



Spatial and temporal variation in fisher-hunter-gatherer diets in southern California: Bayesian modeling using new baseline stable isotope values

Mikael Fauvelle^{a,*}, Andrew D. Somerville^b

^a Lund University, Department of Archaeology and Ancient History, Helgonavägen 3, Box 192, 221 00, Lund, Sweden

^b Iowa State University, Department of World Languages and Cultures, 505 Morrill Rd., Ames, IA, 50011, USA



ARTICLE INFO

Keywords:

Hunter-gatherers
Paleodiet
Stable isotopes
Isotope mixing models
Maritime adaptations
California archaeology

ABSTRACT

Understanding how maritime hunter-gatherer diets changed through time in response to increasing social complexity can help us understand important transitions in early human history. This paper presents new baseline stable isotope values for southern California with an emphasis on marine plant and animal species. We use our baseline database to reevaluate human stable isotope values from the region using Bayesian mixing models to interpret dietary patterns across time and geographic space. Our analysis compares categories of foods consumed between island, coastal, and interior populations across the Middle and Late Holocene (circa 8000 to 168 cal BP) occupational history of precolonial southern California. Our results show a clear increase in the importance of high trophic marine foods, such as finfish, relative to low trophic level food, such as shellfish through time, paralleling increases in population size, economic intensification, and village aggregation in the Channel Region. This case study displays the capacity of Bayesian modeling to infer patterns of dietary change in the past when applied to human isotope values and adds to previous studies on the relationship between population growth, technological innovation, and the intensification of resource extraction in the region.

1. Introduction

Diet and nutrition are central to the lives of all human societies, past and present. Building robust data sets for the analysis of ancient diets is therefore a central challenge for the study of past human behavior (Kintigh et al., 2014:16). The study of hunter-gatherer diets and nutrition has long been an important topic in anthropology and has contributed greatly to our understanding of both human social and biological evolution (Crittenden and Schnorr, 2017). Many traditional studies of hunter-gatherer nutrition have emphasized the importance of terrestrial resources in hunter-gatherer subsistence systems, suggesting that aquatic resources were marginal in most hunter-gatherer diets (Binford, 1990; Kelly, 2013). Archaeologists working in island and coastal settings, however, have critiqued the idea of aquatic resource marginality, arguing that it was precisely due to abundant marine resources that many maritime hunter-gatherer groups developed highly complex political and economic systems (Ames, 2002; Erlandson and Fitzpatrick, 2006; Gill et al., 2019). In order to better understand the role of marine resources in the origins of complex political and economic systems, more work is needed to model how the diets of island and coastal hunter-gatherers may have changed through time and across

different environmental and social boundaries.

The rich archaeological record of the islands, coasts, and inland valleys of southern California provides an opportune case study for the evaluation of spatial and temporal variability in hunter-gatherer diets. The Channel Islands off the coast of southern California were first inhabited during the terminal Pleistocene (Erlandson et al., 2011; Johnson et al., 2002; Rick et al., 2005), and by the Late Period (circa 1300 C.E. to contact) were home to some of the most politically and economically complex hunter-gatherer societies in North America (Arnold, 2001; Gamble 2008, 2011). Over the course of this long history, faunal records indicate that island and coastal diets changed considerably, with an emphasis on shellfish and pinniped consumption during the early Holocene shifting towards a growing focus on fishing as populations increased and coalesced during the Late Period (Erlandson et al., 2009; Glassow, 1993; Jazwa et al., 2020; Kennett, 2005; Raab et al., 2009). Spatial dietary variation between islands and the mainland was also considerable. While mainlanders are ethnohistorically known to have consumed large amounts of storable acorns (Timbrook, 2007), the relative importance of terrestrial foods for island populations has attracted considerable debate (Arnold and Martin, 2014; Fauvelle et al., 2017; Fauvelle, 2011, 2013, 2014; Gill and Erlandson, 2014). Here we

* Corresponding author.

E-mail address: mikael.fauvelle@ark.lu.se (M. Fauvelle).

contribute to these long-standing questions by using new baseline isotope values to construct Bayesian models for dietary variability across both space and time in ancient California.

This paper presents new carbon and nitrogen stable isotope values from 80 samples from 50 terrestrial and marine plant and animal species from across southern California and Baja California. Several previous isotope studies from southern California have made important contributions to our understanding of the region's prehistory, especially with respect to the role of marine resources in island diets (Goldberg, 1993; Harrison and Katzenberg, 2003; Rick et al., 2011; Walker and DeNiro, 1986). We expand on this previous work by providing new baseline values for local marine and terrestrial plants and animals that may have been consumed by the region's ancient inhabitants. Prior to our study, the largest baseline isotope database for southern California was compiled by Goldberg (1993), who reported carbon and nitrogen values for a total of 39 plant species, 6 terrestrial mammals, 6 marine mammals, and 1 finfish. In addition to duplicating many of Goldberg's results, our work adds 26 new plant species, 13 finfish, 3 mollusk, 2 crustacean, and 1 echinoderm to the available database of southern California carbon and nitrogen stable isotope values. The new values reported here greatly expand our coverage of local marine resources while adding important terrestrial species that were likely consumed by residents of the region such as blue dicks (*Dichelostemma capitatum*) and western sea purslane (*Sesuvium verrucosum*). All values used in the present study were taken from samples collected from the waters of San Diego and Santa Barbara counties, or were taken from plants grown in the same regions with natural soils and local rainwater.

Our baseline isotope database allows us to reevaluate dietary variability in ancient southern California using previously published (Goldberg, 1993; Harrison and Katzenberg, 2003; Rick et al., 2011) human stable isotope data. Past isotopic studies from the region have reported higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in island populations relative to the mainland, suggesting that islanders consumed relatively more food from marine sources (Goldberg, 1993; Harrison and Katzenberg, 2003; Walker and DeNiro, 1986). Here we use Bayesian modeling to predict

contributions from both high trophic level (including vertebrates such as finfish and marine or terrestrial mammals) and low trophic level (such as shellfish and plants) food sources. These techniques allow us to go beyond comparing marine versus terrestrial diets and instead allow for the quantitative evaluation of the relative contribution of different categories of foods to ancient diets. Our models show a general trend of increased reliance on higher trophic level species relative to shellfish through time, punctuated by regional variability between island, coastal, and mainland populations. These results support similar patterns identified in the faunal record of the Channel Islands (Erlandson et al., 2009; Glassow, 1993; Jazwa et al., 2020; Kennett, 2005; Raab et al., 2009), adding another line of evidence to our understanding of prehistoric diets in the region. Together, our results encompass data from 21 island, coastal and interior sites from across the region's occupational history and present one of the most complete pictures of dietary change through time and space available for the archaeological record of southern California.

