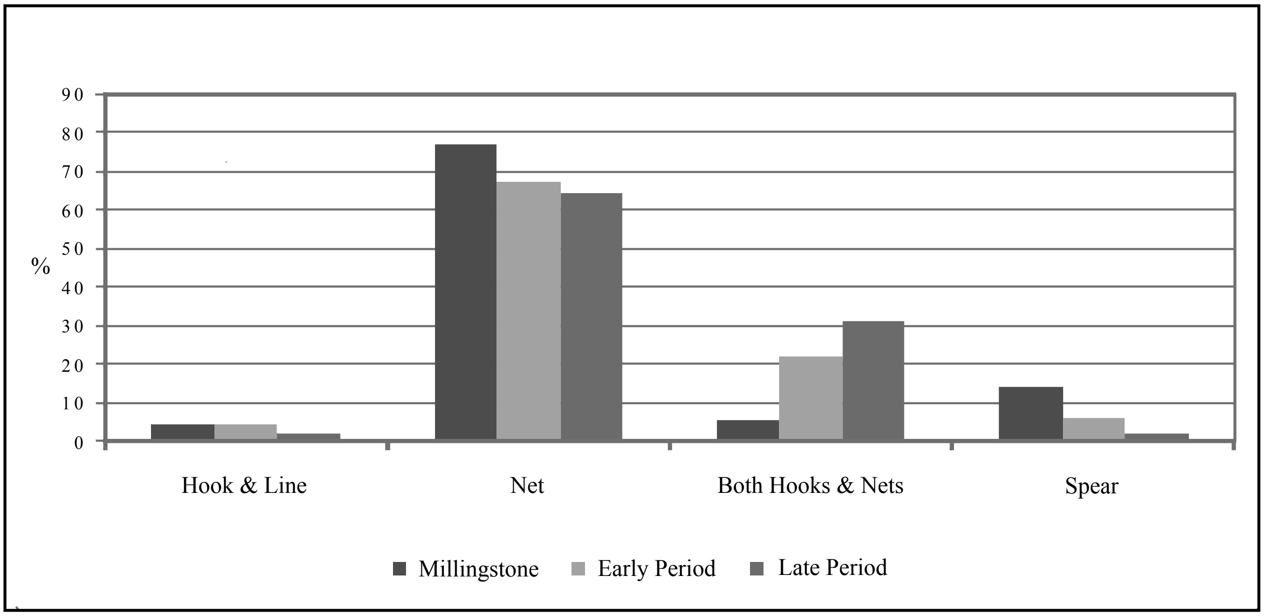

Figure 12.4. Estuarine fishing techniques through time.

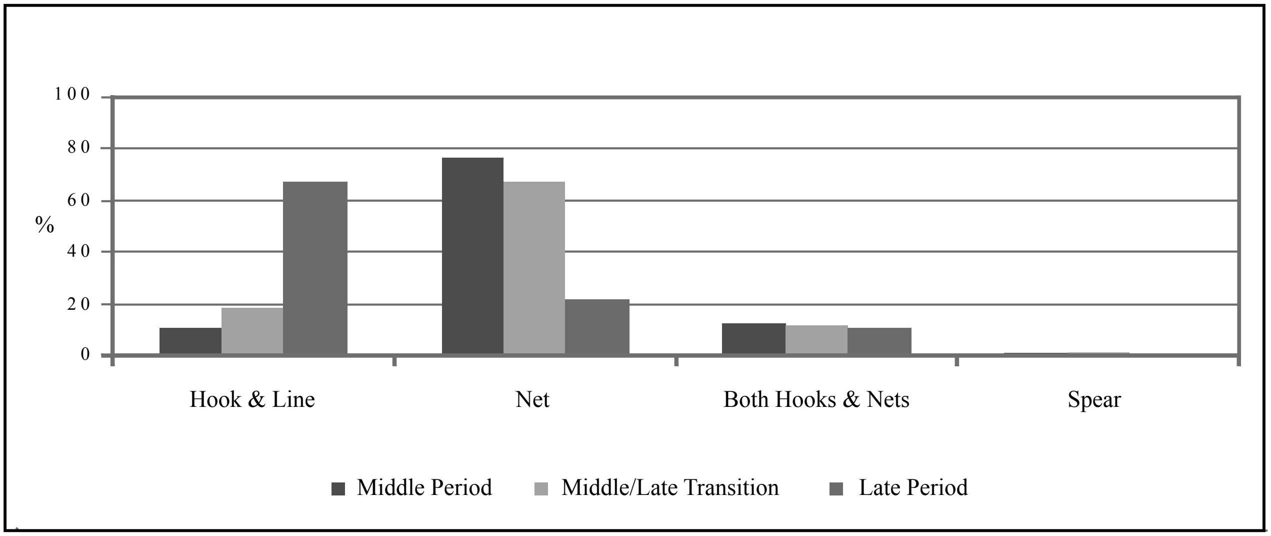

Figure 12.5. Rocky shore fishing techniques through time.

relationship between the size of fish vertebrae and overall size of the living fish. Although the accuracy of inferences based on these assumptions has been justifiably questioned (Carpenter 2002), previous researchers have used size of fish bones to produce insightful interpretations regarding prehistoric fishing techniques (Rick and Erlandson 1999).

As noted earlier, certain fish species are clearly tied to specific fishing techniques, but other fish, such as surfperch (Embiotocidae), can be effectively caught using either method. To resolve this issue, we propose that certain thresholds in fish size must be crossed for hook and line to be effectively used. With this in mind, we compared an assemblage from a site where netting was almost exclusively used with one from a site where hook-and-line fishing predominated. As discussed below, precaudal vertebrae recovered from archaeological contexts were used exclusively to estimate the size of living fish at the time of capture.

The selection of skeletal elements appropriate for this comparison was of concern to us. Because of the distinctiveness of cranial elements, bones from this portion of the body offered a good opportunity to identify elements of lower taxonomic levels, such as genus or species, but identifiable portions of these elements are relatively uncommon in archaeological sites in the study area. An exception is otoliths, which are denser and of a more compact shape, allowing better preservation than typical fish bones. In fact, successful studies similar to the one presented here have been based solely on otoliths (Balme 1983). Despite these qualities of otoliths, we selected vertebrae as the focus of this study for the following reasons:

- They tend to preserve as well or better than other fish elements (Butler 1996; Casteel 1976b).
- They are less likely to be misidentified as being from a terrestrial animal (Olsen 1968).
- They are more easily identified to genus or species than many other elements.
- They typically comprise a significant portion of the skeleton, making their recovery in archaeological deposits more likely and more representative of the fish brought to a site.
- Processing techniques favor the transportation of vertebrae to the final butchering/consumption stage, whereas other elements, such as cranial remains, may be removed off site or much earlier during the processing stage.
- Studies have demonstrated that correspondence between centrum width (of the vertebrae) and fish weight is an important quality for projecting fishing techniques (Casteel 1976b).

These reasons are true for bony fish (Teleostii), but not all of them are necessarily true for cartilaginous fish (Elasmobranchii). The differences are a result of the "softer" quality of the less calcified cartilaginous elements found in sharks and rays. Although elasmobranch centra occur in archaeological deposits, they are often in lower frequencies and sometimes are overshadowed by the more resilient elements of sharks and rays, such as teeth, spines, and dermal denticles. An example of this disparity is illustrated in the assemblage from CA-SLO-267, located at Piedras Blancas (Table 12.7).

Once again, we focus on rockfish and surfperch remains collected from two archaeological sites, CA-SLO-2227 and CA-SLO-71. Overlooking a reef and kelp forest habitat well suited for hook and line but poorly suited to net fishing, CA-SLO-71 produced clear archaeological evidence of hook-and-line fishing. The second site, CA-SLO-2227, on a stabilized dune overlooking the back bay of the Morro Bay estuary, yielded an assemblage dominated by small schooling fish but yielded little evidence of the fishing technology practiced there (Bertrando 2009). As mentioned above, both sites are roughly contemporaneous, having been occupied within the last 1,000 years.

These archaeological sites and particular fish taxa were selected for analysis based on the following assumptions: (1) the ichthyofaunal assemble from CA-SLO-2227 would reflect the exploitation of estuary environs, and the fish remains from CA-SLO-71 would reflect the exploitation of rocky reef/kelp forest zone; (2) these environments would have been most effectively exploited with different fishing strategies; (3) differential fishing strategies should appear in the differential size of surfperch remains at each site; and (4) rockfish would provide

Table 12.7. CA-SLO-267 Vertebrae Compared to Other Elements by Species.

Species	Number of Vertebrae	Percentage of Vertebrae	Number of Nonvertebrae	Percentage of Nonvertebrae	Total
Teleosts					
Silversides	803	100	0	0	803
Clupeidae	161	100	0	0	161
Embiotocidae	442	93	36	7	478
Mackerel	10	100	0	0	10
Sebastes	22	100	0	0	22
Prickleback	8	100	0	0	8
Smooth hound	5	100	0	0	5
Lingcod	4	100	0	0	4
Midshipman	3	100	0	0	3
Cabezon	1	50	1	50	2
Elasmobranchs					
Thornback	0	0	2	100	2
Bat ray	2	7	26	93	28

Note: From Jones and Ferneau 2002.

a comparative baseline, since we assume that these will be caught primarily by hook and line wherever they are encountered.

The sample from CA-SLO-2227 included 166 complete surfperch vertebrae and 21 complete rockfish vertebrae. CA-SLO-71 contained 33 complete surfperch vertebrae and 132 complete rockfish vertebrae. Only complete precaudal vertebrae recovered from these sites were measured and included in this study. Calipers were used to measure the maximum width of the posterior face of precaudal vertebrae. Measurements were recorded to the nearest .1 mm, and data were entered into an Excel spreadsheet. Identification of skeletal elements to species was accomplished in part through the use of the comparative ichthyofaunal collection maintained by the Department of Anthropology, University of California, Santa Barbara.

The rank-order plots of rockfish precaudal vertebra measurements pertaining to each site are strongly congruent. Based on their habits and environment, rockfish would be particularly challenging to retrieve using any form of prehistoric netting technologies. The congruent pattern may be seen as evidence that hook-and-line techniques were used at both sites to catch rockfish (Figure 12.6). Furthermore, the curving ascendance of the pattern in the measurements follows the logarithmic growth pattern of fish. In short, the closely overlapping patterns are presented here as evidence of parallel fishing techniques, namely the use of hook and line at both locations.

The study becomes more complex when a fish can be acquired effectively with more than one technique. For comparison, we looked at surfperch from these two sites. Surfperch bones are relatively abundant at both sites, but we suspected that differing fishing strategies were being used at each. When the diameter measurements are plotted in rank order, the curves show greater dissimilarity when compared with the distribution of rockfish. This is particularly true with regard to the smaller vertebrae. One of our assumptions is that fish must reach a minimum size threshold before they can be successfully captured with hook-and-line technology. Netting has no such requirement, and the range of sizes recovered in a net should be fairly reflective of the total population of the school.

When surfperch vertebrae from these two sites are compared, a disparity among those smaller than approximately 3 mm is apparent. This is the case when the surfperch vertebrae from CA-SLO-71 are plotted at regular intervals to provide a comparative plot to the more abundant remains of CA-SLO-2227 (Figure 12.7). Of the total sample, 88 percent of the surfperch from CA-SLO-71 measured larger than 2.7 mm. In contrast, only 55 percent of the surfperch from CA-SLO-2227 are

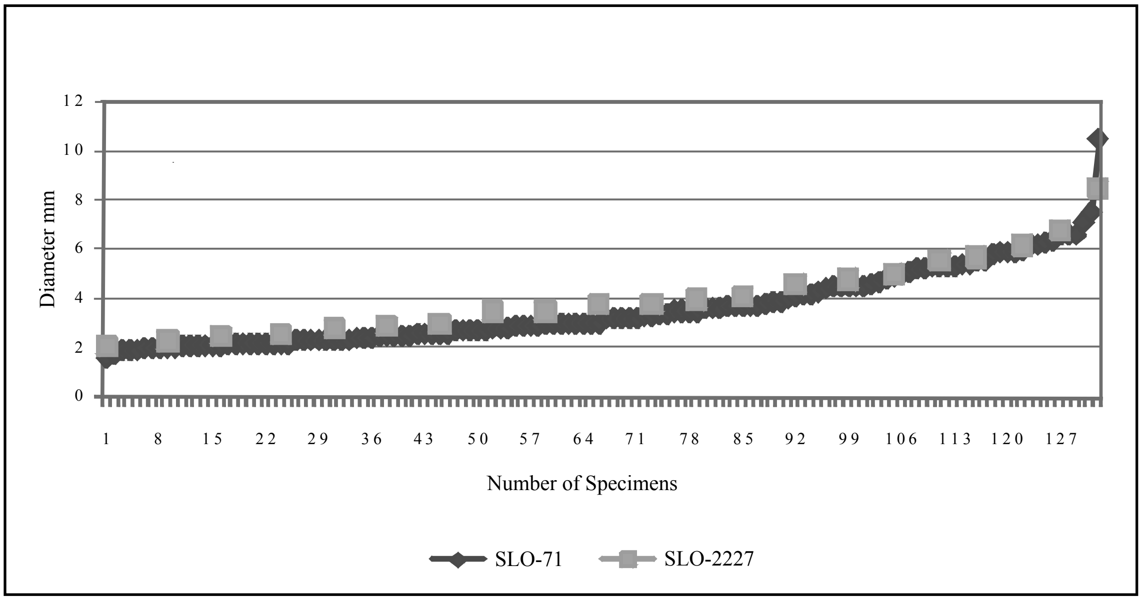

Figure 12.6. Hooked rockfish vertebra diameters, with specimens from CA-SLO-2227 evenly overlaid on CA-SLO-71 specimens.

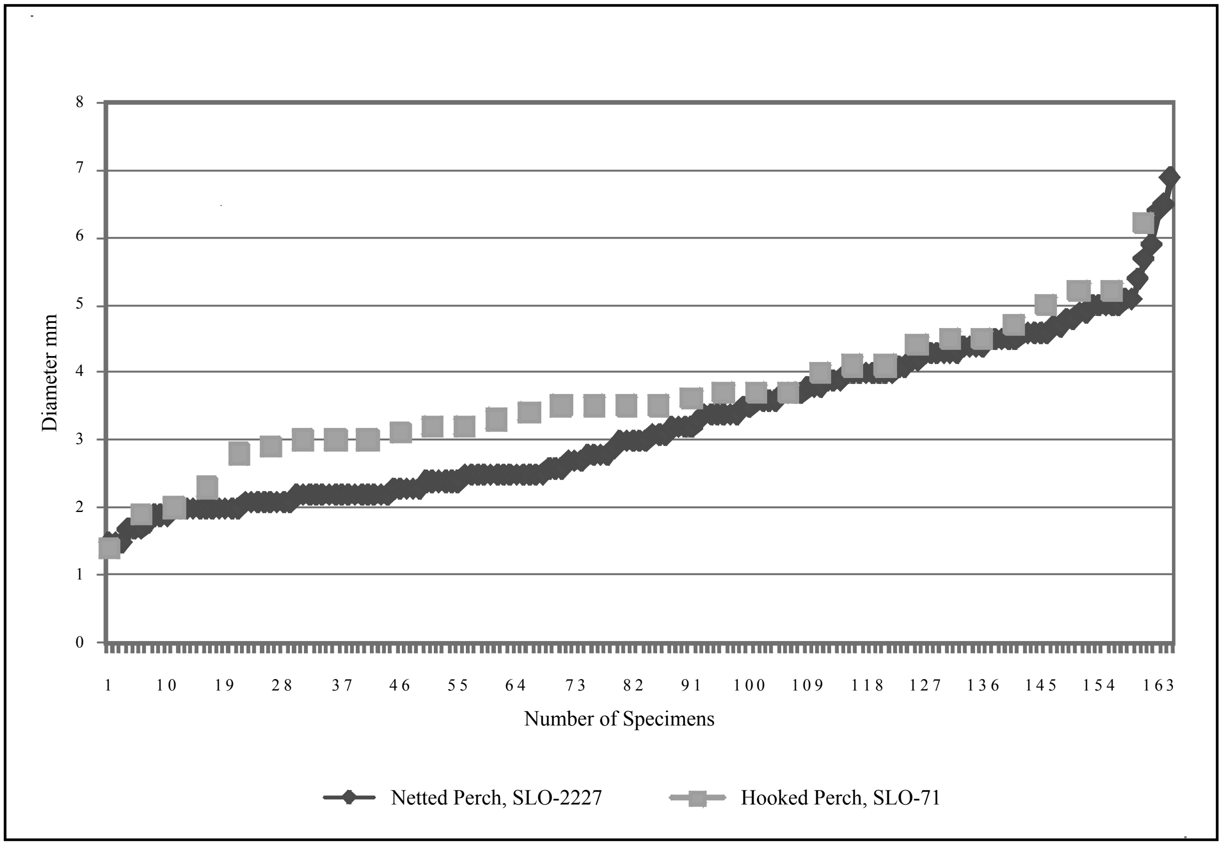

Figure 12.7. Hooked versus netted perch vertebra diameters, with specimens from CA-SLO-71 evenly overlaid on CA-SLO-2227 specimens.

larger than 2.7 mm. We believe this measurement marks the approximate cutoff or threshold that we were anticipating. Basically, it appears very unlikely that surfperch with precaudal vertebrae diameters smaller than 2.8 mm would be large enough to be caught by hook and line. The four specimens from CA-SLO-71 smaller than 2.8 mm—including the smallest vertebra recovered from either site, at 1.4 mm—are significantly smaller (Figure 12.8). These few small examples can be easily explained as incidental catches or as food remains from the stomachs of larger fish butchered at the site, such as cabezon.