2. Geographic, cultural, and environmental background

The geographic and environmental context of this study includes the islands, coasts, and adjacent interior regions of the southern Californian Bight (see Fig. 1). In general, the region is characterized by a Mediterranean climate with cool winters and dry, hot, summers (Smith, 1976). Considerable differences in weather and precipitation exist across the region, with interior areas susceptible to more extreme temperatures than island and coastal zones (Erlandson, 1991). Precipitation also varies across the study area, with the Southern Channel Islands of San Clemente and San Nicolas receiving considerably less rainfall than Santa Cruz or San Miguel Islands (Erlandson et al., 2019). Groves of live oak tress (*Quercus* sp.) would have been a major subsistence resource for inland and coastal peoples, but are less common on the islands, where inhabitants would have exploited abundant grasses, herbs, and geophytes (Gill, 2013, 2015; Gill et al., 2019). Large terrestrial mammals would also have been important resources on the mainland, but are

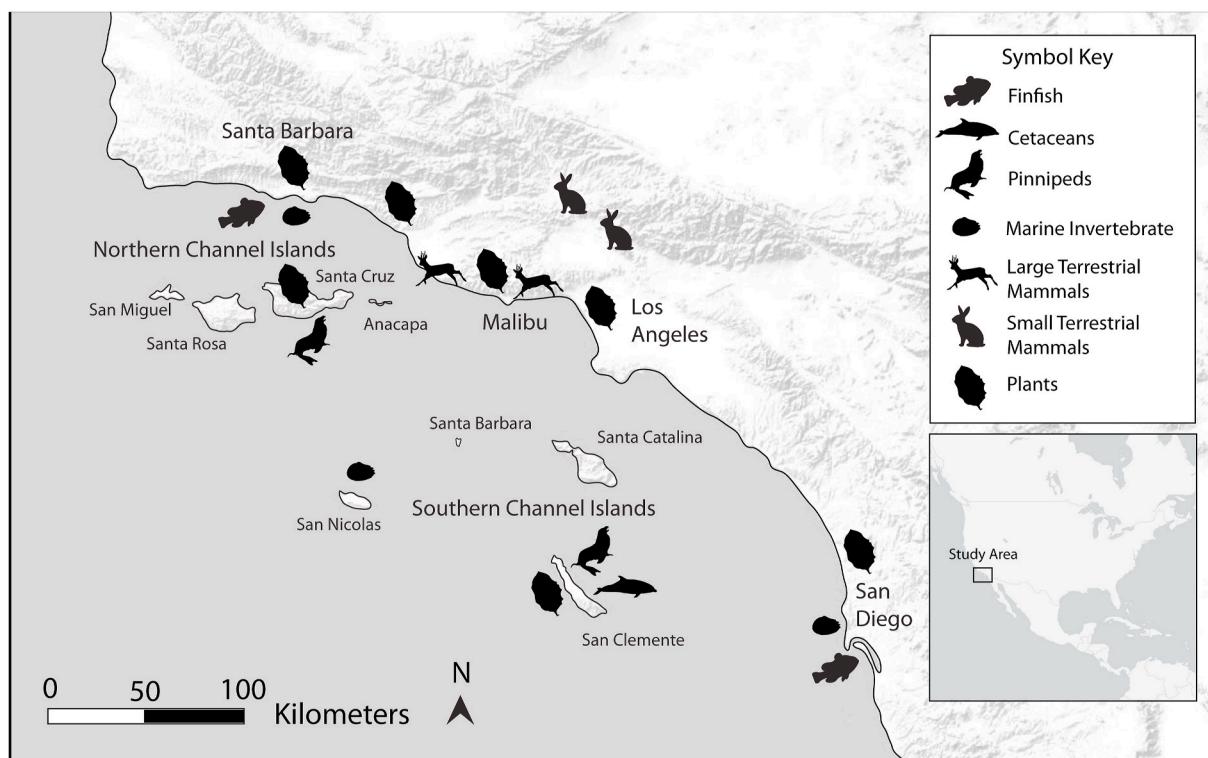


Fig. 1. Map of the Channel region displaying locations of food resources included in database.

notably absent from the Channel Islands with the exception of possibly translocated species such as the island fox (*Urocyon littoralis*), the spotted skunk (*Spilogale gracilis amphiala*), and the domestic dog (*Canis familiaris*) (Rick et al. 2009, 2019). Localized upwelling of nutrient-rich waters in the Santa Barbara Channel create highly productive fisheries that would have provided coastal and island peoples with abundant marine resources including finfish, pinnipeds, and marine mammals (Kennett, 2005).

The first archaeologically documented human settlers arrived in southern California by around 13,000 years ago (Erlandson et al., 2011; Johnson et al., 2002). These early inhabitants were the descendants of populations who migrated into the Americas down the Pacific Coast, likely following a “kelp highway” of similar littoral and near-shore marine resources found across the western coast of the Americas (Erlandson et al., 2007). Early Holocene coastal and island populations would have had access to abundant marine resources, with faunal assemblages at locations such as Eel Point on San Clemente Island and Daisy Cave on San Miguel Island containing shellfish, finfish, and pinniped remains (Gusick et al., 2020; Rick et al., 2001). Island populations would also have exploited numerous marine and terrestrial floral resources including seaweeds and geophytes (Ainis et al., 2019; Gill et al., 2019; Gill, 2016), while mainland populations increased their consumption of seeds, agave, and other terrestrial plants throughout the Early Holocene (Erlandson, 1991; Jones, 2008).

Populations increased in southern California during the region's Middle Period (600 BC to AD 1150), with evidence for increased sedentism and early social ranking dating to around 600 BC (Gamble et al., 2001; King, 1990). The invention of the circular shell fishhook near the start of the Middle Period may have led to a subsequent increase in finfishing, possibly linked to the need to provision increasing populations (Rick et al., 2002). The sewn plank canoe was another major technological development dating to around AD 500 (Gamble, 2002) which would have greatly facilitated pelagic fishing as well as travel and trade between California's Islands and the mainland coast (Arnold, 1995; Fauvelle and Perry, 2019; King, 1976). Much of this trade was fueled by the exchange of Olivella shell beads (made from the species *Callianax biplicata*, previously *Olivella biplicata*), the production of which was centered on the Northern Channel Islands and intensified greatly over the course of the Middle Period (Arnold and Munns, 1994; Gamble, 2020). Shell beads produced on the Channel Islands were traded across western North America and have been found by archaeologists working in regions such as the Great Basin and the American Southwest (Bennyhoff and Hughes, 1987; Smith and Fauvelle, 2015). By the Late Period (circa AD 1300), elites in the Santa Barbara Channel region of southern California were able to amass considerable resources and formed political entities that many archaeologists have described as chiefdoms (Arnold, 2001; Gamble, 2008).

3. Materials and methods

3.1. Baseline plant and animal Sample Collection

A total of 80 samples representing 50 species were collected and analyzed for this project. This total includes 31 plant species, 13 finfish species, 3 mollusk species, 2 crustacean species, and 1 echinoderm. Although some common foods such as California mussels are represented by multiple individual samples, many finfish are represented by only a single sample per species. Most samples were collected by a student research affiliate and the authors from either San Diego or Santa Barbara counties. When collecting samples, we attempted to broadly represent species represented as important to indigenous diets in the ethnohistoric literature (e.g. Timbrook, 2007). The collection of all samples took place between 2014 and 2017.

A total of 40 plant samples from 31 different species were collected and analyzed for this project. Samples were collected from trails in north San Diego county, as well as from the Mission Canyon area of Santa

Barbara and along the Camino Cielo north of Santa Barbara. One plant species, western sea purslane (*Sesuvium verrucosum*), was grown from seed at the experimental garden in the Biology Field Station at the University of California, San Diego (UCSD). These plants were grown using local soils and captured rainwater. Out of the 31 species represented in our database, 26 are documented as having been consumed as food or for medicinal purposes in the ethnohistoric literature. Four additional species (*Epilobium canum*, *Keckiella cordifolia*, *Matteuccia struthiopteris*, and *Sequoia sempervirens*) were used for construction or topical medical purposes, but are not documented as having been consumed.

A total of 40 marine animal samples representing 19 species was collected for this project. All finfish samples were collected in the wild off the shores of San Diego or Santa Barbara counties during June of 2016. Most of these samples were procured from local fishers at the Dockside Harbor Market in San Diego or at the Fish Market at the Santa Barbara harbor. Crustacean and echinoderm samples were also procured from local fishers at the Santa Barbara harbor market. Mussel samples (*Mytilus californianus*) were collected by the authors in Santa Barbara County, while our Turban Snail (*Megastrea undosa*) sample was also procured at the Santa Barbara Harbor market.

The foodweb baseline database was supplemented by the addition of previously-analyzed plant, terrestrial mammals, marine mammals, and invertebrates. This included the stable isotope values from 36 modern terrestrial plants (Goldberg, 1993), and 9 terrestrial mammals, including two modern hares (*Lepus* spp.; Somerville et al., 2018) and seven archaeological deer (*Odocoileus virginianus*; Goldberg, 1993). Supplemental marine specimens include seven invertebrates (Newsome et al., 2010), and 24 archaeological marine mammals (Goldberg, 1993). The marine invertebrate sample from Newsome et al. (2010) includes averages of multiple individuals for each species, but because they report only mean values, we treat each mean as a single individual. Animal samples reported in the Goldberg (1993) were taken from bone collagen. Fig. 1 displays a map of sampled resource categories and their distribution within the Channel system. A full library of available baseline stable isotope values for southern California can be found in the companion article to this paper (Fauvelle and Somerville, 2021).

3.2. Stable isotope analysis and paleodiet reconstructions

Stable carbon and nitrogen isotope analyses have greatly advanced our understanding of variation and temporal changes in hunter-gatherer diets in both northern California (Bartelink, 2009; Bartelink et al., 2020; Beasley et al., 2013) and southern California (Goldberg, 1993; Harrison and Katzenberg, 2003; Walker and DeNiro, 1986). Stable isotope studies of ancient diets have also proved useful in tracking the development of social complexity and inequality in societies throughout the world (Ambrose et al., 2003; Lambert and Walker, 1991; Linderholm et al., 2008; Somerville et al., 2013). Because carbon and nitrogen stable isotope values in organic tissues are primarily influenced by dietary sources of C and N, their values can serve as dietary tracers in tissues of the consumer (Fry, 2007; Schwarcz and Schoeninger, 2011). Stable carbon isotope values ($\delta^{13}\text{C}$) represent the ratio of $^{13}\text{C}/^{12}\text{C}$ relative to an international standard (VPDB) and are primarily influenced by the photosynthetic pathway of consumed plants (DeNiro and Epstein, 1978). Plants utilizing the C₄ and Crassulacean Acid Metabolism (CAM) photosynthetic pathways exhibit relatively high $\delta^{13}\text{C}$ values (range ~−15 to −7‰) (O'Leary, 1988). Most plants, however, utilize the C₃ pathway, and tend to exhibit values between −30 and −20‰ (Kohn, 2010; O'Leary, 1988). Marine organisms exhibit elevated $\delta^{13}\text{C}$ values comparable to C₄ and CAM plants (Schoeninger and DeNiro, 1984). The carbon atoms used to synthesize the amino acids of bone collagen derive from dietary carbon, but about 75% of collagen carbon is preferentially routed from dietary protein sources with the remaining quarter routing from dietary carbohydrates and lipids (Ambrose and Norr, 1993; Froehle et al., 2010). Thus bone collagen $\delta^{13}\text{C}$ values reflect the $\delta^{13}\text{C}$ values of

their diet with a strong bias towards the $\delta^{13}\text{C}$ values of their dietary protein (Fernandes et al., 2012).