Application of this technique is easily accomplished. Through measuring a statistically valid sample of surfperch vertebrae from coastal middens, one should be able to predict the predominant fishing technique based on the percentage of surfperch vertebrae below 2.8 mm in diameter. The greater the percentage of vertebrae over 2.8 mm, the more likely that hook-and-line fishing was the primary fishing technique. This approach would complement others focused on artifacts associated with fishing tackle and would compensate for situations in which the remains of fishing technology are altogether absent. The limitation of this proposed threshold is based on the technology. Specifically, it is appropriate only when applied to assemblages caught using fishing techniques common in prehistoric California. The method does have broader applications but must be adjusted to specific regions based on the fish taxa present in assemblages and the fishing technologies used. Within California, this method may be expanded to identify other fish that could be caught by hook and line or by nets, such as silversides (Atherinidae).

To determine whether this observed pattern has any statistical significance, we conducted a t-test of the two datasets and found the resulting *p*-value to equal .094. This suggests a likely difference between the two populations, but the differences are not strong. While we feel this result supports our conclusions about the size threshold for hook-caught surfperch, we encountered similar results when the same test was conducted for the rockfish from both sites. The *p*-value for the rockfish was .099, again suggesting a difference between the populations from both sites. This information contradicts our suggestion that both taxa were obtained with hook and line. We also found that for each comparison, the smaller datasets had a larger average vertebra diameter. In the case of the rockfish, the difference was as much as .5 mm. One possible explanation

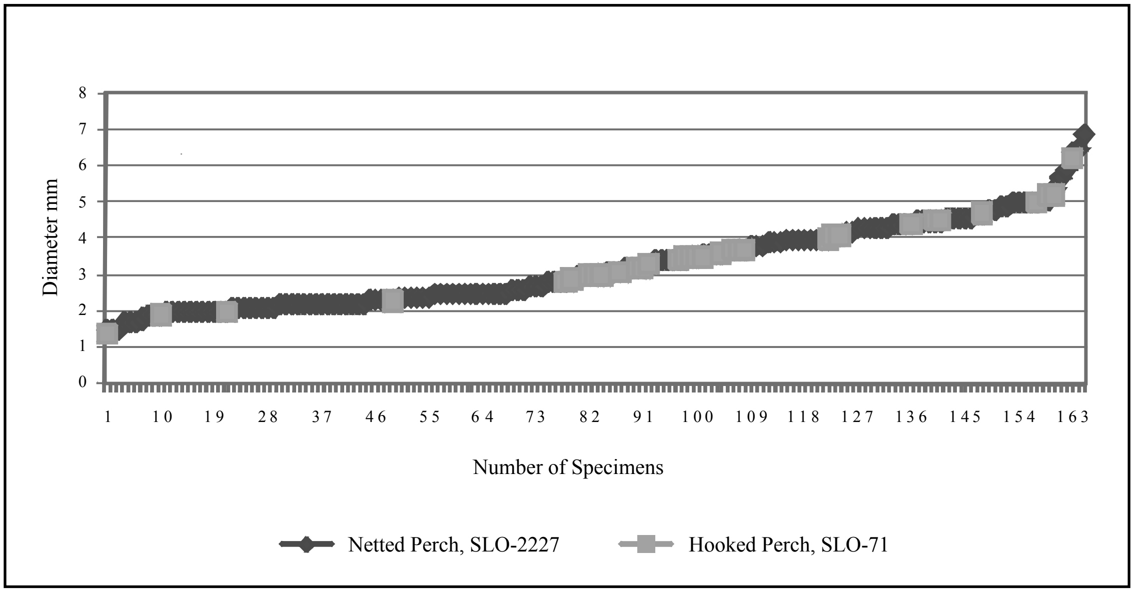

Figure 12.8. Netted versus hooked perch vertebra diameters plotted sequentially by size.

is that the rockfish recovered from CA-SLO-2227 represented only large, mature adults that had ventured into the estuary to spawn, whereas the populations from CA-SLO-71 were more representative of a general population. Clearly, further research is needed to support these findings, but the initial results are encouraging.

CONCLUSIONS

The results of these analyses demonstrate that fishing techniques can be implied from the ichthyofaunal assemblage with reasonable confidence. Size and behavior of the fish can, in some instances, be sufficient for predicting the type of fishing technique employed. Anomalies in the species caught also point out that prehistoric fishers' predictions are as reliable as those of modern fishers. We also demonstrated that recovery methods affect our ability to discern fishing techniques. The simple application of larger screen mesh can effectively eliminate, or at least downplay, the importance of netting in capturing fish. Additionally, sample size has an effect on distinguishing relative frequencies of fishing techniques at sites where a variety of strategies were used, although the effect is not as profound as when remains recovered from different mesh sizes are compared.

Perhaps of greatest interest were the findings that netted fish can be distinguished from those caught by hook and line through metrical studies of the ichthyofaunal assemblage. Using diameter measurements of fish vertebrae, we demonstrated that assemblages with robust samples typically produce size curves that allow distinctions to be made between the two fishing techniques. The physical requirements necessary for fish to be caught by hook and line result in a vertebra size profile restricted to larger fish with bigger mouths capable of ingesting a hook, whereas no such minimum size limitation restricts the fish caught with nets.

Developing alternative approaches to distinguishing fishing techniques that do not rely on recovering the fishing tackle is important for number of reasons. Fishing techniques that involve the use of stone, bone, and shell in the construction of the fishing implement are much more visible archaeologically. Foremost among these is the hook and line. At the other end of the spectrum, complex technologies related to nets, seines, and weirs are typically invisible archaeologically. Our research leads to the conclusion that, in most cases, there is an inverse relationship between the most archaeologically visible fishing techniques and those that were the most commonly employed and economically most important.

Although our intent was to present methods designed to identify prehistoric fishing techniques, our larger goal was to develop better approaches for understanding culture change through study of the archaeological record. Fishing strategies have many implications for other aspects of cultural systems. Optimal foraging theory and ecologically based models would be well served by the type of information contained in fish bone assemblages. As pointed out in other studies, least-cost models used to understand fishing strategies must also consider the effects of time, energy, risk, and social factors to produce more comprehensive explanations of the past (Colley 1983). Decision making for fishing events may have surprising implications. Large-scale netting of schooling fish requires substantial amounts of front-loaded investment of time to make the nets and complex coordination of activity to effectively use relatively large numbers of people to obtain the highest return yield for a given investment of time and energy. Hook-and-line fishing is a much more solitary strategy and affords the fisher the opportunity to pursue a food resource that benefits the individual or a small group. Additionally, gender- and age-based issues come into play, assuming that netting was a communal effort that included females as well as young and elderly group members, whereas hook-and-line fishing is more likely to have been the domain of adult men. These are just some of the research directions that can be addressed with fishing data. Developing improved methods of collecting and evaluating data regarding fishing techniques, such as those discussed here, opens new doors to the study of coastal adaptation and social interaction involving acquisition of resources from the marine environment.

NOTE

The collections referenced in this study were produced during various unrelated archaeological investigations. The assemblages from these sites are currently housed at several locations. Those from CA-SLO-165, CA-SLO-267, and CA-SLO-832 are housed at the San Luis Obispo County Archaeological Society facilities at Cuesta College. The CA-SLO-71 collections are now curated by the Repository for Archaeological and Ethnographic Collections, Department of Anthropology, University of California, Santa Barbara, under accession number 695, and collections from CA-SLO-2227 will be submitted to the San Luis Obispo County Archaeological Society's facility when analyses of these collections are complete.

ACKNOWLEDGMENTS

Much of the data presented in this paper was collected by Far Western Anthropological Group Inc. as part of data recovery efforts for the California Department of Transportation, District 5. Ken Gobalet kindly reviewed our fish vertebrae identification. Tim Carpenter provided valuable advice and information regarding skeletal studies of fish and our positions in this paper. Terry Joslin generously provided collections from her research along the San Simeon Reef for our metrical analysis. Useful comments from two anonymous reviewers were also gratefully received. We are also grateful to both Terry Joslin and Michael Glassow for inviting us to participate in the symposium that led to this research. We alone take full responsibility for our findings and their implications.

CHAPTER 13

Sampling Issues in Evaluations of Diet and Diversity:

Lessons from Diablo Canyon

TERRY L. JONES AND BRIAN F. CODDING

Although California can lay claim to some of the earliest studies of hunter-gatherer faunal residues in western North America (e.g., Howard 1929), problem-oriented faunal analysis is a relatively recent development that emerged coeval with and as an integral part of the "new" archaeology in the 1970s. California had a long history of involvement with shell midden archaeology prior to the processual revolution, with much thought devoted to problems of sampling and interpreting invertebrate remains (e.g., Gifford 1916, 1949; see reviews by Claassen 1998; Waselkov 1987). Studies of vertebrate remains, however, were relatively uncommon until the 1970s (although see Follett 1957). While the early faunal studies were innovative in simply completing and reporting bone identifications (e.g., Busby 1975; Follett 1975), remarkably sophisticated analyses of specific classes (for example, fish remains) were also undertaken (e.g., Casteel 1974; Casteel et al. 1977; Fitch 1972). By the 1980s, collection of all vertebrate remains was standard practice in California, and a number of studies used robust, statistically meaningful vertebrate samples to address issues of subsistence and cultural ecology (e.g., Cope 1985; Dietz and Jackson 1981; Gifford and Marshall 1984; Hildebrandt 1981; Koerper 1981; Simons 1979, 1981a, 1981b; Watts 1984).

Since the 1990s, vertebrate remains from California have been increasingly used to address questions derived from optimal foraging and other applications of human behavioral ecology. While many studies continued to focus on molluscan remains (e.g., Erlandson 1991; Jones 1991; Jones and Richman 1995; Raab 1992), issues of optimization and resource suppression have been increasingly addressed with vertebrate collections (e.g., Broughton 1994a, 1994b, 1997, 1999; Hildebrant and Jones 1992, 2002; Salls 1992; Simons 1992). Most recently, these studies have extended beyond optimal foraging to include costly signaling (e.g., Broughton and Bayham 2003; Codding and Jones 2007; Hildebrant and McGuire 2002; Jones, Porcasi, et al. 2008; McGuire and Hildebrandt 2005; McGuire et al. 2007). Inherent in many hypotheses derived from behavioral ecology are questions about diet and diversity. While methods used to reconstruct diet from faunal residues have been productively debated (Claassen 2000; Glassow 2000; Mason et al. 1998, 2000), techniques used to assess diversity have not received nearly as much attention in California as they have elsewhere (e.g., Cannon 1999, 2001; Grayson and Delpech 1998, 2003; Jones 2004; Leonard and Jones 1989; Vale and Gargett 2002; Zohar and Belmaker 2005). This is in spite of the importance of diet breadth and relative evenness to optimization models, and the likelihood that such variables can be influenced by field and analytical sampling strategies. Kintigh (1989) was one of the first to evaluate the effect of sample size on assemblage diversity. Here we build on his work using the trans-Holocene faunal collection from CA-SLO-2 at Diablo Canyon on the coast of San Luis Obispo County in central California to discuss how certain aspects of field sampling, particularly excavation volume and screen size, influence perceptions of faunal diversity. The faunal remains from this site were recovered 40 years ago from an extensive mixed-recovery strategy that combined a large excavation volume processed with 1/4-inch (6-mm) mesh with a smaller recovery volume (a column sample) processed intensively with 1/16-inch (1-mm) mesh (Fitch 1972; Greenwood 1972). Findings from this investigation show that with respect to diversity, it might be more important to control mesh size in comparisons between spatial and temporal faunal components than to rely exclusively on one particular mesh (for example, 1/8 inch [3 mm]) for all sampling. Residues obtained from smaller mesh yield greater numbers of species and produce higher diversity values, but relative diachronic trends are exactly the same for assemblages collected with small versus large mesh. Overreliance on smaller mesh in field recovery can generate robust assemblages of microfauna, but samples of large vertebrates may be inadequate for statistically meaningful evaluation because such remains often occur in low frequencies. Thus the only way to obtain reasonable samples is to excavate sufficient volumes from deposits. Lost in all the discussions about mesh bias, however, is the fact that any mesh size provides only a relative index of the faunal component of subsistence. Relative diachronic patterns over time, regardless of mesh size, are probably more important than any one mesh class as a representation of "absolute truth."

OPTIMIZATION MODELS, DIVERSITY, AND SAMPLE SIZE

Optimization models have been employed in California for more than three decades (e.g., Beaton 1973; Broughton 1997; Erlandson 1991; Hildebrandt 1984; Jones 1991; Kennett 2005), although the earlier applications were less explicit in their use of optimization theory and/or less rigorous in their evaluation of empirical evidence. Typically, archaeologists implicitly or explicitly draw on one (or more) of four models: the prey choice model (e.g., Bayham 1979), the patch choice model (e.g., Jones 1991), central place foraging models (e.g., Cannon 2003), and ideal free (or despotic) distribution models (e.g., Kennett 2005; Kennett et al. 2006). Of these, archaeologists most frequently rely on the prey choice model. Prey choice models evaluate the resources a forager should take on encounter within a homogenous patch (Stevens and Krebs 1986; Winterhalder 1981). The model predicts that foragers should preferentially select prey to maximize the rate at which resources (typically measured in kilocalories) are acquired; whether or not a resource should be taken on encounter depends on the abundance of the *highest* ranking resource. When encounter rates with the highest ranking resource decline, foragers should widen their diet breadth, in turn selecting a more diverse set of prey. Since these newly incorporated prey types are relatively low ranked, widening diet breadth is typically associated with declining foraging returns (e.g., Broughton 1997; Jones 2004).

For these reasons, diet breadth and diversity are the key components of prey choice models that researchers rely on to evaluate zooarchaeological assemblages. However, our interpretations of these models may be prejudiced by sampling bias, since some excavation techniques, particularly mesh size, can strongly influence perceptions of diet breadth and diversity (Cannon 1999, 2001; Vale and Gargett 2001). Here we suggest that three problems related to mesh size influence attempts to evaluate diet breadth archaeologically: (1) large mesh underrepresenting small taxa such as fish and rabbits; (2) large mesh misrepresenting diversity because small species are either under- or unrepresented in collections; (3) small samples that are inadequate for statistical analysis, the smallness of the sample being the result of the time involved in processing with small mesh and small excavation volumes. This

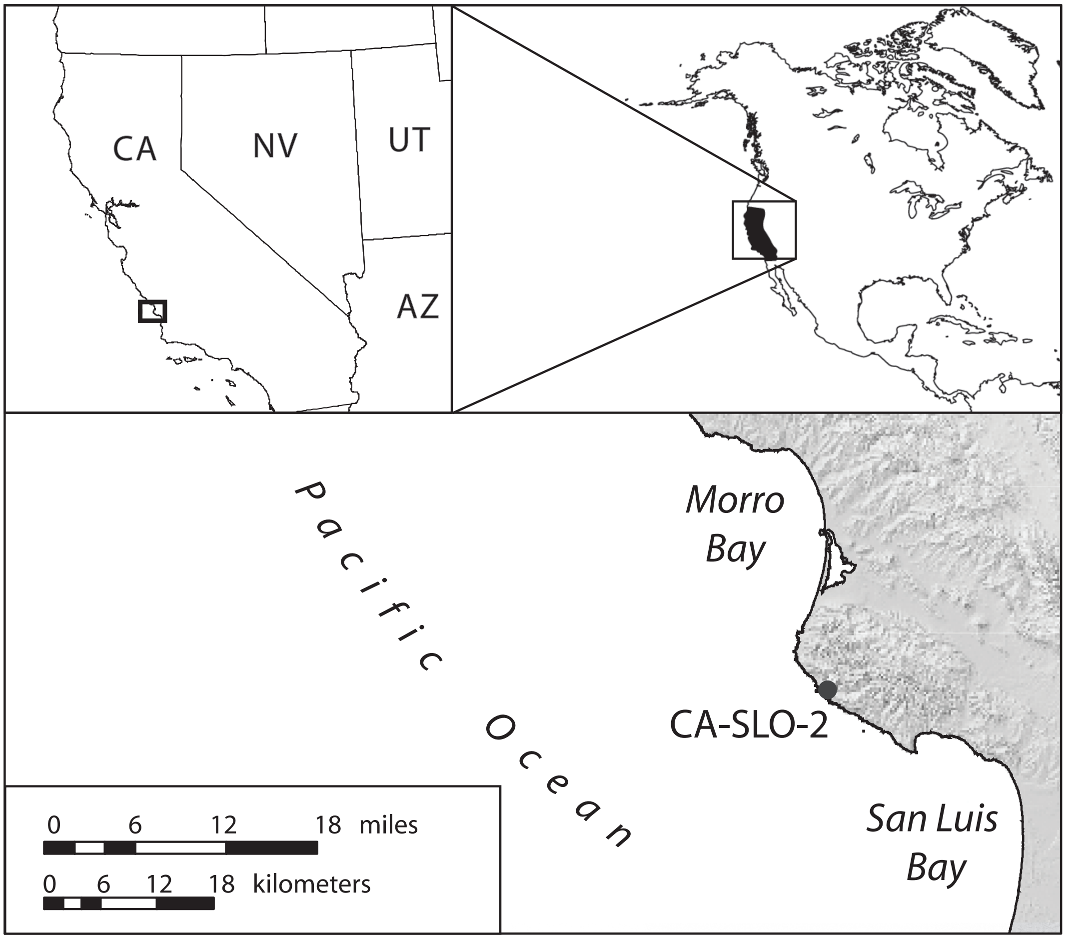

Figure 13.1. Location of CA-SLO-2.

latter issue has been well documented by ecologists who attempt to sample and quantify biological diversity among living populations (see Magurran 1988, 2004).