Stable nitrogen isotope ($\delta^{15}\text{N}$) values represent the ratio of $^{15}\text{N}/^{14}\text{N}$ relative to atmospheric $^{15}\text{N}/^{14}\text{N}$. Within animal tissues, all nitrogen comes from their dietary protein sources. $\delta^{15}\text{N}$ values of animal tissues reflect their trophic position within a foodweb as the fractionation processes associated with each ascending trophic step result in an enrichment of approximately 3–5‰ (DeNiro and Epstein, 1981; Hesslein et al., 1991; Minagawa and Wada, 1984; Post, 2002). Among humans consuming primarily terrestrial diets, $\delta^{15}\text{N}$ values are considered to reflect the degree of meat consumption or carnivory as the ingestion of animal tissue would raise their trophic position (Hedges and Reynard, 2007). Marine organisms, however, exhibit much higher $\delta^{15}\text{N}$ values on average than do terrestrial organisms, and thus elevated $\delta^{15}\text{N}$ values in human bone collagen enable assessments of the relative proportion of marine foods in the diet (Schoeninger et al., 1983).

3.3. Human data

Using our stable isotope baseline data, this study reanalyzes human dietary practices of the California Bight region. A sample of stable isotope values from 381 human individuals that inhabited the Channel area was compiled from previous paleodiet studies (Table 1). Data come from Goldberg (1993, n = 348) and Harrison and Katzenberg (2003, n = 33). The sample contains individuals from 21 archaeological sites. These include inland, coastal, and island settlements. Islands represented in the sample include two northern Channel Islands (Santa Cruz and Santa Rosa) and two southern Channel Islands (San Clemente and San Nicolas; Fig. 2). Sampled individuals represent a long temporal sequence, which we divide into Early (circa 6000 BC to 600 BC), Middle (600 BC to AD 1150), and Transitional/Late (AD 1150 to contact) periods. Chronological affiliations for individual sites were based on information in the original paleodiet studies (Goldberg, 1993; Harrison and Katzenberg, 2003) and updated based on more recent or site-specific publications (Gamble et al., 1996; Goldberg et al., 2000; Greenwood et al., 1986; Lambert, 1993). Detailed information on the age and sex identifications of these individuals can be found in the original literature (Goldberg, 1993; Harrison and Katzenberg, 2003). Goldberg (1993:139–142) also provides a discussion of differences in diet attributed to age and sex within the sampled populations.

Table 1

Human bone collagen stable isotope means and standard deviations compiled from previous studies (Goldberg, 1993; Harrison and Katzenberg, 2003).

Provenience	Period	$\delta^{13}\text{C}$ (‰)			$\delta^{15}\text{N}$ (‰)		
		Mean	SD	N	Mean	SD	N
Inland	Early	−17.8	0.8	10	9.8	2.1	10
	Late	−16.8	1.2	30	11.4	2.5	30
	Subtotal	−17.1	1.2	40	11	2.5	40
Coastal	Early	−15.7	2	10	14.4	3.8	10
	Late	−14.8	1	104	15.4	2.6	104
	Subtotal	−14.9	1.1	114	15.3	2.7	114
Santa Cruz	Early	−14.2	0.6	34	15.2	1.1	34
	Middle	−14.2	0.7	11	16.3	1.3	11
	Middle/Late	−14	0.8	16	16.5	2.1	16
Santa Rosa	Subtotal	−14.2	0.7	61	15.7	1.6	61
	Early	−14.3	0.8	17	16.1	1.4	17
	Late	−13.6	0.8	32	17.4	1.7	32
San Clemente	Subtotal	−13.8	0.9	49	16.9	1.7	49
	Early	−12.7	1.3	5	21.1	2.5	4
	Early/Middle	−13.4	0.8	11	20.0	1.9	11
San Nicholas	Middle	−13.5	0.8	11	18.0	2.1	11
	Late	−13.2	1.2	2	19.6	0.1	2
	Subtotal	−13.3	0.9	29	19.3	2.2	28
	Early	−10.4	1	46	17.5	1.7	46
	Late	−10.4	1	5	18.4	1.6	5
	Subtotal	−10.4	1	51	17.6	1.7	51

3.4. Sample processing

The plants, finfish, and invertebrate samples collected to reconstruct the baseline foodweb were processed by the authors and an undergraduate research assistant in the Paleodiet Laboratory at the University of California, San Diego, directed by Dr. Margaret Schoeninger. Plant samples were cleaned in ultrasonic baths of double distilled water, shredded in a blender, dried for 24 h at 60 °C, and then reduced to a fine powder by grinding in an agate mortar and pestle and passing the plant material through a sieve. Finfish and invertebrate samples were removed from the organism with a stainless steel scalpel, cut into small pieces (~3 mm diam.). Flesh samples were then divided into two aliquots. Because lipids are more depleted in ^{13}C than other tissues (e.g. Post et al., 2007), one aliquot was subjected to lipid extraction and the other was left untreated. The first aliquot received a 2:1 chloroform: methanol treatment for 20 min in an ultrasonic bath to remove lipids, followed by a 10-min ultrasonic bath in double distilled water. The second aliquot received no treatment. Both aliquots were frozen and then lyophilized using a Labconco benchtop freeze dryer set at −50 °C and 0.133 mb for 24 h.

3.5. Stable isotope analysis

Stable isotope analyses were conducted at the Scripps Institution of Oceanography's Analytical Facility at UCSD. Isotopic analyses of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were accomplished by combusting 1 mg of sample within tin capsules in a Costech 4010 Elemental Analyzer coupled to the Thermo-Finnigan Delta XP Plus mass spectrometer. Carbon isotope ratios are presented relative to the VPDB international standard by calibrating to NBS-18 and NBS-19, and nitrogen isotope ratios are presented relative to atmospheric $\delta^{15}\text{N}$ (AIR) by calibrating to USBS and IAEA ammonium and nitrate standards. Long-term analyses of an internal glycine standard resulted in a reproducibility of ±0.2‰ for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values.

3.6. Stable isotope mixing model

Stable isotope mixing models are mathematical tools used to estimate the relative proportions of food source biomass in the diet of a consumer (Ben-David et al., 1997; Fernandes et al., 2014; Jackson et al., 2011; Newsome et al., 2004; Parnell et al., 2010; Phillips, 2001). Our results, however, will have a bias towards dietary protein sources as bone collagen is formed primarily from dietary protein (Ambrose and Norr, 1993; Froehle et al., 2010). An advantage of Bayesian mixing models is their ability to account for uncertainty in both the measurements of dietary items and consumer tissues. Here, we use the results of our stable isotope analysis of plant and animal samples from the Channel region to construct a Bayesian stable isotope mixing model that quantifies the proportional contribution of different foods in the diet of prehistoric human populations over time. All calculations were performed in the R computing environment version 4.02 (R Core Team, 2020) and we constructed the models with the MixSIAR package, version 3.1.11 (Stock and Semmens, 2013; Stock et al., 2018).

Data for the baseline food data analyses were corrected to account for variation between biological tissues, trophic enrichment factors, atmospheric changes through time, and for elemental concentrations of C and N (e.g. Phillips et al., 2014). We first transformed the stable isotope values from dietary sources to be equivalent to that of the consumed tissues by adjusting the bone collagen $\delta^{13}\text{C}$ values of dietary sources (marine and terrestrial mammal bones) to be equivalent to muscle $\delta^{13}\text{C}$ values. Previous research suggests that $\delta^{13}\text{C}_{\text{collagen}}$ values are approximately 1.0‰ higher than $\delta^{13}\text{C}_{\text{muscle}}$ values (Crowley et al., 2010; Jansen et al., 2012), and we thus subtracted this amount from the terrestrial mammal and otter bone collagen values. For the non-otter marine mammals (cetaceans and pinnipeds), however, we assume that a major portion of the consumed tissues would have been comprised of

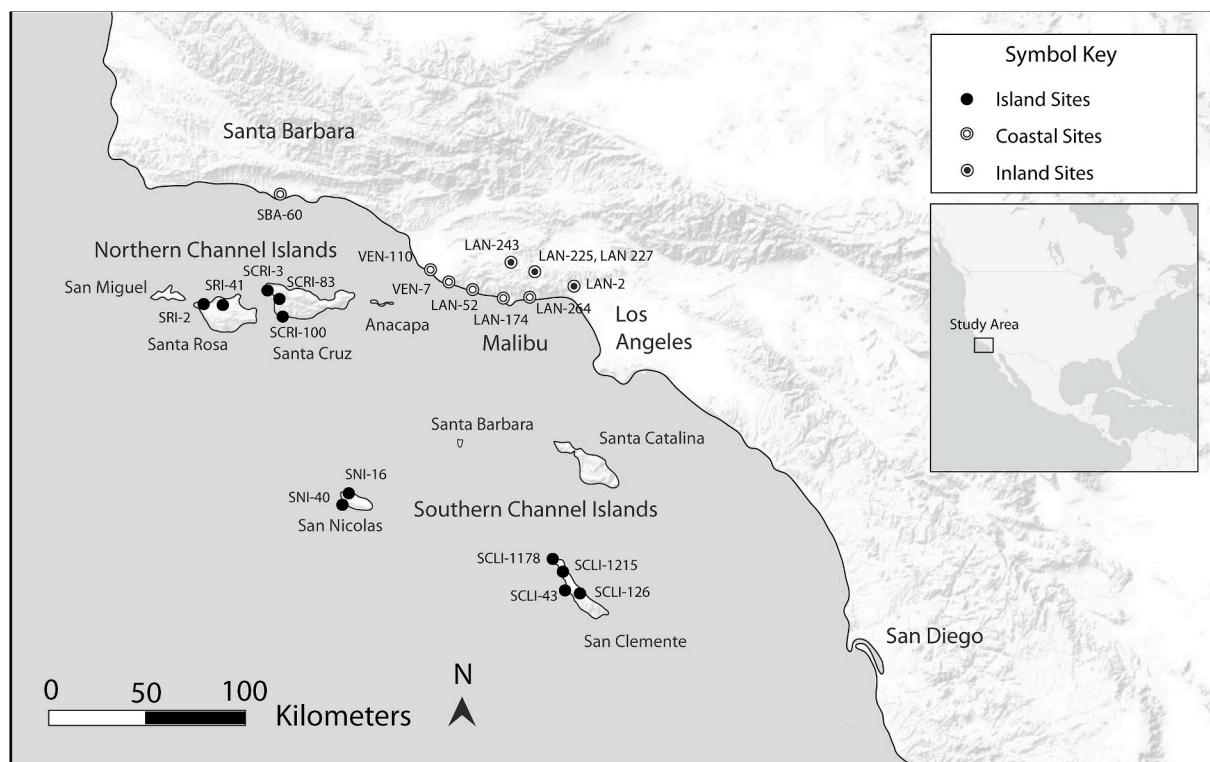


Fig. 2. Map of the Channel region displaying sites from which human isotope data was drawn.

blubber, which is depleted in $\delta^{13}\text{C}$ relative to flesh, and we thus follow Newsome et al. (2004:1105) and subtract 5.6‰ from their bone collagen $\delta^{13}\text{C}$ values. We assumed muscle and bone collagen $\delta^{15}\text{N}$ values to be equivalent (Crowley et al., 2010).

Trophic discrimination factors for human bone collagen were determined from previous literature. Field and captive feeding studies have produced a large range of trophic discrimination factors (TDF) of stable carbon isotope values in bone collagen relative to diet ($\varepsilon^{13}\text{C}_{\text{collagen-diet}}$), with values ranging from $\varepsilon^{13}\text{C}_{\text{collagen-diet}} = +1\text{--}7\text{‰}$ (Szpak et al., 2012), but appearing to converge around $+4.4\text{‰}$ on monoisotopic diets (Froehle et al., 2010; Ambrose and Norr, 1993). Part of the uncertainty and variability in trophic enrichment factors may be due to the quantity and quality of protein sources, physiological differences between organisms, variation in experimental conditions, and to variation in stable isotope values between laboratories. In line with previous studies (e.g. Bocherens and Drucker (2003); Cheung and Szpak (2020); Szpak et al., (2012)), we set the TDF for carbon ($\varepsilon^{13}\text{C}_{\text{collagen-diet}}$) to $+4 \pm 0.63\text{‰}$. For nitrogen, trophic enrichment factors tend to exhibit lower variation, typically ranging from $\Delta^{15}\text{N}_{\text{collagen-diet}} = +3\text{--}5\text{‰}$ (Hedges and Reynard, 2007; Bocherens and Drucker, 2003). Following recent reviews of experimental feeding and field studies (Bocherens et al., 2015; Cheung and Szpak, 2020; Szpak et al., 2012), we assumed a $\varepsilon^{15}\text{N}_{\text{collagen-diet}}$ value of $+4.0\text{‰} \pm 0.74$.