Mesh Size and the Underrepresentation of Microfauna

Early thinking on the issue of screen size in faunal recovery and interpretation focused on the fact that the remains of small animals can be either wholly unrepresented in samples collected with large mesh (larger than 1/4 inch) or underrepresented (Thomas 1969). The logic underlying this issue is relatively simple in that screens with larger apertures fail to capture the remains of small animals whose skeletons are composed of small bones (as well as small artifacts such as certain types of shell beads [Erlandson 1994:54]). This issue is most apparent with fish bones (e.g., Casteel 1972; Fitch 1967, 1972), which are commonly underrepresented in samples from large mesh (e.g., Butler 1993; Gobalet 1989; and many others), but small mammals (James 1997; Stahl 1996) and mollusks (Muckle 1994) have also been shown to be underrepresented in samples collected with large mesh. Underrepresentation of certain molluscan taxa with use of larger mesh is more a problem of taphonomy than sampling, however, since fragile, thin-shelled species tend to be more underrepresented in samples from large mesh than species with durable shells. With fish and other small vertebrates, taphonomy is a contributing factor, but the size of the animal is clearly the most important variable.

The dietary importance of small but ubiquitous taxa, such as anchovies and rabbits, might be underrepresented in samples processed exclusively with large mesh. These taxa might have been dietary mainstays in certain places at certain times, but an adaptation in which such resources were staples could be easily misinterpreted with a field program that relied exclusively on large mesh. This point has been made most frequently for fish remains, with the idea that the importance of fish in prehistoric diets can be seriously underestimated when 1/4-inch mesh is employed to investigate deposits that contain the remains of many small-bodied fish (see Gordon 1993; James 1997). The same basic case has been made for rabbits (James 1997).

Importantly, James (1997) is one of the few to suggest that a solution to the mesh bias problem might be found in field programs that incorporate multiple sampling strategies (for example, partial wet-screening of deposits with 1/8-inch mesh) and proportional "correction factors" to make the samples comparable. Cannon (1999) subsequently rejected this proposal on the grounds that "correction factors" do not produce accurate results. Nonetheless, James stands as one of the few researchers to acknowledge the costs of time and money associated with exclusive use of small mesh.

Mesh Size and the Underrepresentation of Diversity

Beginning in the 1990s, problems with mesh-related recovery bias were increasingly related to issues of diversity and its two subcomponents: richness (the number of taxa present) and evenness (the relative abundance of taxa). This shift was a direct result of the increasing application of diet breadth and economic intensification models that emphasize the number of species exploited by prehistoric people and the relative importance of various taxa. The basic issue of large mesh underrepresenting small taxa, as discussed above, is the same, but the shift to an emphasis on diversity brought with it a slightly different quantitative focus.

The problems involving mesh size and diversity are well summarized by Gordon (1993), who compared faunal findings from two excavations at the Nu'alolo Kai site on Kauai Island, Hawaii: one completed in 1960 that employed "old-fashioned" methods (for example, a large excavation volume [382 m^3] screened exclusively with 1/4-inch mesh), and the second a single 1-×-2-m (3.4 m^3) unit excavated in 1990 with 1/8-inch mesh. Findings were similar to many previous studies showing that units processed with small mesh produced substantially more fish bones than those processed with 1/4-inch mesh. The overall adaptation suggested by the 1/4-inch investigation showed a heavy focus on birds, parrot fishes, rainbow fishes, wrasses, and pigs, while the 1/8-inch residues suggested an emphasis on a variety of different fishes and rats, with less use of pigs. More importantly, Gordon (1993) also showed that more fish taxa were recovered from the unit processed with 1/8-inch mesh (Table 13.1), indicating greater taxonomic richness for fish than was suggested by the earlier study. Furthermore, evenness was misrepresented by the findings from the ¼-inch excavation, which suggested a fairly specialized fishery dominated (65 percent) by parrot fishes, rainbow fishes, and wrasses (Table 13.2). Findings from the 1/8-inch excavation showed a more even distribution of taxa, with the wrasse family accounting for only 32 percent of the NISP. However, Gordon failed to acknowledge that the 1/8-inch sample of nonfish showed lower richness (fewer exploited taxa) than the 1/4-inch sample. She was also criticized for including taxa that may not have been dietary (rats and filefishes) in her analysis (Dye 1994). Nonetheless, she concluded, as have many others, that "interpretations of prehistoric human subsistence from faunal remains recovered by the larger screen sizes are questionable" (Gordon 1993:523).

Table 13.1. General Findings from Two Excavations at Nu'alolo Kai, Kauai Island, Hawaii.

Mesh Size	**¼ inch**	**1/8 inch**
Excavation volume (m3)	382	3
Fish NISP	714	857
Number of fish taxa	19	21
Nonfish NISP	1,176	352
Number of nonfish taxa	8	5
Total NISP	1,890	1,209
Total number of taxa	27	26

Note: From Gordon 193:454–455.

Table 13.2. Summary of Key Fish and Nonfish Findings from Two Excavations at Nu'alolo Kai, Kauai Island, Hawaii.

Rank	1/4- inch Common name (Taxon)	NISP	%	1/8-insch inch Common name (Taxon)	NISP	%
			Fish			
1	Wrasses (Labridae)	463	65	Wrasses (Labridae)	277	32
2	Parrotfishes (Scaridae)	92	13	Filefishes (Monacanthidae)	201	24
3	Surgeonfishes and tangs (Acanthuridae)	34	5	Surgeonfishes and tangs (Acanthuridae)	86	10
			Non-Fish			
1	Bird	493	42	*Rat* *Rattus* sp.	166	47
2	Dog (*Canis familiaris*)	244	21	Bird	129	37
3	Pig (*Sus scrofa*)	220	19	Dog (*Canis familiaris*)	28	8

Gordon's conclusions were subsequently challenged by Vale and Gargett (2002) based on findings from an Australian shell midden (Arrawara I), where they found no additional taxa with 1/8-inch mesh than with 1/4-inch mesh, meaning no difference in richness between the two mesh sizes. Furthermore, a subsample processed with 1/16-inch mesh produced only a single additional taxon. Importantly, they recognized that most of the bony elements from that small fishes available to the Alawarra I inhabitants became unidentifiable when fragmentary; therefore the smaller mesh residues added nothing to the overall sample. They concluded that while zooarchaeologists have long said it is imperative that 1/8-inch mesh be employed at all times, the contribution of the 1/8-inch mesh depends on the nature (and size) of fishes available in local fisheries and post-depositional conditions. These conclusions were subsequently challenged by Zohar and Belmaker (2005), who questioned the small size of the 1/16-inch subsample analyzed by Vale and Gargett and suggested that if a volumetrically appropriate 1/16-inch sample was analyzed, 14 additional taxa would have been discovered. Their reanalysis of the Vale and Gargett data was strictly mathematical, however, and did not demonstrate that 14 additional small taxa were present to be found in the Australian fishery. Gobalet (2005) expressed similar concerns about the methodology employed by Vale and Gargett. Overall, these three studies offer no clear consensus on the issue of diversity (and its two subcomponents, richness and evenness) and mesh size.

Diversity and Sample Size

Underlying the issue of screen size are more basic issues related to the measurement and statistical evaluation of diversity, addressed most thoroughly by ecologists (see Magurran 1988, 2004). In many archaeological applications of the prey choice model, a key variable is dietary diversity (e.g., Grayson et al. 2001; see also Jones 2004). In attempts to measure biological diversity, it has long been recognized that number of taxa identified is clearly correlated with sample size. As sample size increases, the number of taxa identified increases, until a point at which further sampling would be redundant; however, this point is rarely, if ever, reached by archaeological research programs (Orton 2005). This situation is directly relevant to archaeological sampling strategies, as larger excavation volumes inevitably produce evidence of a greater number of taxa. Such results can be seen in the Gordon study, where more taxa were recovered from the 1/4-inch sample because excavation volume was considerably larger than with the 1/8-inch sample (Table 13.1). Fish remains showed greater richness in the 1/8-inch sample, but nonfish remains did not. Mathematical calculations (for example, Margalef's Index) have been developed to compensate for the effect of sample size, but it is important to realize that even these cannot deal effectively with small samples. A basic premise underlying diversity sampling is that a reasonable attempt must be made to try to identify the range and relative representativeness of taxa within the sampling universe. For archaeological sites, this generally means that a substantial excavation volume must be investigated. Because it is more time-consuming to process deposits with small mesh, it is common for investigations relying exclusively on small mesh and targeting microfauna to be limited to relatively small recovery volumes. In California, the remains of larger animals are usually highly fragmentary and cannot be readily identified to species. To recover robust collections of identifiable specimens, it is usually necessary to excavate large excavation volumes. While there is no consensus on what constitutes an adequate sample for this purpose, findings from CA-SLO-2 at Diablo Canyon on the central California coast provide some insights into this issue and questions concerning evaluations of diversity and mesh size.

THE DIABLO CANYON FAUNA

CA-SLO-2 was one of six sites investigated in 1968 in anticipation of the construction of the Diablo Canyon Power Plant. The site is an unusually large (approximately 400-×-320-m) and deep (3.4-m) midden, situated on a narrow coastal terrace on the north bank of Diablo Creek in San Luis Obispo County. Its formal artifacts and a sample of faunal remains were reported in 1972 by Roberta Greenwood. More recently the remainder of the faunal collection was analyzed, and a suite of new radiocarbon dates shows that the site was occupied intermittently from ca. 8300 cal B.C. through historic contact (A.D. 1769) (Jones, Porcasi, et al. 2008). Four temporal components have been identified within this overall span of occupation: component I (280–340 cm), dating to 8300–6500 cal B.C.; component II (200–280 cm), dating to 5000–3000 cal B.C.; component III (70–200 cm), dating to 1600 cal B.C.–cal A.D. 1000; and component IV (0–70 cm), dating to cal A.D. 1500–1769. The faunal collection associated with these occupations included more than 35,000 bird, mammal, reptile, and fish remains with more than 12,000 identified to a meaningful taxonomic level (genus for mammals and birds; family for fish). The collection is curated by the San Luis Obispo County Archaeological Society Collection Repository on the Cuesta College campus in San Luis Obispo.

Sampling Strategy

From the standpoint of sampling methodology, the Diablo faunal collection was generated through a mixed recovery strategy that was designed to sample artifacts, microfaunal remains, and macrofaunal remains as efficiently as possible. Three different field sampling methods were employed, each with a different objective. Thirty 1-×-2-m units, distributed randomly through the direct impact area, were processed with 1/4-inch mesh and were intended to provide large samples of artifacts and remains of large animals; a 25-×-25 cm column (0.8 m^3) was water-processed with 1/16-inch mesh to recover fish bones; and a 1-×-1-m unit was processed with nested 1/4-inch and 1/8-inch mesh to recover shell remains. A total of 109 m^3 of deposit was excavated from the 1-×-2-m units, although only 98.9 m^3 could be accounted for in the most recent faunal analysis due to attrition to the collection while it was in storage for 30 years. Findings from the fish and shell columns were reported in detail in the 1972 monograph (Fitch 1972; Greenwood 1972), while the complete vertebrate findings from the 1-×-2-m units were reported more recently (Jones, Porcasi, et al. 2008). Fitch's analysis of the fish bone column is particularly important because it represents one of the most intensive analyses of fish bone ever completed in California. Fitch used a microscope to sort and identify fish bones from the column and took approximately 900 hours to complete the identifications (Fitch 1972:102). It is highly unlikely that anyone will ever repeat such an intensive analysis. Given the constraints of time and money on archaeological excavations, both the macro and micro samples from Diablo Canyon must be considered adequate representations for the site as a whole. The Diablo collection also provides an opportunity to evaluate relative diachronic trends based on variation across four temporal components. Such diachronic variability was not considered in either the Gordon (1993) or Vale and Gargett (2002) studies.

The faunal collection from CA-SLO-2 is similar to that from the Gordon (1993) study from Hawaii in that it includes remains recovered from a relatively large recovery volume (98.9 m^3) excavated with 1/4-inch mesh and a control sample recovered from a smaller volume (0.8 m^3) and processed more intensely, in this case with 1/16-inch mesh. Details of the analytical procedures employed in the analyses of these remains are found in Fitch (1972) and Jones, Porcasi, et al. (2008). A total of 13,517 bird, mammal, and reptile remains, including specimens from of a variety of small burrowing animals (for example, Botta's pocket gopher [*Thomomys bottae*] and California ground squirrel [*Spermophilus beecheyi*]), were identified from the 1/4-inch mesh sample. Because it is highly likely that these elements were intrusive, they were removed from further consideration. Dye (1994) noted that Gordon (1993) did not take this step in her analysis of finds from the Hawaiian middens, which flawed the study. For interpretive purposes, the Diablo collection was further compressed by eliminating specimens that could not be identified to the genus level for birds and mammals or to the family level for fish. The resulting sample for birds and mammals includes 2,789 NISP (Table 13.3) representing 29 species of birds, 15 terrestrial mammals, seven marine mammals, and one reptile (the western pond turtle [*Clemmys marmorata*]). A total of 9,646 fish bones was identified from the 1/4-inch sample; 6,070 to the family level or better.

Analytical Methods

Analysis focused on two measures: bone counts, and diversity measures derived from those counts. To assess trends in the variation of bone counts, an χ^2 test was performed. Because χ^2 tests run on contingency tables with small marginal totals should be regarded with suspicion (Shennan 1997), we ran a Monte Carlo simulation with 2,000 iterations based on the structure of the data; χ^2 and alpha (p) value were then calculated by comparing the actual data to the simulated data (R Development Core Team 2008). To further examine how the bone counts of particular species varied between the 1/4-inch and 1/16-inch mesh samples, the adjusted residuals (calculated as the observed count minus the expected count over the square root of the expected count) were examined for the five highest ranking taxa in each sample, and alpha (p) values were calculated utilizing a function in R that draws on the binomial probability theorem to generate probabilities based on observed and expected cell counts (see Everett 1977).[1]

Further analysis utilized four diversity measures. The first two (ΣTAXA [or *S*] and Margalef's index) are a measure of species richness, while the second two (Berger-Parker's index and Simpson's evenness) examine species evenness (see Magurran 1988, 2004). While the number of taxa in a sample (ΣTAXA) is the typical measure of species richness, Margalef's index attempts to control for sample size by normalizing the sum of all taxa by the sum of individual specimens. Species evenness (and the inverse, dominance) are best thought of as a measure of the relative abundance of each taxa represented in the sample. Berger-Parker's index measures evenness by the number of specimens in the highest ranking taxa over the sum of all individual specimens. It is usually expressed as its reciprocal to ensure that an increase in the index value corresponds to an increase in diversity; thus a decrease in the index value corresponds to increasing dominance (or specialization). Simpson's evenness is one of the more robust and easily interpretable evenness measures (Magurran 2004). To help control for bias introduced by sample size, Simpson's is typically expressed as its inverse over the sum number of taxa represented in the sample. In this form, its value ranges between 0 and 1 and is typically interpreted as the probability that two specimens come from two different taxa if randomly drawn from the sample. Equations and worked-out examples are found in Magurran (2004).

To evaluate the relative trends in diversity between assemblages through time, a generalized linear model

(GLM) with specified family (or error structure) and link function was run on the diversity values for each assemblage per component. Poisson-log, gamma-inverse, and binomial-logit family and link functions were used for count data, nonnormally distributed data, and data bound between 0 and 1, respectively (see Faraway 2005, 2006). All analysis was performed in R 2.6.2 (R Development Core Team 2008).

Sample Comparisons

An χ^2 test comparing the overall 1/4-inch sample with the 1/16-inch sample shows that the two differ from one another significantly ($\chi^2 = 4{,}638.71$, $p = .0004$; see Table 13.3). An examination of the adjusted residuals shows that four of the top five taxa are overrepresented in the 1/4-inch sample when compared to the 1/16-inch sample. These are lingcod (*Ophiodon elongates*), cabezon (*Scorpaenichthys marmoratus*), rockfishes (*Sebastes* spp.), and pricklebacks (*Stichaeidae*); all differ significantly than what might be expected by chance alone (see Table 13.3). Likewise, four of the top five represented in the 1/16-inch sample are overrepresented when compared to the 1/4-inch sample. These are wolf-eel (*Anarrhichthys ocellatus*), surfperch (*Embiotocides*), northern anchovy (*Engraulis mordax*), and night smelt (*Spirinchus starki*). The former four are all relatively large, line- or spear-caught taxa, while the latter four are all relatively small, typically net-caught taxa (Love 1996; Salls 1988).

Overall, the 1/4-inch mesh sample suggests that larger species—rockfish and cabezon—were the most commonly exploited fish (Table 13.3). Surfperches, on the other hand, are not represented among the top five taxa in the 1/4-inch sample, but they dominate the 1/16-inch sample. Northern anchovies, a very small fish, are also represented in considerably higher frequencies by the 1/16-inch mesh sample. This pattern is very similar to that identified in the Gordon study, in which a small taxon, filefish, was more heavily represented in the small-mesh samples. As with the Hawaiian study, there are unresolved questions about the dietary significance of the small fish, since Fitch (1973:108) realized that the anchovy bones in the CA-SLO-2 midden probably arrived via the stomach contents of larger fish and marine mammals and do not necessarily reflect human subsistence. Thus, while smaller fish are underrepresented by the larger mesh size, the implications of this difference for issues of diet and prey diversity are less clear.

Comparisons of ratios derived from the two samples demonstrate more clearly the differences in interpretation caused by mesh size. For the site as a whole, a ratio of fish bone ($n = 6{,}007$) to deer bone ($n = 1{,}201$) based on the 1/4-inch sample is approximately 5:1, while in the 1/16-inch sample, the ratio of fish to nonfish is only 2.1:1. Fitch (1979) did not provide a detailed report of nonfish remains in the 1/16-inch column. However, if the 1/16-inch

Table 13.3. Summary of Macro- and Microfaunal Samples from CA-SLO-2.