Because the $\delta^{13}\text{C}$ values of atmospheric CO₂ have decreased since the industrial revolution due to anthropogenic emissions, a process known as the Suess effect (Keeling, 1979), we corrected all modern plant and animal samples to the preindustrial mean. Using compiled historical records of atmospheric $\delta^{13}\text{C}$ values (Graven et al., 2017), we calculated the difference in the atmospheric $\delta^{13}\text{C}$ value of the year of data collection ($\delta^{13}\text{C} = -8.4\text{‰}$) and the preindustrial mean ($\delta^{13}\text{C} = -6.5\text{‰}$) and subtract the difference (1.9‰) from modern plant and terrestrial mammal samples. The hare samples, however, were collected in the late 1960s/early 1970s, and we thus applied a smaller correction factor (-0.8‰). For dietary sources from the marine environment (Finfish, invertebrates, and marine mammals), we accounted for the differential

impact of the ^{13}C Suess effect on $\delta^{13}\text{C}$ values in ocean waters by multiplying the calculated Suess effect value for the year by 0.65 (Eide et al., 2017; Lewis and Sealy, 2018) and subtracting the product from the $\delta^{13}\text{C}$ value of the analyzed modern tissue. Finally, because the differential concentration of C and N in consumed foods can influence their contribution to the isotopic values of the consumer's tissues (Phillips and Koch, 2002), we used a concentration-weighted model within the MixSIAR package with the atomic weight percentages of C and N from potential food sources as determined by the analyses of this study and by the USDA Nutrient Database.

To compare dietary differences between geographic locations, we ran an overarching Bayesian mixing model with provenience set as a fixed factor and time period set as a nested factor. No informed Bayesian priors were used for this model. Additionally, five separate Bayesian stable isotope mixing models were generated for each primary geographic division of the data, which included (1) inland sites; (2) coastal sites, (3) Santa Cruz Island sites, (4) Santa Rosa Island sites, (5) and San Clemente Island sites. The time period (e.g. Early, Middle, Late) of the analyzed human samples from each site was set as a fixed factor. Knowledge of the environmental settings of the site locations (inland, coastal, island), led us to establish simple Bayesian 'priors' for the expected importance of different food sources. We ranked food sources on a simple scale of 0–2 in order of their relative importance at each site. For food sources "marine high", "marine low", "plants", and "terrestrial mammals" (categories discussed more below), we assigned ordered informed priors as relative importance scores to the models for inland sites (0, 0, 2, 2), coastal sites (1, 1, 1, 1 [uninformed]), and island sites (2, 2, 2, 0). Three Markov Monte Carlo chains were run with the "normal" argument where chain length is set as 100,000, the burn set at 50,000, and the chains are thinned at 50. We set the model to account for 'residual error' or the consumers, but not for 'process error' of the sources. To ensure chain convergence, we assessed the Gelman-Rubin and the Geweke Diagnostics.

4. Results

4.1. Food categories

Results of our stable isotope analyses of baseline foods, when combined with previous studies, produce a representative baseline for paleodiets of southern California. The summary statistics of food resources are presented in Table 2, and the full list of all new and previously analyzed food samples are found in Supplementary Table 1. Fig. 3 displays the stable carbon and nitrogen isotope values of all diet sources. Data from plants analyzed as part of the present study ($n = 40$) and Goldberg's (1993) previous research ($n = 35$) exhibit similar values, and the data are combined for all following discussions.

Analyzed faunal samples include marine fish and invertebrates. Both underwent a lipid extraction treatment. The results of paired samples displaying the stable isotope values for aliquots that underwent lipid treatment and those that did not can be found in a companion article to this paper (Fauvelle and Somerville, 2021). Because ^{13}C -depleted lipids were removed with a 2:1 chloroform: methanol solution, the treated specimens display higher average $\delta^{13}\text{C}$ values with a mean $\Delta^{13}\text{C}_{\text{treated-untreated}}$ value of $+0.33 \pm 0.88\text{‰}$. Differences between the treated and untreated sample, however, are not significant (t -test, $P = 0.703$). All subsequent discussions focus on the untreated specimens.

Our analyses of the faunal samples found significant differences between marine fish and invertebrates (t -test, $P < 0.05$) for both stable carbon and nitrogen isotope variables. However, we note that significant overlap exists between these categories. As displayed in Fig. 4, several invertebrate species, including rock crabs (*Cancer* sp.) and spiny lobsters (*Panulirus interruptus*), display relatively high $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, while some fish, particularly tuna species (*Thunnus* spp.), exhibit relatively low $\delta^{15}\text{N}$ values. Notably, the single turban snail analyzed as part of this study (*Megastraea undosa*; $\delta^{13}\text{C} = -20.0\text{‰}$; $\delta^{15}\text{N} = +11.7\text{‰}$) is very close to the turban snail average reported by Newsome (2010); $\delta^{13}\text{C} = -19.1\text{‰}$; $\delta^{15}\text{N} = +11.2\text{‰}$), providing an additional degree of confidence to our integration of multiple datasets.

While the database of human stable isotope values includes divisions according to sex and age, we reserve a detailed consideration of how dietary patterns vary according to these variables for future studies. Here we focus on how the broader-scale variables of geography and time relate to human consumptive practices (Table 1). For previous discussion of the differences in stable isotope values between age and sex categories in southern California, see Goldberg (1993).