				6-mm (1/4-Inch) Mesh Sample					1-mm (1/16-Inch) Mesh Sample		
Taxon	**Common Name**	**Count**	**Rank**	**Percent**	**Residuals**	***p***	**Count**	**Rank**	**Percent**	**Residuals**	***p***
Anarrhichthys ocellatus	Wolf-eel	0	-	.00	-9.75	< .0001	116	3	8.72	20.83	< .0001
Embiotocides	Surfperch	225	4	3.71	-14.52	< .0001	473	1	35.54	31.01	< .0001
Engraulis mordax	Northern anchovy	0	-	.00	-12.01	< .0001	176	4	13.22	25.66	< .0001
Ophiodon elongatus	Lingcod	200	5	3.29	2.60	.0058	3	-	0.23	-5.55	< .0001
Scorpaenichthys marmoratus	Cabezon	2,176	2	35.85	9.07	< .0001	9	-	0.68	-19.37	< .0001
Sebastes spp.	Rockfishes	2,788	1	45.93	6.44	< .0001	221	2	16.60	-13.76	< .0001
Spirinchus starki	Night smelt	0	-	.00	-8.83	< .0001	95	5	7.14	18.85	< .0001
Stichaeidae	Pricklebacks	357	3	5.88	3.75	.0001	0	-	0.00	-8.01	< .0001
Other		324	-	5.34	-	-	238	-	17.88	-	-
	Total (*n*)	6,070					1,331				

Notes: From Jones et al. 2008; Fitch 1972. An χ^2 test was run on all identifiable taxa ($\chi^2 = 4{,}638.71$, $p = .0004$); only a subset of the top five for each sample are shown here.

mesh sample is extrapolated volumetrically to make it comparable to the 1/4-inch sample, the fish-to-deer bone ratio is 137:1. While ratios derived from the 1/4-inch mesh suggest a modest emphasis on fishing by the Diablo inhabitants, the 1/16-inch sample suggests an intensely maritime adaptation. This is the same relative trend identified in many other comparisons between mesh sizes, but in this instance the results are slightly exaggerated by the strong differences between 1/4-inch and 1/16-inch mesh rather than between 1/4-inch and 1/8 inch mesh. Many studies suggest that the true nature of subsistence adaptations can be revealed only with findings from 1/8-inch mesh. Do findings from 1/16-inch mesh provide an even more accurate characterization?

Comparing the two samples also reveals variation in diversity related to mesh size. Comparison of indices for richness (ΣTAXA and Margalef's index) and evenness (Berger-Parker's index and Simpson's evenness) derived from the two samples shows greater richness and evenness in the 1/16-inch sample (Table 13.4). This is consistent with the species abundance rank distributions from the Gordon (1993) study, but it conflicts with Vale and Gargett's (2002) findings from Australia. However, it does not necessarily indicate that those findings were inaccurate, since the Australian fishery may be different from those of Hawaii and central California in terms of the range of the availability of tiny fishes.

Overall, these findings imply, not surprisingly, that the microsample processed with 1/16-inch mesh reported by Fitch (1972) shows a greater representation of smaller taxa (Table 13.3) and dramatically higher volumetric concentrations of fish bone. While the majority of the bones recovered from the 1/16-inch sample were unidentifiable (10,834 out of 12,165), the identifiable portion of the samples still produced a wider range of taxa (40 compared to 29 taxonomic classes) and higher overall diversity (Table 13.4).

Table 13.4. Diversity Indices Comparing Fish Bone from the Two Samples from CA-SLO-2.

	6-mm (1/4-inch) Mesh Sample	**1-mm (1/16-inch) Mesh Sample**
Fish NISP (*n*)	6,070	1,331
Excavation volume (m^3)	98.9	0.8
ΣTAXA (*S*)	29	40
Margalef's richness	3.21	5.42
Berger-Parker's index	2.18	2.81
Simpson's evenness	0.05	0.14

Intercomponent Comparison

When the Diablo findings are classified into more meaningful temporal components, they show clear if not important patterns. The 1/4-inch sample is dominated throughout by rockfish (*Sebastes* sp.), while the 1/16-inch sample emphasizes the importance of surfperch (*Embiotocidae*) (Table 13.5). The 1/16-inch fish bone samples also show consistently higher richness (Figure 13.2) and evenness (Figure 3) than the 1/4-inch samples over time (Table 13.5). However, the relative diachronic trends within each sample are nearly the same for three of the indices. A comparison of the diachronic trends between the differing mesh samples shows that the trends are highly correlated for the number of taxa (poisson-log GLM, $z = 52.46$, $p < 0.0001$), Margalef's index (gamma-inverse GLM, $t = -5.0$, $p = 0.0377$), and Simpson's evenness (binomial-logit GLM, $z = 7.484$, $p < 0.0001$). This implies that while there might be quantitative differences in these diversity measures, the relative trends through time are nearly indistinguishable. This was not the case for Berger-Parker's index (gamma-inverse GLM, $t = -0.76$, $p = 0.524$), however. This is largely due to discrepancies in the diachronic change from the Middle- to Late-period components: while the 1/4-inch sample is marked by a decrease in evenness, the 1/16-inch sample shows an increase (see Figure 13.3). Magurran (2004) notes that Berger-Parker's index may be biased by sample size when the number of taxa in a given sample are fewer than 100, and this may be the cause of the discrepancy here. If anything, this confirms Magurran's (2004) suggestion that Simpson's evenness measure should be used when the number of taxa in a sample equals less than 100. Despite this statistical difference, the overall trends between the 1/4-inch and 1/16-inch samples are remarkably similar, with only a minor

Table 13.5. Summary of Key Findings from the CA-SLO-2 Faunal Remains by Temporal Component.

		6-mm (1/4-Inch) Mesh Sample								1-mm (1/16-Inch) Mesh Sample							
		IV		III		II		I		IV		III		II		I	
Taxon	**Common Name**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Anarrhichthys ocellatus	Wolf-eel	0	.0	0	.0	0	.0	0	.0	5	1.6	57	8.1	45	16.6	9	20.9
Embiotocides	Surfperch	41	2.3	166	4.3	16	4.3	2	5.6	106	33.8	240	34.1	113	41.7	14	32.6
Engraulis mordax	Northern anchovy	0	.0	0	.0	0	.0	0	.0	44	14.0	104	14.8	27	10.0	1	2.3
Ophiodon elongatus	Lingcod	47	2.6	128	3.3	19	5.2	6	16.7	1	.3	0	.0	1	.4	1	2.3
Scorpaenichthys marmoratus	Cabezon	587	32.4	1,372	35.6	199	54.1	18	50.0	3	1.0	4	.6	2	.7	0	.0
Sebastes spp.	Rockfishes	961	53.1	1,733	45.0	88	23.9	6	16.7	101	32.2	90	12.8	25	9.2	5	11.6
Spirinchus starki	Night smelt	0	.0	0	.0	0	.0	0	.0	18	5.7	68	9.7	9	3.3	0	.0
Stichaeidae	Pricklebacks	96	5.3	244	6.3	16	4.3	1	2.8	0	.0	0	.0	0	.0	0	.0
	Total (*n*)	1,811		3,855		368		36		314		703		271		43	
	ΣTAXA (S)	15		26		15		8		20		35		21		12	
	Margalef's	1.87		3.06		2.39		1.99		3.30		5.19		3.57		2.92	
	Berger-Parker's	1.88		2.04		1.8		2.13		2.96		2.93		2.40		3.07	
	Simpson's	.17		.11		.19		.43		.21		.16		.21		.51	

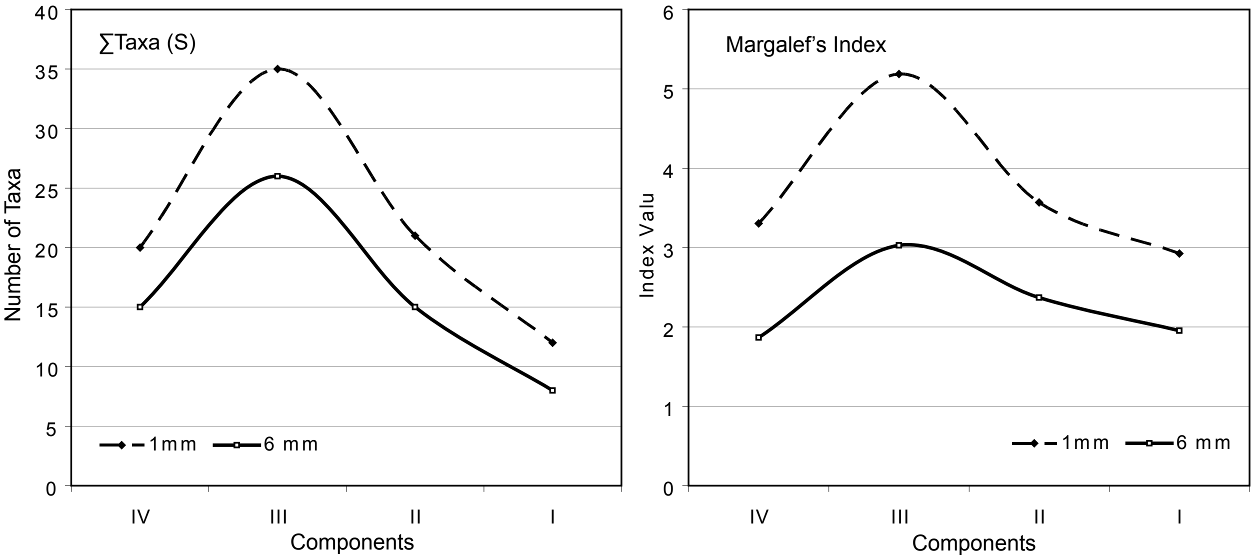

Figure 13.2. Richness (ΣTAXA and Margalef's index) values from CA-SLO-2 fish remains by temporal component and mesh size.

deviation in the transition between the last two temporal components (Figure 13.3).

On the whole, these data suggest that smaller mesh can indeed produce more species, indicating greater richness and a more even distribution of those taxa. However, the relative diachronic trends in diversity are, for the most part, statistically the same, regardless of mesh size. In the case of the Diablo fauna, this provides strong justification for relying on the evenness and richness values from the combined fish, bird, and mammal remains from the 1/4-inch mesh samples (Figure 13.4) for interpreting subsistence because the samples are robust and were recovered with the same technique. In terms of absolute dietary preferences, large mesh suggests that the Diablo inhabitants were more interested in terrestrial foods, whereas 1/16-inch mesh suggests they were intensive fisherpeople. However, issues of absolute sample size still confound this difference, since a larger sample screened through 1/16-inch

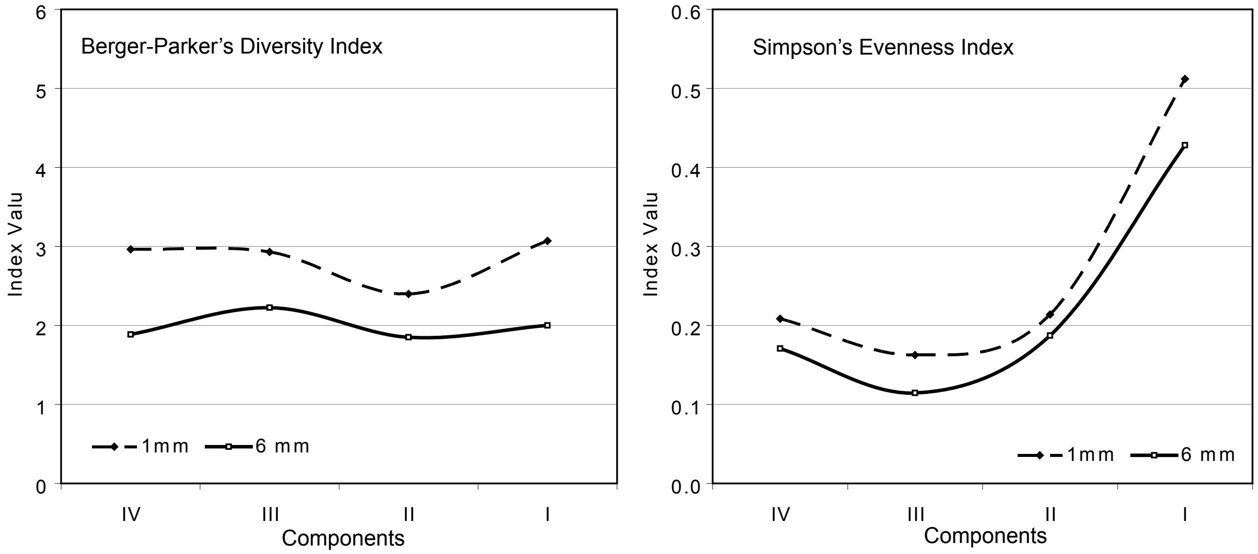

Figure 13.3. Evenness values (1/Berger-Parker's index and Simpson's evenness) from CA-SLO-2 fish remains by temporal component and mesh size.

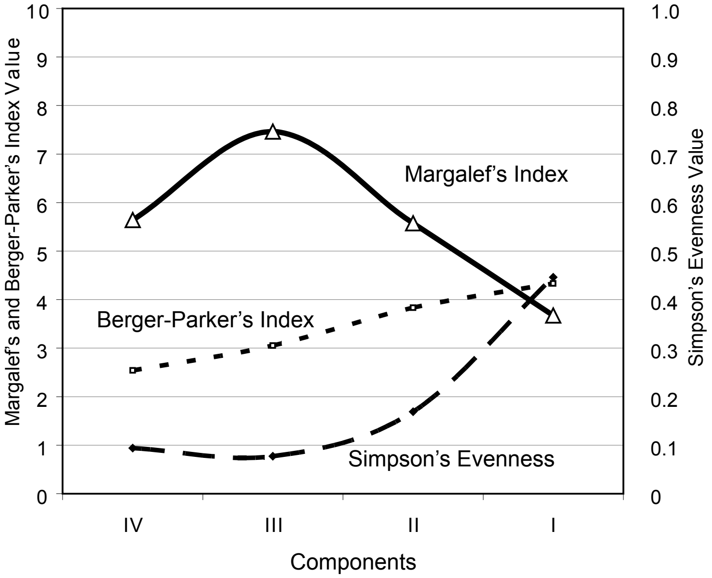

Figure 13.4. Richness and evenness over time for combined bird, mammal, and fish bones from 6-mm mesh samples from CA-SLO-2.

mesh would surely produce a greater quantity of larger fauna. Had a 1/8-inch mesh sample been obtained from Diablo Canyon, it almost certainly would have provided values between the 1/4-inch and 1/16-inch samples. Given these findings, there is no justification for deciding which of these characterizations is "more accurate." Rather, it should be recognized that 1/4-inch, 1/8-inch, and 1/16-inch samples all provide relative indices.

DISCUSSION AND CONCLUSION

Issues of diet, diversity, and mesh size have been heavily debated over the last several decades with no emergent consensus. The Diablo Canyon fish remains recovered from an intensive analysis of residues from 1/16-inch processing confirm findings from Gordon's (1993) study, which showed that smaller mesh yields a broader (richer) fish assemblage than larger (1/4-inch) mesh. More

Table 13.6. Diversity Values by Temporal Component from CA-SLO-2.

	Component				Total
	IV	III	II	I	
Bird and Mammal (nonfish)					
ΣTAXA (*S*)	30	39	23	9	50
Simpson's evenness	.10	.09	.16	.45	.07
Berger-Parker's index	1.95	2.13	2.11	2.33	2.08
Margalef's index	4.50	5.23	3.68	2.14	6.26
Combined (fish and nonfish)					
ΣTAXA (*S*)	45	65	38	17	79
Simpson's evenness	.09	.08	.17	.45	.06
Berger-Parker's index	2.54	3.05	3.83	4.33	2.95
Margalef's index	5.64	7.46	5.57	3.67	8.61

importantly, the Diablo findings highlight the fact that any mesh size only provides a relative index of subsistence. Diachronic trends in richness and evenness, when based on robust samples, are the same regardless of mesh size. Thus it may be more important to produce robust, statistically meaningful samples and to hold mesh size constant across temporal and spatial components. In other words, no single mesh size provides the absolute truth on subsistence. Findings from CA-SLO-2 also highlight the value of large excavation volumes for producing statistically meaningful assemblages of remains of larger animals. While diversity statistics from small volumes processed with small mesh can be considered meaningful for microfauna (for example, fish) because robust samples can be generated, larger excavation volumes are often needed in California to produce meaningful measures of diversity for large animals and for the combined vertebrate component of diets. Because excavation with small mesh is generally time-consuming and it may be difficult to excavate large volumes, the Diablo project shows the value of mixed recovery strategies for developing robust samples of all types of constituents.

ACKNOWLEDGMENTS

We continue to be deeply indebted to Roberta Greenwood for completing such a thorough investigation of CA-SLO-2 in 1968 and to Ken Gobalet, Jereme Gaeta, and John Fitch for identifying the fish remains. We are also thankful to Michael Glassow and Terry Joslin for organizing the symposium in Mexico City in 2006 and seeing to it that the papers from the session were published. The assistance of Ian G. Robertson was instrumental to the analyses performed in R. Funding for dating and analysis of faunal remains from Diablo Canyon was provided by California Sea Grant R/CZ-187. Any mistakes in fact or judgment are strictly the responsibility of the authors.

NOTE

1. This function was written in R by Ian G. Robertson based on a function in Keith Kintigh's commercially available package Tools for Quantifying Archaeology (see http://tfqa.com/).