4.2. Stable isotope mixing model

Due to overlapping distributions of stable isotope values across dietary categories, we combined several food sources and excluded others

to create idealized diet end-member values. After visual inspection of the data (Fig. 3) and preliminary exploratory cluster analyses, we split the marine resources into two primary categories: marine high and marine low. Other paleodiet studies using stable isotope mixing models have used similar divisions in their data (Commendador et al., 2019). The marine high category contains predators with high trophic positions, including marine finfish and pinnipeds. Some finfish exhibit relatively low values, despite their high trophic position, which may be due to age and size-related trophic dynamics. Otters (*Enhydra lutris*) were excluded due to their intermediate nitrogen values, their exceptionally high carbon values, and because they were likely not a primary dietary resource for prehistoric human communities. Similarly, we excluded cetaceans because some analyzed cetacean specimens exhibit relatively low $\delta^{15}\text{N}$ values and because of the ambiguities in correcting their isotope values to account for blubber and collagen-to-flesh tissue differences. The marine low category includes all marine invertebrates other than lobsters. Lobsters were excluded as their particularly high nitrogen values makes them difficult to distinguish from other high-trophic position species (i.e. finfish). Species of the marine low category include sea urchins (*Strongylocentrotus* spp.), mussels (*Mytilus californianus*), abalone (*Haliotis* spp.), and snails (*Megastrea* sp. and *Chlorostoma*). Terrestrial food sources were divided into two categories: plants and terrestrial mammals. The plants category excludes C4 and CAM plants, which we assume were not large portions of the diet. The terrestrial mammal category (T.Mammal) includes hares (*Lepus californicus*) and deer (*Odocoileus hemionus*). Stable isotope data for these four source categories are presented in Table 3. One-way analyses of variance (ANOVA) found that means of diet categories were significantly different in terms of $\delta^{13}\text{C}$ ($F(3, 128) = 45.728, p < 0.000$) and $\delta^{15}\text{N}$ ($F(3, 128) = 45.728, p < 0.000$) values. All post hoc pairwise comparisons (Tukey HSD) were significantly different, with the exception marine high vs. marine low $\delta^{13}\text{C}$ values ($p = 0.638$) and plant vs. terrestrial mammal $\delta^{15}\text{N}$ value differences ($p = 0.635$).

Using the stable isotope values and elemental concentrations of the baseline food sources (Table 3), the Bayesian stable isotope mixing model (MixSIAR) was used to estimate dietary patterns among human populations at different geographical areas within the Southern California Bight. Initial plotting of the human values against the food sources, however, revealed that San Nicolas Island individuals fell outside of the model parameters (Fig. 5), indicating that our baseline food database does not contain appropriate sources to model the diet of these island inhabitants. The general mixing model thus excluded San Nicolas island sites, and subsequent discussions on dietary modeling do not include this location.

Posterior diagnostics (Gelman-Rubin and Geweke) revealed that MCMC chains had sufficiently converged, suggesting the model provides a robust estimation of food consumption practices. The results of the

Table 2
Descriptive statistics for food resources.

Resource	N	Mean $\delta^{13}\text{C}$	SD of $\delta^{13}\text{C}$	$\delta^{13}\text{C}$ min	$\delta^{13}\text{C}$ max	Mean $\delta^{15}\text{N}$	SD of $\delta^{15}\text{N}$	$\delta^{15}\text{N}$ min	$\delta^{15}\text{N}$ max
C3.Plant ^{a,d,e}	70	-24.9	2.4	-29.8	-16.3	2.9	4.4	-3.1	20.9
C4.Plant ^{a,d,e}	2	-10.3	3.5	-12.7	-7.8	2.5	5.2	-1.1	6.2
CAM.Plant ^{a,e}	3	-11.0	0.4	-11.4	-10.7	6.2	4.2	1.4	9.2
Cetaceans ^{b,e}	13	-18.3	0.5	-13.2	-11.7	16.3	2.6	11.7	20.0
Mar.Fish ^{a,d}	22	-16.5	1.2	-18.3	-14.8	14.8	2.7	9.8	18.9
Mar.Invert ^{a,d,f}	21	-15.6	2.2	-20.3	-10.4	11.0	2.6	9.0	15.7
Otter ^{c,e}	5	-10.9	1.3	-13.5	-10.0	13.7	2.3	9.8	15.7
Pinnipeds ^{b,e}	11	-18.5	0.5	-13.5	-12.0	17.8	1.0	15.8	18.9
T.Mammal ^{a,d,e,g}	9	-20.7	0.8	-21.8	-17.1	4.5	1.0	2.9	8.7

^a Corrected $\delta^{13}\text{C}$ values for Suess effect.

^b Tissue correction (-5.6‰) for $\delta^{13}\text{C}$ values (collagen to flesh and accounting for blubber) as per Newsome et al. (2004).

^c Tissue correction (-1‰) for $\delta^{13}\text{C}$ values (collagen to flesh).

^d Data from this study.

^e Data from Goldberg (1993).

^f Data from Newsome et al. (2010).

^g Data from Somerville et al. (2018).

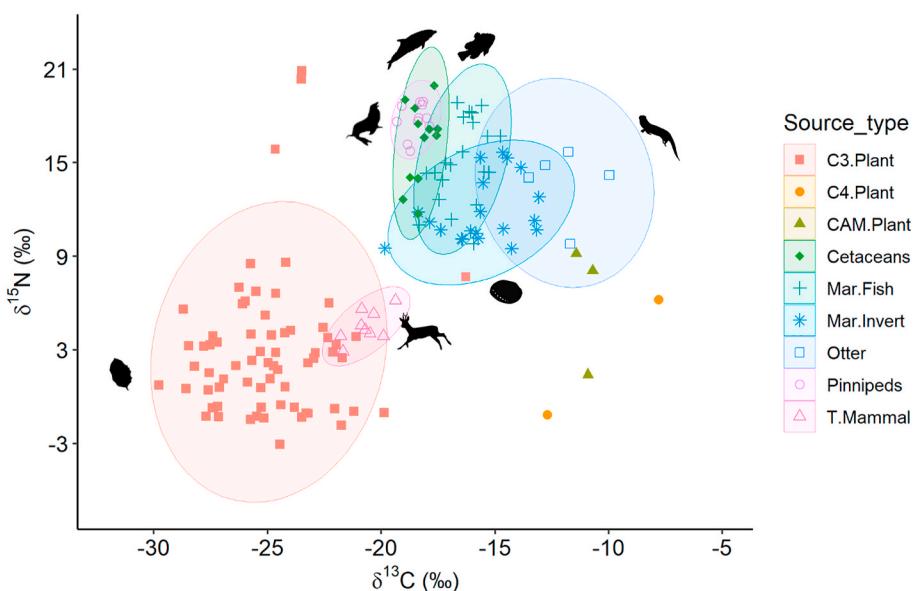


Fig. 3. (Color). Stable isotope values of food sources in the Southern California Bight region sorted by source type. Ellipses represent the 90% confidence level for each source. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