CHAPTER 14

Deer Bone Fragmentation in Coastal Southern California Prehistoric Sites

MICHAEL A. GLASSOW

Analysts of faunal remains from prehistoric sites in coastal southern California occupied before 4000 B.P. are typically challenged by the high degree of bone fragmentation—so high that few fragments can be attributed to a particular skeletal element of an animal taxon, particularly animals the size of dogs or larger. Typically, bones in an assemblage are rarely more than 20 mm long, and most may be less than 10 mm long. Despite this high degree of fragmentation, bones of large mammals clearly are present, as indicated by fragments of thick cortical bone derived from shafts of limb bones and perhaps also by a few fragments attributable to a particular skeletal element. In these coastal sites, thick cortical bone is probably of deer or large pinnipeds, the former being most likely. Aside from fragmentation, bone is generally in good condition as a result of basic soil pH and semiarid climatic conditions. Cancellous (trabecular) bone typically is in small chunks no more than several millimeters long, often with thin cortical bone adhering. The character of these fragments allows them to be attributed to mammals at least the size of dogs, with no further distinctions possible.

Processes of fragmentation in deposits of early coastal southern California sites do not affect bones of all vertebrate taxa equally. In particular, larger mammal bones tend to fragment into many more pieces than smaller bones, a phenomenon that analysts working elsewhere in the world also have recognized (Lyman 1994b:429). A deer limb bone may be represented by a few hundred pieces, whereas a rabbit or rodent limb bone may be represented by fewer than 10. Artiodactyl teeth may be represented only by small enamel fragments, whereas rabbit and rodent teeth may be complete or nearly so. In other words, the smaller the mammal bone, the less it is affected by the various processes that cause fragmentation. Not surprisingly, in light of its thinness, bird bone is usually highly fragmented. Fish bone also tends to be highly fragmented, although the centra of fish vertebrae often are complete.

The implications of differential mammal bone fragmentation are obvious. Bone assemblages typically contain few or no bone fragments of large mammals exhibiting the distinctive features that zooarchaeologists generally use for assignment to a particular species, genus, or family, whereas bone fragments of small mammals often do exhibit such features, including complete or nearly complete articular ends of limb bones or substantial fragments of the skull or mandible. Consequently, if an objective of a faunal analysis is to assess the relative dietary importance of different taxa of vertebrates, regardless of their size, conventional approaches to taxonomic identification of bones will be biased against large mammals and consequently their dietary importance will not be recognized.

This paper presents a method for compensating, at least in part, for the absence or minimal presence of conventionally identifiable deer bones in assemblages from early coastal southern California sites. It takes advantage of the presence of thick cortical bone fragments that are highly unlikely to be from any other animal aside from California mule deer (*Odocoileus hemionus californicus*), or perhaps other artiodactyls that occupied restricted areas of coastal southern California. The method is applied to a bone assemblage from the Aerophysics site, CA-SBA-53, a habitation site located within the city of Goleta, California.

PAST RESEARCH ON BONE FRAGMENTATION

Although interest in bone fragmentation, as well as loss through destruction, may be traced back to the 1950s (Gifford 1981:377), a main impetus to this research was Binford's ethnoarchaeology-based arguments of the 1970s and 1980s (Binford 1981; Binford and Bertram 1977). The objective of this research has been to understand the patterns of breakage resulting from butchering and scavenging/ravaging by carnivores (Bartram and Marean 1999; Blumenschine and Marean 1993; Faith and Behrensmeyer 2006; Hudson 1993; Klein et al. 1999; Marean and Kim 1998; Todd and Rapson 1988) and if possible to develop methods for distinguishing between the two processes if both occurred at an archaeological site (Binford 1981:183–242; Johnson 1985; Outram 2001).

An important contribution of this research trajectory is that carnivores frequently contribute to the nature and composition of bone assemblages from archaeological sites. Beyond this, however, investigators have determined that density of bone material strongly influences its survival (Binford and Bertram 1977:106–152; Lyman 1993), which has led to research into how to measure bone density objectively (Lam et al. 1998; Lyman 1984). Those researchers who have studied the effects of carnivores on bones have recognized that hyenas and various canids not only break bones but also may destroy articular ends of limb bones, thus eliminating those portions traditionally used for taxonomic identification (Bartram and Marean 1999:25; Hudson 1993:311; Todd and Rapson 1988:313). Much of this research has implicitly assumed that archaeological bone assemblages have not been significantly affected by post-depositional processes. Because many of the studied assemblages have come from rockshelters or open-air surfaces that were rapidly buried, this assumption may be warranted in many instances.

A parallel research focus, beginning about the same time, has been investigation of various other taphonomic processes that affect bone preservation after discard, this research being informed by observations of modern bones of animals that died of either nonhuman or human causes (that is, actualistic studies). Behrensmeyer and her colleagues (Behrensmeyer 1978; Trueman et al. 2004) studied the process of weathering while bones were exposed on the ground surface within a national park in southern Kenya. Gifford (1978, 1980) also studied bones exposed on the surface in southern Kenya. Her research was within an ethnoarchaeological context in that she considered bones on campsites during and after human occupation. In addition to weathering, she considered such processes as trampling under human feet, consumption by carnivores, fluvial action, and tree fall.

Behrensmeyer's weathering stages may be considered standards for describing the process of weathering leading to fragmentation. These are abstracted below:

- Stage 1. Cracks are present, normally parallel to the fibrous structure of the bone. On long bones shafts, the cracks are longitudinal.
- Stage 2. The outermost layers show flaking, generally associated with cracks, leading to exfoliation of the layers.
- Stage 3. Portions of the bone surface lack the outermost layers, leaving a rough, fibrous texture.
- Stage 4. The bone surface becomes coarse textured, and splinters may become separated from the rest of the bone.
- Stage 5. The bone separates into many pieces.

Fragmentation as a result of weathering in subaerial contexts, therefore, would happen late in the process, during stages 4 and 5. Behrensmeyer (1978:158) observed that most bones in her study area in Kenya disintegrated within 15 years. Gifford, whose study area was near Behrensmeyer's, noted that bones of medium to large ungulates lasted at least 15 years on the surface and some survived more than 20 years (Gifford 1978:91, 1980:102–103). When fragmentation began within a particular region, it was the result of a variety of factors affecting weathering rate, such as those discussed by Lyman and Fox (1989). They noted such factors as taxon, skeletal element, the microenvironment surrounding an individual bone, length of exposure once covering tissue was gone, and history before deposition. With regard to the influence of microenvironment, Hill (1980) observed that bones protected by vegetation survive longer than those that are fully exposed (see also Behrensmeyer 1978:158).

Some of these researchers also observed fragmentation and weathering of bone once it became buried. A few mentioned that weathering either stops or the rate significantly slows upon burial (e.g., Hill 1980; Trueman et al. 2004:736). Chaplin (1971:18) noted that the expansion and contraction in clay soils causes bone to break into small fragments. This minimal information on weathering of buried bone is not surprising given that actualistic studies comparable to those of subaerial weathering would require observation over the course of decades. Moreover, just as Lyman and Fox noted that many factors affect subaerial weathering, a great variety of agents undoubtedly operate on buried bones as well. Some analysts have proposed methods for measuring relative amounts of fragmentation. Klein and Cruz-Uribe (1984:70–71) proposed using the ratio of NISP to MNI per skeletal part as a measure of fragmentation. Marean (1991) focuses on the completeness of ungulate carpals and tarsals—that is, small compact bones that can survive actions of humans and carnivores but not necessarily post-depositional agents (see also Lyman 1994b:427–431).

AGENTS OF BONE FRAGMENTATION AND LOSS WITHIN COASTAL SOUTHERN CALIFORNIA SITE DEPOSITS

Analysts of animal bones generally recognize that many factors affect an assemblage before it reaches their hands and that these factors must be controlled to the extent possible when making meaningful inferences about human behavior (Klein and Cruz-Uribe 1984:6–10; Lyman 1994b; Reitz and Wing 1999:110–141). Assemblages from coastal southern California sites are likely to have been affected by a variety of human activities common to hunter-gatherers around the world, by natural factors that begin to affect an assemblage even before a site is abandoned, and by archaeological excavation and collections processing techniques.

Human Activities

Faunal analysts have devoted a great deal of attention to the manner in which humans have affected bone assemblages through their various activities. In particular, ethnoarchaeological observation has produced a number of insights. Butchering, for instance, may result in breakage of bones. Specifically, marrow extraction from limb bone shafts requires breakage of bones into at least several fragments with a hammerstone (Binford 1981:87–181; Bonnichsen 1978; Johnson 1985:192–194). Bones rich in fat, particularly articular ends of limb bones, may be broken into pieces and then boiled to release the fat (Todd and Rapson 1988:313). Also important to consider, butchering may take place at more than one site. For instance, less meaty parts of a large mammal may be left at a kill site, with the remainder brought to a residential base (but see Binford 1981:184–186). Some California peoples pulverized rodents, including the skeleton and attached tissue, with a mortar and pestle and consumed the product (Sparkman 1908:197, 198). The use of limb bones, particularly metapodials, for the manufacture of tools will result in both fragmentation and destruction of bones. Finally, differences in the location of bone disposal may result in differences in fragmentation and destruction. Gifford (1980:101; Gifford-Gonzalez et al.

1985) demonstrated that bones deposited on the surfaces of soils with different degrees of looseness will be differentially fractured by trampling by a site's occupants.

Modern human activities—the most obvious being plowing—may also result in bone fragmentation. Lyman and O'Brien (1987) provide an example from a plowed site in Missouri. They noted that deer bones within the plow zone were in smaller fragments than those below the plow zone. As well, movement of heavy equipment such as large bulldozers may produce enough compacting pressure on buried bones to cause their breakage.

Action of Canids and Other Scavengers

As discussed above, a prominent interest of faunal analysts has been the effects of canids and other scavengers on bone assemblages. In southern California, dogs and/or coyotes would be expected to be the main scavengers in most instances. Ethnoarchaeological and actualistic studies cited above have revealed that scavengers affect certain parts of the skeleton more than others. In general, the least dense parts of an animal skeleton, including vertebrae, ribs, and articular ends of limb bones, which often are the parts with the most grease, are most affected by scavengers. Scavengers may also break limb bone shafts to extract marrow, although this action appears more closely associated with humans.

Weathering

Weathering refers to "the process by which the original microscopic organic and inorganic components of a bone are separated from each other and destroyed by physical and chemical agents operating on the bone in situ, either on the surface or within the soil zone" (Behrensmeyer 1978:153). Physical weathering is caused by exposure to the sun, wetting and drying, and temperature variation. Chemical weathering is the alteration of the chemical composition of bone, such as loss of its organic content (collagen) as a result of the action of microorganisms or the physical agents just mentioned. It is also possible that bone will take up chemicals from the ground on which it lies via wicking—that is, the passage of moisture from the ground to the upper surface of the bone, where it evaporates (Trueman et al. 2004:735). Not only does weathering result in the disintegration and fragmentation of bone, it also makes the bone more fragile and therefore more prone to breakage by physical forces unrelated to weathering.

As mentioned, researchers have given little attention to weathering after a bone becomes buried. In coastal southern California, with its distinct wet and dry seasons, buried bone is subject to wetting and drying as it would be while lying on the surface. In some depositional contexts, bone will become completely saturated during the winter rainy season and completely dry or nearly so during mid- to late summer and early fall. Buried bone will also undergo chemical weathering as a result of the action of microorganisms, as well as the passage of chemicals such as soil acids within groundwater as it passes through the bone. Nonetheless, in coastal southern California site deposits, the bone material itself is generally in good condition, even though it may be fragmented. Even small fragments generally do not show obvious effects of subaerial weathering—that is, they show no evidence of surface alteration consistent with Behrensmeyer's stages 2 through 4. To what extent weathering agents directly contribute to fragmentation while bones are buried is unknown, although it seems plausible that the cracking that occurs in the course of subaerial weathering also would affect buried bone and eventually bone fragments would result.

Bioturbation

Three types of bioturbation—tree uprooting, growth and decay of plant roots, and rodent burrowing—undoubtedly affect buried bones. The roots of an uprooted tree often envelope considerable quantities of soil from depths as much as 1 m below the surface, sometimes even deeper. If the uprooting occurs at an archaeological site, buried bones might be exposed (or re-exposed) to subaerial weathering, and the uprooting itself might cause bones to break. Once the roots decay (or burn), the soil clinging to them, as well as any bone within this soil, falls back to the ground, perhaps filling the hole left when the tree uprooted.

Living roots of all kinds of vegetation also may cause bone breakage. As a plant of any size grows, its roots may come into contact with bones. If bones are cracked, roots may grow into or through cracks, either enhancing the process of cracking or increasing the separation of fragments resulting from cracking. Roots, particularly root hairs, may also etch the surface of bones, although this is not likely to contribute to fragmentation.

Rodent burrowing clearly has been extensive at many sites, the evidence being not only fresh tailings next to entries of active burrows but also krotovina, which may be seen on the sidewalls of excavation units when soil conditions favor them. Two animals—Botta's pocket gopher (*Thomomys bottae*) and the California ground squirrel (*Spermophilus beecheyi*)—are the principal burrowers in southern California archaeological deposits. The amount of bone fragmentation caused by their digging is difficult to assess, however, as their gnaw marks are seldom seen on smaller bone fragments. Regardless, the soil displacement they cause as they move soil within their burrows and dens and as these cavities collapse or are filled with sediments, as well as the periodic exposure of bone to sunlight when brought to the surface in their tailings, undoubtedly contributes to fragmentation. Of course, burrowing activity also disperses bone fragments, as studies of rodent burrowing in archaeological sites have shown (Erlandson 1984; Johnson 1989).

Soil Movement and Compaction

In addition to the soil movement caused by rodent burrowing, deposits may move as a result of annual wetting-drying cycles. Deposits rich in clay may swell during the rainy season and shrink during the dry season, and cracking may also occur. In fact, clay-rich soils are common at sites occupied earlier than about 4000 B.P. The effects on bone of these shrink-swell cycles are poorly understood, but the increase and decrease of pressure on bones is likely to cause breakage in some circumstances (Chaplin 1971:18), especially if bones fall into cracks during the dry season and are squeezed as the cracks swell shut during the wet season. Compaction of deposits containing bones may also result in breakage (Klein and Cruz-Uribe 1984:70; Lyman 1994b:423–426), particularly if the deposits are deeply buried by later archaeological or nonarchaeological deposits.

In summarizing this discussion, bone fragmentation and loss caused by prehistoric peoples, carnivores, and subaerial weathering are relatively well understood, but the factors operating once bones become buried are poorly known, largely because of the relatively long time periods that must transpire before effects are noticeable. Undoubtedly, most archaeologists working in coastal southern California assume that fragmentation and loss occur among buried bones, but the manner in which the agents discussed above affect bones is still largely a matter of speculation. It is interesting to note, however, that bone fragments seldom show the surface alterations associated with subaerial weathering. It is also noteworthy that sites occupied earlier than about 4,000 years ago typically contain bone that is more highly fragmented than that in younger site deposits. In very broad terms, therefore, it seems safe to conclude that bone fragmentation and loss occur while bone is buried, not just when it is exposed on the surface. Furthermore, the factors causing fragmentation of buried bone are progressive, although there may be a point at which fragmentation into smaller pieces slows down because a critical small size has been reached.

ASSEMBLAGE BIAS CAUSED BY COLLECTION PROCEDURES

Excavation tools may break bones as deposits are loosened and transported to a sifting screen. Shaking the screen also may cause breakage if bones are impacted by objects such as stones or dirt clods, or if dirt clods are crushed with a trowel. Of course, excavators typically are careful during excavating and screening to minimize breakage of items of interest, but some breakage is inevitable in most situations.

Procedures for collecting bones from a sifting screen are also important factors. Prior to about 30 years ago, most archaeological excavation in coastal southern California entailed sifting deposits through 1/4-inch (6-mm) mesh screens and collecting whatever could be readily seen in the screens once the loose soil had been sifted through. If the deposits were dry and clayey, clods would need to be broken apart in the screen, a procedure that varied in thoroughness from one screener to the next. Significantly, the 1/4-inch mesh was large enough that many small bone fragments would be lost during sifting (Shaffer and Sanchez 1994). Today many archaeologists working in the region use 1/8-inch (3-mm) mesh screens and regularly spray water on the material left in the screen after sifting to ensure that all material finer than the mesh size is removed. If sorting through the material caught by the screens takes place in a laboratory rather than the field, small bone fragments are systematically recognized and collected.

There is a dramatic difference between a bone assemblage collected using earlier techniques and one employing the more intensive techniques often used today. Publications concerning sites at which the earlier screening procedures were used frequently mention finding minimal amounts of bone, not enough to justify the serious attention of a faunal analyst. In contrast, collections resulting from water-screening and laboratory sorting typically contain considerable amounts of bone, even though the degree of fragmentation may be high in assemblages dating prior to about 4000 cal B.P.

Of course, some bone fragments may be smaller than would normally be caught by the finest mesh sizes typically used in archaeological excavation. Especially in the case of bone assemblages exhibiting a high degree of fragmentation, some bone inevitably would not be recovered even if screen with 1/6-inch (1.5-mm) mesh is used. In short, bone fragments may vary in size, from those barely visible to the naked eye to those large enough not to require screening to recognize. Furthermore, the degree of fragmentation may vary from site to site. In some situations screening may result in recovery of nearly all bone that was deposited prehistorically; in others fragmentation is so great that screens with a conventional 1/8-inch mesh may recover no more than 75 percent.

NATURE OF ARTIODACTYL BONE FRAGMENTATION IN COASTAL SOUTHERN CALIFORNIA SITE DEPOSITS

The nature of bone fragmentation of course varies between taxa. As mentioned, at coastal southern California sites, bones of larger mammals generally fragment into many more pieces than bones of smaller mammals. Skeletal elements of deer and other artiodactyls fragment differentially, depending largely on thickness of cortical bone. Most elements in a deer skeleton have relatively thin cortical bone, and fragments in site deposits less than 4,000 years old generally have a nondescript form typically less than 10 mm long. Although articular ends of limb bones also fragment into many small pieces, shafts have a different breakage pattern because of the greater thickness of the cortical bone and their structure. As Behrensmeyer (1978:151) discusses, a weathering shaft will develop longitudinal fissures distributed around its perimeter (her stage 1). If the bone shaft is exposed on the ground surface to sun and rain, this change may begin within a few months. If the shaft is quickly buried, fissuring may also occur, but later. The result is elongate fragments of bone that are fragile enough that breakage from various mechanical forces is likely to occur. However the fragmentation proceeds, the results as seen in bone assemblages are segments of cortical bone typically less than 10 mm long but sometimes as long as 20 mm or more. These are frequently the most distinctive fragments of artiodactyl bone in an assemblage. Sometimes these fragments are so narrow that only one surface of the bone is extant. That they often exhibit no surface exfoliation characteristic of Behrensmeyer's weathering stages 2 and 3 may be an indication that fracturing occurred largely or exclusively within archaeological deposits.

A problem with classifying small fragments of large mammal bones from coastal southern California sites is the prospect of confusion between pinniped and artiodactyl bones. However, pinniped limb bone shafts typically have cancellous bone on the interior surface of cortical bone, which allows them to be distinguished from limb bone shaft fragments of artiodactyls. If pinniped bone were completely absent from a bone assemblage, all fragments and cortical bone with vestiges of cancellous bone on their interior surfaces most likely would be from artiodactyls, much of it from portions of limb bones at or near articular ends.

AN EXAMPLE: THE ASSEMBLAGE OF BONES FROM THE AEROPHYSICS SITE

The bone assemblage from the Aerophysics site (CA-SBA-53) provides a useful example for elucidating the problems associated with high degrees of fragmentation. This site is located about 2.3 km from the Santa Barbara Channel coast. It overlooks the northwestern margin of a former estuary, the modern vestige of which is known as the Goleta Slough. The site was occupied by hunter-gatherer-fishers between 5650 and 5300 cal B.P. and is one of the few sites of this time period having deposits not mixed with those of an earlier or later time period (Glassow 2004; Rick and Glassow 1999). A major excavation took place at the site in 1956–1957 (Harrison and Harrison 1966) in response to its imminent destruction as a result of grading associated with construction of commercial buildings. In 1985 a UC Santa Barbara archaeological field class under my direction undertook a small-scale test excavation in a small area of intact deposits. The excavation had the purpose of acquiring a sample of faunal remains (both bone and shell) that was missing in collections obtained earlier (Glassow 2004). Three 1-x-1-m test pits were excavated, each to a depth of 90 cm. All material caught by 1/8-inch mesh screens was washed in water using a garden hose with a spray nozzle attached, and after drying it was sorted in an archaeological laboratory. The collection contains 2,621.7 g of bone, the number of individual pieces being 68,150.[1] Consequently, the average weight of a bone fragment is 0.04 g. Few bones are larger than 20 mm in length.

Because of the high degree of fragmentation, the bone from the 1985 test excavation was sorted into categories defined with respect to descriptive characteristics of the bone, rather than into categories that are strictly taxonomic (Table 14.1). Nonetheless, these categories have varying taxonomic meaning. Some categories, such as the "small fauna" category, undoubtedly contain bones of animals of more than one class, whereas other categories, such as the "large land mammal category," which is the focus of this example, have a decent degree of taxonomic integrity.

Fifty-two mammal bone fragments are of identifiable skeletal elements and could be assigned to a taxon. This number excludes bones of pocket gopher and ground squirrel, most of which undoubtedly are of natural origin (Table 14.2). Significantly, 25 of the 52 fragments are of rabbit (*Sylvilagus* sp.), but only 3 are of deer. The three identified deer bones (Table 14.2) are small fragments ranging in length from 15 to 29 mm. In addition to these are a number of cortical bone fragments that are likely to be of deer limb bones. Many of these cortical fragments appear to have resulted from the longitudinal cracking described above, combined with breakage of the resulting elongate fragments. Typically such fragments are 2 to 4 mm wide and 5 to 15 mm long, and they approximate a rectangular or triangular shape. Deer also are represented by small tooth fragments, sometimes just plates of enamel, but these are not considered here.

In the Santa Barbara Channel area today, deer is the only artiodactyl present, although there is some possibility that elk was also present when the Aerophysics site was occupied. Small fragments of limb bones of bear (*Ursus* spp.) would be expected to have characteristics similar to those of deer. However, the prospect that significant quantities of bear bone are present is highly unlikely given the rare occurrence of identified bear bones in regional assemblages of any age.

The bone assemblage from the Aerophysics site epitomizes the problem of properly assessing the importance of deer in the diet of the site's inhabitants. Because the bone is highly fragmented, an obvious bias favors the identifiability of small mammal bones in relation to large mammal bones. The three identified deer bones are barely large enough for confident taxonomic identification, whereas most of the rabbit bones are whole articular ends of limb bones. Do the three identified deer bones provide a realistic picture of the

Table 14.1. Distribution of Bone by Taxonomic Category and Weight (g).

Unit	Level	Sea Mammal[a]	Dolphin[b]	Large Land Mammal[c]	Unidentified Mammal	Small Fauna[d]	Teleost	Elasmobranch	Bird[e]	Reptile and Amphibian[f]	Unidentified Bone	Total
1	0–20	13.71			45.87	1.97	5.32	0.24	0.45		12.43	79.99
	20–40	69.58	1.19	7.53	62.97	20.40	10.20	2.36	2.59	0.32	4.76	181.90
	40–60	42.81	0.73	15.22	34.42	23.91	14.77	1.61	3.21	1.03	10.40	148.11
	60–80	69.14		10.13	48.76	36.13	27.76	6.26	3.53	0.41	8.79	210.91
	80–90	25.84	0.31	3.96	37.07	17.13	27.96	6.58	4.07	0.41	0.21	123.54
Unit 1 total		**221.08**	**2.23**	**36.84**	**229.09**	**99.54**	**86.01**	**17.05**	**13.85**	**2.17**	**36.59**	**744.45**
2	0–20	47.97	0.71	6.71	54.75	15.64	6.09	0.63	6.85	0.24	0.84	140.43
	20–40	77.98	1.99	7.11	125.86	53.27	12.19	2.13	1.99	0.32	0.97	283.81
	40–60	47.76	6.06	7.85	88.91	40.23	8.58	2.65	5.52	0.54	4.71	212.81
	60–80	27.11	0.32	4.30	50.39	30.81	8.63	2.10	2.15	0.25	3.25	129.31
	80–90	8.10	0.14	1.66	23.99	11.13	4.97	1.04	0.53	0.28	3.81	55.65
Unit 2 total		**208.92**	**9.22**	**27.63**	**343.90**	**151.08**	**40.46**	**8.55**	**17.04**	**1.63**	**13.58**	**822.01**
3	0–20	11.98		16.19	91.75	18.22	9.45	4.75	0.91	0.28	18.08	171.61
	20–40	89.35	1.84	24.31	112.95	45.48	18.00	2.32	0.80	0.55	9.01	304.61
	40–60	40.80	2.28	22.49	97.17	48.53	15.77	3.23	0.58	0.95	1.40	233.20
	60–80	42.55	32.23	7.93	85.55	58.46	17.05	3.05	0.64	0.81	1.80	250.07
	80–90	9.17	0.41	4.11	46.78	22.60	8.77	2.16	0.28	0.51	0.93	95.72
Unit 3 total		**193.85**	**36.76**	**75.03**	**434.20**	**193.29**	**69.04**	**15.51**	**3.21**	**3.10**	**31.22**	**1,055.21**
Grand Total		**623.85**	**48.21**	**139.50**	**1,007.19**	**443.91**	**195.51**	**41.11**	**34.10**	**6.90**	**81.39**	**2,621.67**

[a] Pinnipeds and small cetacean.
[b] Vertebral epiphyses only.
[c] Deer-sized mammals but probably including some dog-sized mammals as well.
[d] Animals the size of a jackrabbit or smaller but probably including some bird, reptile, and amphibian bone.
[e] Thin limb bone fragments only.
[f] Vertebrae only.

Table 14.2. Distribution of Taxonomically Identified Mammal and Bird Bones.

Taxon	**Skeletal Element**	**Confidence**[a]	**Unit**	**Level (cm)**
Pinnipedea (seals and sea lions)	Phalanx, shaft	1	2	20–40
	Left scapula, articular end	1	1	60–80
	Left pelvis, acetabulum fragment	1	2	60–80
Otariidae (eared seal)	Tooth	2	1	60–80
Zalophus californianus	Phalanx (female), distal end	2	1	20–40
(California sea lion)[b]	Phalanx (female), shaft	2	1	80–90
	Phalanx (female), distal end	2	1	40–60
	Phalanx (female), distal end	2	1	20–40
	Phalanx (female), distal end	2	1	40–60
	Carpel or tarsel fragment	3	3	80–90
	Atlas fragment	1	3	20–40
	Left occipital condyle	2	1	20–40
	Left tibia (female), proximal end	3	3	20–40
Delphinidae (dolphin)[c]	Vertebra fragment	1	1	40–60
	Vertebra fragment	1	2	40–60
Cetacea (whale)[c]	Indeterminate	1	2	20–40
	Indeterminate	1	3	60–80
Canis sp. (dog or coyote)	Right (?) mandible fragment	2	1	20–40
	Tooth (left molar?)	1	1	40–60
	Tarsal (cuboid?) fragment	2	3	40–60
	Right astragulus	1	2	60–80
	Phalanx, distal end	1	2	0–20
Odocoileus hem. (mule deer)	Left femur, distal end fragment	1	2	80–90
	Metatarsal or metacarpal, distal end fragment	1	2	0–20
	Metatarsal or metacarpal, distal end fragment	1	2	60–80
Sylvilagus sp. (rabbit)	Left calcaneus	1	1	40–60
	Left calcaneus fragment	1	3	80–90
	Right calcaneus	1	2	40–60
	Right calcaneus fragment	1	3	20–40
	Left humerus, proximal end	1	2	20–40
	Left humerus, proximal end	3	3	80–90
	Left humerus, distal end	1	1	0–20
	Left humerus, distal end	1	1	40–60
	Left humerus, distal end	1	2	0–20
	Left humerus, distal end	1	3	20–40
	Right humerus, distal end	1	3	40–60
	Right ulna, proximal end	1	3	60–80
	Right ulna, proximal end	1	3	80–90
	Left ulna, proximal end	1	3	40–60
	Left femur, proximal end	1	3	20–40
	Left femur, distal end	1	3	60–80
	Right tibia, proximal end	1	2	80–90
	Right tibia, proximal end	1	3	40–60
	Left tibia, distal end	1	3	20–40
	Right maxilla fragment	1	2	40–60
	Right maxilla fragment	1	3	40–60
	Left mandible fragment	1	3	40–60
	Right mandible fragment	1	1	60–80
	Left pelvis fragment	1	2	40–60
	Right pelvis fragment	1	3	60–80
Branta hutchinsii (cackling goose)[d]	Left humerus, proximal end	2	2	0–20
Buteo jamaicensis (red-tailed hawk)[d]	Tibiotarsus, proximal end	2	1	40–60

[a] Confidence of taxonomic identification: very confident = 1; not confident = 4.

[b] More likely *Zalophus californianus* than other species within Otariidae.

[c] Identified on the basis of the large size of the fragments and the coarse structure of cancellous bone.

[d] Identification by Dan Guthrie, Joint Science Department, Claremont McKenna College.

dietary importance of deer relative to rabbit or other taxa represented among the faunal remains? Consideration of the other deer remains in the bone assemblage, namely the thick cortical bone, may provide a partial answer to this question.

A PROPOSED METHOD FOR IDENTIFYING THE DIETARY IMPORTANCE OF DEER

One way of coming closer to understanding the dietary significance of deer when confronted with assemblages such as that from the Aerophysics site is to determine how much cortical bone lacking a cancellous interior exists in the limb bones of an individual deer. If the amount were known, it could be compared to the amount of thick cortical bone in an assemblage, thus allowing the number of deer represented in the bone assemblage to be estimated. The first step, therefore, was to separate from the Aerophysics site bone assemblage all the cortical bone that confidently could be attributed to deer limb bone shafts, this bone being defined as "thick cortical bone." The fragments had to meet the following criteria:

1. They had to be dense cortical bone lacking the "woody" or porous appearance characteristic of pinniped bone.
2. They had to have curvature consistent with deer bone shafts, although narrow fragments generally were too small to exhibit curvature.
3. Vestiges of cancellous bone had to be absent, although a portion of the interior surface of a few included fragments did have the beginnings of cancellous bone that occurs at either end of a shaft.
4. At least a portion of the bone had to be at least 2 mm thick.

A total of 291 fragments, weighing 70.4 g, are in this category. Applying the criteria above meant that a number of smaller fragments of cortical bone were rejected. For instance, some elongate fragments lacked one of the surfaces, usually the interior; if the fragment thickness was less than 2 mm thick, it was not included. A few fragments of this sort greater than 2 mm thick were included, however, because the fragments clearly satisfied criteria 1 and 2. Also, some fragments appeared to be too weathered for us to be sure that they had once been dense cortical bone; these were rejected because they could not confidently be distinguished from sea mammal bone. Overall, the selection of thick cortical bone fragments was conservative, and undoubtedly many small fragments of deer limb bone shafts were rejected. Given the variable size of the fragments and therefore their variable representation of the amount of thick cortical bone in a deer skeleton, the unit of analysis is most appropriately weight.

Next I acquired a reference collection of deer limb bones from the University of California Sedgwick Reserve, located in the interior of Santa Barbara County. Most of the bones were fresh, seemingly less than one year old, and most had to be cleaned of connective tissue. Those limb bones with thick cortical bone include the humerus, radius, femur, tibia, metacarpal, and metatarsal, and their numbers in the reference collection vary from one (metacarpal) to nine (tibia). The bones did not come from complete skeletons; at least seven individuals are represented in the collection. Some of the bones are from subadults, indicated by unfused epiphyses, and some of the subadults were not fully grown, their bones being approximately 10 mm shorter than the bones of adults.

Each bone in the reference collection was sectioned lengthwise using a band saw. Then the portions of each bone with cancellous bone adhering to the interior surface and thinner than 2 mm were removed using a Dremel rotary tool. Each half was then weighed, and the weights of the two halves of each bone were combined (Table 14.3).

To estimate the amount of thick cortical bone in a deer, I averaged the weight of bones within each skeletal element category, regardless of right or left side. I then totaled the averages of the elements and multiplied the total by two to represent the amount of thick cortical bone in one deer. In light of some bones coming from deer that had not reached their full adult size, I produced three alternative cortical bone weights: one derived from all bones regardless of size, one derived only from bones of fully grown

Table 14.3. Weights of Modern Bones used in the Analysis.

Spec. desig.	**Element**	**Side**	**Total Weight (g)**	**Age**	**Condition**
1	Femur	L	53.70	Adult	Longitudinal cracks
1	Femur	R	53.25	Adult	Longitudinal cracks
1	Metatarsal	L	68.12	Adult	Longitudinal and transverse cracks
1	Metatarsal	R	66.66	Adult	
1	Tibia	L	101.76	Adult	Longitudinal cracks
1	Tibia	R	102.54	Adult	
2	Femur	L	29.98	Subadult, not full size	
2	Femur	R	31.79	Subadult, not full size	
2	Humerus	R	27.40	Subadult, not full size	
2	Metacarpal	R	30.39	Subadult, not full size	
2	Metatarsal	L	46.89	Subadult, not full size	
2	Metatarsal	R	46.42	Subadult, not full size	
2	Radius	R	32.44	Subadult, not full size	
2	Tibia	L	72.55	Subadult, not full size	
2	Tibia	R	72.48	Subadult, not full size	
3	Femur	L	58.47	Subadult, full size	
3	Femur	R	58.96	Subadult, full size	
3	Humerus	L	43.78	Subadult, full size	
3	Humerus	R	41.14	Subadult, full size	
3	Radius	L	48.33	Subadult, full size	
3	Radius	R	48.37	Subadult, full size	
3	Tibia	L	92.11	Subadult, full size	
3	Tibia	R	91.52	Subadult, full size	
M48	Humerus	L	39.36	Adult	
M48	Radius	L	42.72	Adult	
Misc.	Femur	R	24.41	Subadult, not full size	
Misc.	Metatarsal	L	54.97	Subadult, not full size	
Misc.	Metatarsal	R	56.56	Subadult, full size	
Misc.	Metatarsal	R	40.21	Subadult, not full size	
Misc.	Metatarsal	R	50.56	Adult	Longitudinal and transverse cracks
Misc.	Tibia	L	80.11	Subadult, full size	Longitudinal cracks
Misc.	Tibia	R	55.02	Subadult, not full size	
Misc.	Tibia	R	96.01	Adult	Longitudinal cracks, exfoliation

deer (including some with unfused epiphyses), and one derived only from bones of deer not yet fully grown (all with unfused epiphyses). I also considered the possibility that metapodials (metacarpals and metatarsals) may have been systematically used to manufacture tools and consequently would be poorly represented within an archaeological collection of thick cortical bone (Table 14.4).

Of course, archaeological bone has lost some of its original weight due to weathering, particularly chemical weathering. In other words, one of the modern bones processed for this analysis would be heavier than a comparably sized archaeological bone, and the difference between them would depend on the degree of weathering. This difference is partly compensated for by the loss of bone material when the modern bones were sawed in half. In general, however, the use of modern bone weight will result in underestimation of the amount of deer represented by the thick cortical bone in an archaeological assemblage.

It is important to recognize that this approach to estimating the dietary importance of deer depends on a series of assumptions that may not always be warranted. First, the approach assumes that most or all thick cortical bone present in excavated

Table 14.4. Weights of Shafts, Based on Average Element Weights.

Category	Weight of all elements (g)	Weight less metapodials (g)
All bones	294.35 (588.70)	210.16 (420.32)
Full size	328.88 (657.76)	238.01 (476.02)
Subadult, less than full size	232.76 (465.52)	155.25 (310.50)

Note: The weights doubled appear in parentheses.

deposits has been collected, or that failure to collect is no worse than it is for other categories of faunal remains. Second, it assumes that the thick cortical bone fragments in an archaeological assemblage have been accurately identified. Third, it assumes that cortical bone is well preserved and that the amount recovered bears a close relationship to that actually deposited. Forth, it assumes that all portions of a butchered deer remained at the site from which the bone assemblage came. In specific cases, there may be good reasons for suspecting that one or more of these assumptions cannot be made in the analysis of data derived from a bone assemblage, but any approach to faunal analysis and dietary reconstruction necessarily relies on a series of assumptions comparable to these.

RESULTS

As mentioned, 70.4 g of thick cortical bone are in the assemblage from the Aerophysics site. If these bones came from a mixture of fully grown and nearly fully grown individuals, the weights in Table 14.4 derived from all bones in the reference collection may be used. The cortical bone in the site collection equals 12 percent of the weight of thick cortical bone of a deer, or 16.7 percent if the metapodials are excluded. If the bones of only full-sized individuals are used, the thick cortical bone in the site collections is equal to 10.7 percent of the weight of thick cortical bone of a deer, or 14.8 percent if metapodials are excluded. Similarly, if the bones of only subadults not fully grown are used, the thick cortical bone in the site collection is equal to 15.1 percent of the weight of thick cortical bone of a deer, or 22.7 percent if the metapodials are excluded. Conservatively, therefore, the bone in the site collection may be said to represent between 10.7 and 22.7 percent of the amount of thick cortical bone in a deer skeleton.

An individual mule deer weighs an average of 45.4 kg (Glassow and Wilcoxon 1988:43), and using White's (1953a:397) estimate of 50 percent of live weight being edible meat weight, the average edible meat weight of an individual deer would be 22.7 kg. If the percentages just presented also approximate the percentage of the total meat of an individual deer, the bone in the site collection may be said to represent between 2.4 and 5.2 kg of deer meat.

The three identified deer bone fragments represent at a minimum one and possibly as many as three individual deer. If the two metatarsal/metacarpal fragments are from separate individuals, the MNI would be two. It is apparent, therefore, that the amount of thick cortical bone in the assemblage is underestimating the amount of deer represented by these three bones, even if they came from just one individual. Most likely, the discrepancy is a result of the loss of cortical bone thicker than 2 mm due to fragmentation and recovery. In other words, some thick cortical bone fragments were too fragmented to satisfy the sorting criteria specified above, and some of the smaller fragments were lost through sifting screens during excavation.

What if no identifiable deer bones for estimating MNI were recovered, as the case may be in some bone assemblages from coastal southern California sites occupied prior to 4000 B.P.? This would have been the case at the Aerophysics site had unit 2 not been excavated, given that all three fragments were from this unit. Would the thick cortical bone separated from the assemblage give some idea of the dietary importance relative to other taxa? A comparison with rabbit would be meaningful in this regard. Based on the data presented in Table 14.2, a very generous rabbit MNI would be seven individuals, assuming that all fragments of the most abundant element, the humerus, whether right or left side or distal or proximal end, are from separate individuals. A rabbit (*Sylvilagus bachmani bachmani*) weighs approximately .62 kg (Orr 1940:150), and perhaps as much as 60 percent of this weight (.37 kg) is edible. Given an MNI of seven, the meat weight represented by the rabbit bones is equal to 2.6 kg. This amount is close to the minimum amount of meat represented by the thick cortical bone in the site collection. Given that the amount of deer meat was most likely more than the minimum, it would be reasonable to conclude that deer were more important to the diet than rabbits.

This trial application illustrates three reasons for considering the thick cortical bone in assemblages such as that from the Aerophysics site. First, the amount of thick cortical bone in an assemblage can provide some idea of the dietary importance of deer relative to other taxa if identifiable deer skeletal elements are absent in the assemblage. Most likely, the amount of thick cortical bone will underestimate the importance of deer, but this certainly would be a better result than arguing that deer were not hunted because no deer skeletal element fragments could be identified. Second, the amount of thick cortical bone can serve as a check on the MNI values if identifiable deer skeletal element fragments are present, particularly if MNI values are very small. Third, the amount of thick cortical bone relative to deer MNI can serve as a measure of the extent to which agents of fragmentation have affected deer bones.

CONCLUSION

The bulk of the literature concerning methods of faunal analysis places most emphasis on bone fragments having enough distinctive features for us to identify relatively confidently a skeletal element and therefore a particular taxon. Even though analysis typically has considered bone fragments in assemblages, their size generally is much larger than that prevailing in the Aerophysics site. Indeed, many analysts would consider the size of the thick cortical bone fragments in the site assemblage to be below the threshold of "analytical absence," which Lyman and O'Brien (1987:496) define as the size limit of bone fragments useful for faunal analysis. Nonetheless, as Lyman and O'Brien point out, the analyst often must address the question of "whether rare elements are rare because of their analytic absence or because of their prehistoric absence in the systemic context (resulting from transport and/or destruction by consumption or fragmentation)." Surely, the high degree of fragmentation seen in bone assemblages from early coastal southern California sites is not unique. Assuming this, faunal analysts should devote more attention to the recovery and study of small bone fragments to confront the question raised by Lyman and O'Brien.

The degree of bone fragmentation and loss of bones surely varies within and between archaeological deposits. Furthermore, rates of fragmentation and loss will vary between different animal taxa. It follows, then, that meaningful comparisons between different strata or different areas of a site, or between different sites, must control for this variability. For example, two assemblages that contain similarly large numbers of bones identifiable to a particular skeletal element and taxon, thus permitting conventional faunal analysis, may vary significantly in the degree of fragmentation. Modifying the question raised by Lyman and O'Brien, one may ask: Are differences or similarities between the assemblages in proportions of identified taxa a product of differences in cultural behavior, differences in degree of fragmentation, or some combination of the two? The method proposed here is one way this question may be addressed, at least partially. Interestingly, the methods proposed by Klein and Cruz-Uribe (1984:70–71) and Marean (1991) would not be applicable to the assemblage from the Aerophysics site because of the small number of taxonomically identifiable skeletal elements.

It is also the case that faunal analysts have given only minimal attention to what happens to bones once they become buried—that is, incorporated into archaeological deposits. For that matter, little is known about the processes that result in burial of bones in the first place. Knowledge of how buried bone becomes fragmented would aid in our understanding of variation between taxa in an abundance of taxonomically identifiable skeletal element fragments and the varying roles of pre-depositional and post-depositional agents of fragmentation. Site deposits in some contexts, such as dry caves, may be said to be static, in the sense that once objects are buried, little happens to alter bones physically or chemically. Other contexts are dynamic in that different agents cause movement of the deposits and chemical alteration to objects contained within the deposits. Most deposits at open-air sites are dynamic, and this certainly is the case at sites in coastal southern California. The discussion above identified the major agents contributing to this dynamism and likely resulting in fragmentation of buried bones, but the manner in which these agents work is largely unknown. The lack of knowledge concerning these agents of course is part of a larger problem: Few archaeologists, including geoarchaeologists, have given specific attention to how archaeological deposits and their contents are formed and how they change over time.

The comparison between rabbit and deer in the example above has relevance to Hildebrandt and Levulett's (1997:146–148) analysis of the geographic variation in dependence on these two taxa along the length of the California coast. Hildebrandt and Levulett compiled archaeological data from a variety of published sources to show that dependence on deer relative to rabbit decreased in a southward direction along the length of the coast. They argue that this pattern in the archaeological data is a product of the environmental gradient from the northern to the southern extremes of the California coast entailing increasing aridity and consequently lower density of deer populations. Rabbits partly compensated for the lower abundance of deer, which would have been a high-ranking food resource throughout California.

A decline in the dietary importance of deer from northern to southern coastal California certainly makes sense in light of the decline in their density. However, do the archaeological data actually support this argument? They seem to do so, but is the pattern in the archaeological data due to factors other than the dietary importance of deer? Perhaps the agents responsible for fragmentation of bone intensify in a southerly direction along the California coast. Unless some means are developed to control for degree of fragmentation, the archaeological data used by Hildebrandt and Levulett should not be considered a reliable indicator of dietary dependence on deer.

Another factor plaguing the comparability of bone assemblages is variation in field and laboratory procedures that affect how much of the bone present in site deposits actually is collected. The abundance of small fragments in the Aerophysics site assemblage is the result of sifting deposits through 1/8-inch mesh screen, retaining everything caught by the sifting screens, washing and drying all this material, and finally sorting it into constituent categories in the laboratory. Because of the substantial variation in collecting and processing procedures in California, small fragments of bones are variably recovered, and as a consequence bone assemblages are not comparable if analysis incorporates methods similar to those proposed here. Certainly, the intensive techniques used to obtain the Aerophysics site assemblage are time-consuming and potentially expensive, but assessments of degree of fragmentation within a collection require that at least portions of excavated site deposits be processed using techniques similar to these—usually a larger volume than the few column samples that are conventionally obtained during archaeological projects in California.

In conclusion, bone assemblages with many small fragments contain useful information worthy of a faunal analyst's attention. Similarly, there is value in collecting and considering the small fragments, even if complete skeletal elements and large fragments attributable to a skeletal element and taxon are abundant in an assemblage. Establishing comparability of assemblages, or of different taxonomic categories within an assemblage, requires attention to relatively small and seemingly nondescript fragments and the field techniques necessary to obtain systematic samples of these. The method proposed in this paper concerns only one category of small fragments, and it should be considered just one that could be developed to extract useful information.

ACKNOWLEDGMENTS

I thank the many students who helped in the excavation at the Aerophysics site and in the processing of the resulting collections. Permission to carry out the excavation was granted by Delco Systems, owner of the property at the time of excavation. I also thank the staff and the volunteers of the University of California Sedgwick Reserve for collecting most of the deer bones in the reference collection used for this analysis. Helpful comments from two anonymous reviewers led to my improving an earlier version of this paper.

NOTE

5. Collections and field records from the 1985 excavation at CA-SBA-53 are housed in the Repository for Archaeological and Ethnographic Collections, Department of Anthropology, University of California, Santa Barbara, under accession number 347.

CHAPTER 15

Issues Confronting Faunal Analysis in California

MICHAEL A. GLASSOW AND TERRY L. JOSLIN

Several important issues concerning methods of faunal analysis intersect the various chapters in this volume. In fact, it is interesting that a couple of these issues are the focus of at least four chapters and are mentioned by others as well. In the discussion to follow, we identify these issues and consider their significance. Where appropriate, we offer ideas for addressing them. They arise from the nature of faunal remains in California archaeological sites, the practice of archaeology in the state, and historical traditions of faunal analysis that have arisen in different parts of the state. Nonetheless, none is peculiar to California; they also have relevance to zooarchaeology in many other parts of the world.

ARTICULATING METHODS WITH RESEARCH OBJECTIVES

The preceding chapters demonstrate that "method" is more than a technique or procedure. Application of a method has the purpose of reaching a specific objective. Consequently, a method includes, at least implicitly, an argument that use of a technique or procedure, or a series of these, would result in reaching a specified research objective. A clear understanding of what method entails is of fundamental importance if faunal analysis is to serve the discipline of archaeology. Because competency in the techniques and procedures of faunal analysis requires a good deal of training and experience, and because strong traditions in the application of techniques and procedures have arisen, the analyst may lose sight of research objectives or may not be creative in selecting among available methods or devising new methods. It is important to keep in mind that research objectives are at the core of faunal analysis methods and that the link between them and particular techniques and procedures must always be explicit and should always be stated within a research design involving faunal analysis.

Research objectives in zooarchaeology may be viewed at two levels: those concerned with explaining patterning in faunal data, and those concerned with explaining patterning in human behavior. This distinction is similar to that espoused by Gifford-Gonzalez (1991) in her thoughtful treatment of the larger goals of zooarchaeology. Each of the two kinds of explanation requires covering theory. In his chapter in this volume, Pletka refers to the former as middle-level theory and the latter as high-level theory. Explanations of patterning in faunal data generally cite one of two kinds of determinants: natural phenomena or human behavior. Among the preceding chapters, Perry and Hoppa cite a natural phenomenon to account for patterning in faunal data, and Bertrando and McKenzie, Pletka, and Gifford-Gonzalez and Hildebrandt all posit human behavior as the determinant. Distinguishing between these two determinants in the course of developing explanations for patterning identified in faunal data can be a major challenge.

Of course, the explanation of patterns of human use of fauna relates zooarchaeology to the most important goal, indeed the ultimate goal of archaeology: the explanation of variation in human behavior (cultural variation) and the development of high-level theory. Pletka's, Wake's, and Whitaker's chapters exemplify the widespread interest in the application of microeconomic theory to the conception of hypotheses to account for patterning in utilization of different kinds of fauna. All three of these contributors are concerned with resource intensification, a common theme in zooarchaeological research in California. As these authors argue, intensification entails a shift to faunal taxa that are relatively low ranked with regard to nutritional return for a given amount of effort devoted to acquisition and processing. More specifically, intensification frequently entails greater emphasis on lower ranked taxa that are already part of the diet, or expansion of diet breadth to include lower ranked taxa not previously exploited. In her chapter, Grimstead uses a related concept, extensification (originally defined by Beaton [1991]), which entails traveling increasingly farther afield to acquire a given resource, with greater effort expended for a given return.

IDENTIFYING AND COPING WITH SAMPLE BIAS

More than half the chapters are concerned with issues surrounding sample bias, and some are focused specifically on this subject. Clearly, sample bias is of considerable concern to California zooarchaeologists, as well it should be. Chapter authors make the point that we must devote more attention to the prospect of sample bias because it affects the accuracy of inferences about human behavior. Sample bias has three possible sources: cultural factors, taphonomic factors, and sample acquisition procedures.

The first of these concerns the sorts of faunal remains that site occupants have or have not deposited at a site, whether these be parts of an animal carcass or a shellfish. As Gifford-Gonzalez and Hildebrandt point out in their chapter, hunters may bring whole carcasses of small game animals to a site, but they may bring only the high-utility parts of the carcasses of large game animals. Grimstead makes a similar point: the longer the distance a large game animal must be transported, the more likely only high-utility parts will end up at a habitation site (although her research implies that this may not always be the case). Bringing only high-utility parts of a carcass back to a residential base is popularly known as the schlep effect, a term Perkins and Daly (1968) introduced to faunal analysis more than 40 years ago (*schlep* is derived from a Yiddish verb meaning to carry with difficulty). Bias in the elements of an animal skeleton that were deposited at a site and are represented in an assemblage is not *sample* bias in the strict sense of the term, although in the context of Gifford-Gonzalez and Hildebrandt's critique of the use of animal bone and meat weights as analytical units, it may be considered such. Of course, site inhabitants created many sorts of bias in the archaeological record, and archaeologists constantly must take them into consideration. Indeed, as Gifford-Gonzalez and Hildebrandt illustrate, identification of biases in skeletal element representation leads to inferences about the position of a site within a settlement system. Indirectly, information about skeletal element bias also is potentially relevant to a variety of other research topics, including impacts of population growth and environmental change, resource intensification, and shifts in subsistence focus. For example, schlepping is increasingly less likely to occur as subsistence is intensified because hunters would have been increasingly motivated to make use of larger proportions of animal carcasses.

The second source of bias, taphonomic factors, is of particular relevance to California archaeology. As Glassow points out in his chapter, a variety of human behavioral and natural processes may cause fragmentation of faunal remains, and fragmentation may vary in degree among categories of faunal remains (defined with respect to taxon or some other criterion). He also notes that many of these processes are poorly understood. In California, fragmentation of bone and shell resulting from rodent burrowing and land development is common, and at many sites the degree of fragmentation is so extreme that it compromises the prospect of acquiring analytically meaningful collections of faunal remains. Rick and Erlandson's chapter in this volume also is concerned with sources of fragmentation, focusing specifically on fragmentation biases that may frustrate comparative analysis. Regarding assemblages from relatively old sites, Glassow indicates that in some circumstances the contribution of large mammals such as deer may be significantly underestimated due to differential fragmentation of large versus small mammal bones.

Rick and Erlandson advocate dividing weight by NISP to assess the degree of fragmentation within an assemblage of bone, following the logic that lower degrees of fragmentation will result in greater average specimen weight (see Lyman 2008:250–254 and Reitz and Wing 1999:194 for other, similar measures of fragmentation). With regard to shell, they propose that total weight be divided by the total MNI. In this context, they use NISP to refer to relatively broad taxonomic categories, such as all teleost fish bone. Importantly, indices such as NISP and MNI depend on the competence or assiduousness of the faunal analyst in taxonomically identifying highly fragmented faunal remains. For instance, mussel shell MNI is based on counts of umbones divided by two. If mussel shell is highly fragmented, umbones may be very small, requiring a sharp eye and considerable patience to identify them among the many small shell fragments. Another factor, as Rick and Erlandson, Gifford-Gonzalez and Hildebrandt, and Glassow point out in their chapters, is that degree of bone or shell fragmentation varies between taxa, the high vulnerability of bird bone to fragmentation being an obvious example. Nonetheless, if the approach proposed by Rick and Erlandson is used judiciously, comparison may be made between different bone or shell assemblages. It would work best with faunal categories that are easily identifiable, such as bony fish, medium to large mammals, medium-sized clams (for example, within the genera of *Protothaca* and *Chione*), and mussels. Another approach might entail the weight ratios of bone or shell caught by a graduated series of sieves of standard mesh sizes, the smallest having the mesh size used in the field for screening excavated deposits.

Five of the chapters discuss the third type of sample bias: that resulting from archaeological procedures for sample acquisition. Bertrando and McKenzie, Jones and Codding, and Joslin consider two types, sample size and sifting screen mesh size; Erlandson and Braje focus just on issues of small sample size; and Wake considers just screen mesh size. Sample size influences the representativeness of a faunal assemblage in a variety of ways. If a faunal assemblage is derived from a relatively small volume of excavated deposits, the number of bone or shell fragments identifiable to a particular taxon may be too small for meaningful analysis. Abundant and ubiquitous remains, such as shell fragments in many coastal sites, may be abundant enough to allow use of a few small units, such as column samples that typically are no more than 25 × 25 cm in area. Bone fragments also may be relatively abundant in such small samples, but fragments that are large enough to exhibit distinctive features necessary for taxonomic identification typically will be quite rare. Fish bones are a notable exception. The centra of their vertebrae, which are small in size compared to those of mammals and often well preserved, may be similar to shell in abundance and ubiquity. Obtaining adequate samples of large mammal bones often is the biggest problem. As Jones and Codding indicate, the volume of excavation necessary for acquiring a statistically meaningful sample of taxonomically identifiable bones of large mammals generally must be substantial. At most sites in California at least 10 m^3 must be excavated.

The mesh size of screens selected to sift deposits during excavation also may create strong bias. Jones and Codding, Bertrando and McKenzie, and Wake point out that many small shell or bone fragments fall through screens with coarser mesh sizes, such as 6 mm. In fact, essentially all the complete bones of some taxa, such as sardine-sized fish, may be lost through ¼-inch mesh screens, and a large proportion may be lost through 1/8-inch screens. Mesh size, however, is only one aspect of screening that may cause bias in a sample. Screening procedures vary widely across the state, even controlling for mesh size. Dry-screening and picking items out of screens in the field may result in vastly different samples of small faunal remains than water-screening with all washed material caught by the screens sorted in a laboratory setting. Wet-screening combined with field sorting generally would fall between these two extremes. Differences in recovery of small faunal remains also may be the result of characteristics of the archaeological deposits. Very poor recovery during dry-screening and sorting in the field would be expected if deposits are clayey and tend not to divide finely during sifting, and breaking clods of soil to mitigate this problem can result in increased fragmentation of faunal remains. Conversely, loose, sandy deposits that easily pass through a screen will increase recovery and result in little or no breakage. Gravelly deposits obscure the visibility of small faunal remains, whereas sandy or silty deposits allow for greater visibility. The competence and patience of sorters also affect recovery.

Unfortunately, screening procedures and characteristics of deposits frequently are not reported in enough detail for us to ascertain the likelihood or magnitude of sample bias from this source, which frustrates attempts at comparative analysis. In light of the diversity of screening and sorting procedures currently in use in California, details of procedures used must be reported if the data derived from faunal remains are to be amenable to comparative analysis. Similarly, as Glassow notes in his chapter, comparative analyses reported in the archaeological literature may be questioned if the data sets are derived from projects for which these details have not been adequately reported.

APPROACHES TO QUANTITATIVE ANALYSIS

Quantitative analysis of data derived from faunal remains has been part and parcel of zooarchaeology for more than 30 years (Grayson 1984; Lyman 2008). The kinds of quantitative analysis used are diverse, ranging from calculation of averages or proportions to various forms of cluster analysis. At the heart of quantitative analysis of faunal remains are various indices that are meant to translate raw numbers of bones pertaining to a particular taxon into measures that allow comparisons between taxa. The indices NISP and MNI are very commonly used and are represented in most chapters in this volume. Other indices of this sort, but with more specialized purposes—for example, minimum number of elements (MNE) and minimal animal units (MAU); see Grayson 1984:88–90 and Lyman 2008:214–263, 234–241—are used more rarely. Some indices, such as the ratios Wake uses in his chapter to compare the relative abundance of two mammal taxa, have very specific purposes in the context of research, and similar ratios are commonly used in faunal data analysis. Some authors undertook more sophisticated quantitative analysis to discern patterning in their data: Grimstead used stepwise discriminant analysis; Jones and Codding used a form of chi-square analysis and four kinds of diversity analysis; Pletka used mixture analysis.

Gifford-Gonzalez and Hildebrandt address a more fundamental aspect of quantitative analysis: the appropriateness of different basic measures and indices in analysis. They critique the use of bone and meat weights in quantitative analysis of zooarchaeological remains, particularly of animal bones. As Gifford-Gonzalez and Hildebrandt indicate, the use of bone and shell weights as units of analysis has been popular among archaeologists working in the Santa Barbara Channel region. They note that use of weight as a measure of relative dietary importance is an exception to conventional practice in zooarchaeology, which relies on such indices as NISP and MNI, and they see the use of weight as unable to compensate for variation in the parts of animal carcasses that are brought to a habitation site.

It is instructive to delve into the history and rationale of the use of weight among Santa Barbara Channel archaeologists. As Gifford-Gonzalez and Hildebrandt observe, this practice has its immediate origins in research that Clement Meighan carried out in the 1950s. Meighan's (1959:403) article on his investigation of the Little Harbor site on Santa Catalina Island contains an early example of the use of bone weight and its conversion to meat weight, although it is noteworthy that Meighan based his conversion ratio on an earlier study by Cook and Treganza (1950:245). Research programs common in the Santa Barbara Channel region over the last 40 years have entailed small-scale testing and very little large-scale excavation; volumes of excavated deposits at a site typically have been less than one and at most a few cubic meters. The research has been regional in scope, which has entailed learning a little about a large number of sites rather than a lot about a few sites. Expanding knowledge of the regional chronology, identifying basic characteristics of subsistence practices, and identifying the impact of environmental variation on subsistence have been important goals of these research programs. Consequently, collections typically have been too small to contain numbers of taxonomically identifiable skeletal element fragments sufficient for typical forms of zooarchaeological analysis. Weight of various categories of faunal remains has been seen as a viable alternative for gaining some insight into subsistence differences.

Such research programs are relatively rare in world archaeology, and gleaning dietary information from small samples generally is not attempted. Archaeologists are more apt to focus their attention on individual sites and to acquire substantial samples from them—samples that yield collections of faunal remains, bones specifically, that contain numbers of identified skeletal element fragments appropriate for using NISP or other such indices as analytical units. Indeed, zooarchaeology is wholly oriented toward analysis of such samples, and consequently zooarchaeologists often express need for samples of sufficient size to use indices of this sort (e.g., Reitz and Wing 1999:106–107, 146). Nonetheless, it is reasonable to assume that useful information can be gleaned from samples that are too small for conventional zooarchaeological analysis. Wise use of the archaeological record, given its nonrenewable quality, dictates that analytical methods appropriate for small sample sizes should be more adequately developed.

Issues surrounding the use of bone and shell weight are somewhat different from issues surrounding conversion of these weights to meat weights. Use of either as a unit of analysis would be subject to the kind of bias discussed by Gifford-Gonzalez and Hildebrandt. Bone weight by itself, however, may be no more biased than indices such as NISP, which is affected by a variety of factors (Lyman 2008:29–30, see also Grayson 1984:20–24). Of these factors, variation in recovery of the remains of different taxa and variation in fragmentation of bones of different taxa (such as discussed by Glassow in his chapter) are particularly important in California archaeology. Conversion to meat weight, however, adds another level of inference, introducing to the analysis what Gifford-Gonzalez and Hildebrandt call a black box. In particular, the conversion does not consider that the weight of different skeletal elements (or sets of skeletal elements) will represent variable amounts of meat. Incidentally, this issue is not relevant to shells, as whole shellfish typically would have been brought to a site.

Neither NISP nor bone or shell weight directly reflects dietary importance. Gifford-Gonzalez and Hildebrandt argue that for most analytical purposes, there is no need to convert to dietary units such as meat weight because research questions generally have been concerned with "directionality of change over time and space." In other words, conversion to meat weight adds no information of relevance to the analysis. Assuming the type of research programs that have prevailed in the Santa Barbara Channel region continue, weight of bone and shell necessarily must continue to be a unit of measure; the size of the assemblages will not support use of NISP except for faunal categories that are particularly abundant, as shell and fish bone often are. However, conversion to meat weight almost always is unnecessary, even though it has the appearance of meaningfulness.

Interestingly, archaeologists working in the Santa Barbara Channel region are beginning to recognize that significant bias may exist in the representation of different categories of faunal remains within site deposits. In this volume, Erlandson and Braje point out that those faunal remains present at a site may not be telling the whole story of the sorts of fauna incorporated into the diet. Through consideration of the kinds of artifacts present at a site, they suspect that whole categories of fauna actually exploited may be absent. As Erlandson and Braje imply, ascertaining the reasons for the absence most likely would require knowledge about multiple sites with coeval occupation, as an anomaly between faunal remains and artifacts related to acquiring fauna may relate to how different subsistence activities are distributed between different loci within the territory occupied by a group of people.

Santa Barbara Channel archaeologists may wish to reconsider the design of their research programs so that larger collections of identifiable animal bones, particularly of large mammals, may be obtained. The potential to generate useful collections of identifiable mammalian faunal remains is relatively high at certain sites. This is particularly the case on the Channel Islands, where pinniped bones generally are much less fragmented than both pinniped and deer bones are in mainland archaeological deposits. Investigations carried out by Jeanne Arnold and her colleagues and students at late prehistoric sites on Santa Cruz Island (Colten 2001; Colten and Arnold 1998) and by Phillip Walker at a western San Miguel Island site (Walker et al. 2002) demonstrate this potential.

IMPORTANCE OF REFERENCE COLLECTIONS AND INTENSITY OF EFFORT AT IDENTIFICATION

Every zooarchaeologist recognizes the critical importance for taxonomic identification of reference collections of skeletons and shells derived from modern animals. To identify not only taxon but also age and sex of mammals, multiple individual skeletons per taxon generally are necessary. Gifford-Gonzalez and Hildebrandt argue that greater effort should be made to identify more difficult parts of mammal skeletons, such as ribs and lower limb bones, and the ability to make such identifications confidently also implies that multiple individual skeletons per taxon are available in a reference collection. However, the taxonomic richness and depth within each taxon represented in a reference collection affect the quality of any faunal analysis, and for this reason reference collections used in the course of identification of faunal remains should always be indicated in reports and publications.

Reference collections with significant breadth and depth are dispersed throughout much of the state. Particularly strong reference collections exist at University of California, Los Angeles; University of California, Santa Cruz; California State University, Chico; the California Academy of Sciences; the Natural History Museum of Los Angeles County; and the Santa Barbara Museum of Natural History. Others that are comparable may exist elsewhere. Some institutions, as well as archaeological firms involved with cultural resource management, have more specialized collections, such as the shell and fish reference collections at the University of California, Santa Barbara. Most reference collections are accessible to any zooarchaeologist, but an investment of time and money must be made to travel to the institutions housing these collections.

IMPORTANCE OF INFORMATION ON THE BIOLOGY OF TAXA REPRESENTED IN AN ASSEMBLAGE

The chapters by Grimstead, Perry and Hoppa, Wake, and Whitaker all demonstrate the importance of considering the biology of a particular taxon represented in a faunal assemblage to gain insight into food acquisition strategies. Zooarchaeologists often delve into biological literature concerning the animals represented in their faunal assemblages, so the examples represented in this volume are not extraordinary. Nonetheless, it is worth emphasizing how important information about animal biology is to developing hypotheses about techniques and tactics for acquiring a particular taxon, its dietary importance relative to other food resources, and temporal and spatial variation in its relative importance. Consequently, zooarchaeologists often must become very knowledgeable in biology, and indeed some zooarchaeologists have acquired substantial training in biological disciplines.

Unfortunately, the literature concerning animal biology does not always address the issues of animal behavior, distribution, and abundance relevant to faunal analysis. For example, seasonal changes in geographic distribution of a particular species of animal may be reported, but quantitative information may be lacking. A more prevalent problem is that the biological literature typically pertains to present-day conditions, which to varying degrees are the result of human-induced environmental modifications such as agriculture, introduction of exotic animals such as feral pigs, and draining of wetlands. As well, long-term shifts in climatic conditions during the Holocene would have had an effect on the distribution and abundance of taxa of interest to prehistoric human populations. Archaeologists must try to compensate for environmental changes, whatever their causes, in attempting to understand subsistence patterns and change. Doing so is especially important to developing and evaluating models derived from evolutionary ecology.

THE POTENTIAL OF BONE AND SHELL CHEMISTRY STUDIES

In her use of trace elements to identify the geographic origin of deer brought to a site, Grimstead exemplifies the innovative work some zooarchaeologists have undertaken to expand the ways in which faunal remains can contribute to our understanding of human adaptations, as well as to the biology of the exploited taxa. Stable isotope analysis also has considerable potential in tracing geographic origins of animals exploited by prehistoric Californians. Burton et al. (2002) analyzed stable isotopes of carbon and nitrogen in bones of northern fur seal from central California sites and found evidence that the foraging and breeding behavior of these animals was much different than is currently the case. The findings have important implications for how this species was exploited along the California coast. Animal bone DNA analysis is another application with considerable potential (Newman et al. 2002). DNA analysis may allow taxonomic identification of bones not otherwise identifiable and could also be used to check conventional taxonomic identifications. However, DNA analysis still is expensive, and currently few laboratories are accessible to archaeologists. Also, DNA is not always sufficiently preserved, particularly in older bones.

Ascertaining stable isotopes of shell calcite is another application of chemical analysis, and it has become increasingly popular in California since the 1980s (Eerkens et al. 2005; Glassow et al. 1994; Jones, Douglas, et al. 2008; Kennett 2005; Killingley 1981; Rick et al. 2006c). Oxygen isotope analysis of marine shells—California mussel shells are most commonly used—has had two related objectives: determination of local seawater temperatures at the time of site occupation, and determination of the season in which shellfish were collected. The former has implications for the distribution and abundance of marine animals, and the latter contributes to inferences about season of site occupation. A study by Rick et al. (2006c) is particularly intriguing in that isotopic differences between mussel and red abalone shells of the same age revealed that the latter were collected from deeper (cooler) waters than the former, implying that collection probably entailed diving.

ZOOARCHAEOLOGICAL CONTRIBUTIONS TO BIOLOGY

Gobalet's chapter is an example of the interplay between zooarchaeology and biology. His careful examination (or reexamination) of ichthyofaunal collections from a series of sites revealed that coho salmon spawned farther south than they do today. Encountering bones of northern fur seal at central California sites, mentioned above, as well as sea otter bones at sites in southern California well beyond their current southerly distribution (Walker 1982; see also Erlandson, Rick, et al. 2004; Erlandson, Rick, and Vellanoweth 2005; Steneck et al. 2002), also demonstrates the ability of archaeology to contribute to our understanding of the former distribution of marine taxa. The argument that red abalone was a relatively more accessible species during a restricted mid-Holocene period due to cooler water temperatures (Glassow et al. 1994; Glassow et al. 2008) is a similar example. Beyond simply demonstrating differences in geographic distribution (or differences in habitat circumstances in the case of red abalone), however, archaeological data may contribute to discourse concerning contemporary environmental policy. As Gobalet's study demonstrates, such findings have the potential to influence decisions and policies of wildlife managers. Indeed, archaeological data have been brought to bear on ongoing arguments about the relationship between sea otters and various shellfish, such as some species of abalone occurring along the California coast (Erlandson, Rick, et al. 2005).

CONCLUSIONS

The chapters in this volume exemplify the diversity and dynamic quality of contemporary faunal analysis, both in California and beyond. Significantly, although each chapter addresses a specific issue or issues concerning methods of zooarchaeological analysis, they all also address the articulation between method and the larger goals of zooarchaeology and archaeology as a whole. The two principal issues addressed in the chapters concern appropriate types of quantitative analysis of zooarchaeological data and the kinds of bias that may exist in zooarchaeological data and how to compensate for them. The former issue has been of great concern to zooarchaeology for some time, as Grayson's (1984) and Lyman's (2008) books epitomize. Impressively, some of the chapter authors go beyond the methods of quantitative analysis discussed in Lyman's most recent treatment of the subject and demonstrate that quantitative techniques used in other realms of archaeology, or in other disciplines, are also applicable to zooarchaeological data.

The latter issue, sample bias, also has been of perennial concern to zooarchaeologists, but the topic clearly needs more attention, particularly in California, where bias resulting from varying degrees of fragmentation is still poorly understood but clearly is profound in many instances. As discussed in some chapters, bone fragmentation may be addressed by considering field and laboratory techniques for acquiring and processing faunal collections and analytical techniques that allow identification of the degree of fragmentation, and by investigating causes of fragmentation, about which little information is currently available.

At the same time, however, zooarchaeologists are developing new ways of generating useful information from faunal remains that go beyond conventional taxonomic identification. As is the case in archaeology generally, chemical or mineralogical analyses of bones and shells are yielding a variety of new sorts of information that are relevant to zooarchaeology or to archaeology generally. It is apparent that these avenues of data acquisition are still in their infancy, but interest in them is growing.

Rephrasing what we said in this volume's introduction, our objectives in gathering together the studies presented in this volume were to demonstrate the importance of zooarchaeology in California archaeology and to encourage others to explore the issues of method addressed in the chapters. Understanding the diversity of archaeological contexts in which faunal remains occur, methods appropriate to these contexts, and the nature of faunal assemblages will result in wise use of archaeological resources and meaningful information about human exploitation of fauna. Most areas of California are blessed with decent preservation of bone and shell, which are often abundant constituents in habitation deposits. It follows, therefore, that we should do our best to learn as much as possible from them about the lifeways of prehistoric Californians.

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