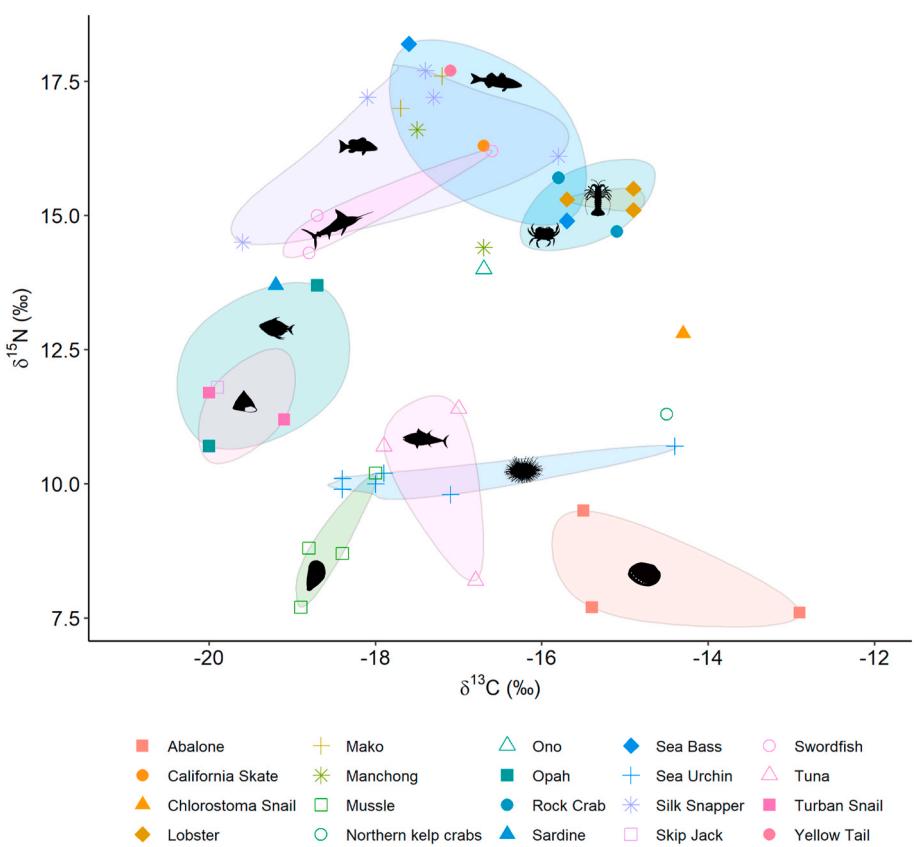


Fig. 4. (Color). Scatterplot of stable carbon and nitrogen isotope values of marine fish and invertebrate specimens collected from the California Southern Bight region. No corrections have been made to the stable isotope data. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

overall MixSIAR model for broad geographic categories (inland, coastal, island) are presented in Table 4. The posterior results of the region-specific mixing models that included informed priors based on geographic location are presented in Supplemental Table 1 and in Fig. 6. The Late period of San Clemente was excluded from temporal analyses

due to the small sample size ($n = 2$).

Table 3

Descriptive statistics of diet source categories.

Source	Mean $\delta^{13}\text{C}$	SD $\delta^{13}\text{C}$	Mean $\delta^{15}\text{N}$	SD $\delta^{15}\text{N}$	C %	N %	N	Taxa
Marine.High	-17.0	1.4	15.7	2.6	51	15	33	Marine fish, pinnipeds
Marine.Low	-16.0	2.3	9.9	1.4	50.8	12.9	15	Urchins, abalone, mussels, snails
Plants	-24.0	4.3	3.0	4.4	43.8	1.5	70	C3 plants
T.Mammal	-20.7	0.8	4.5	1.0	51.5	14	9	Deer, hares

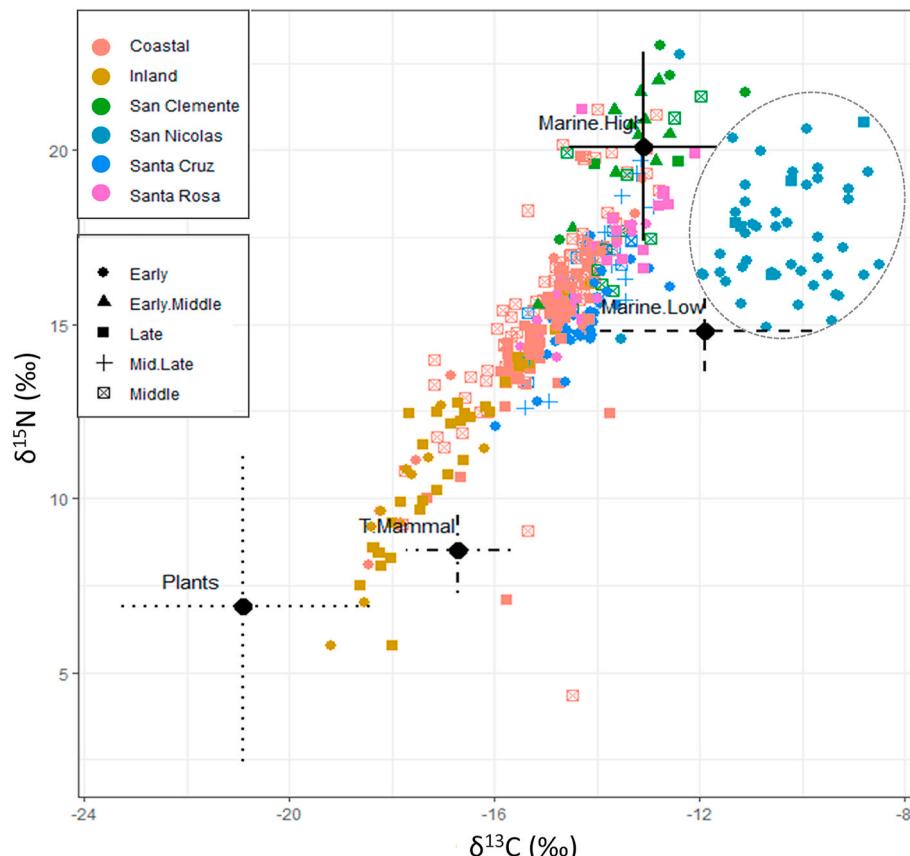


Fig. 5. (Color). Scatterplot of dietary source values with human stable isotope values adjusted according to trophic discrimination factors. San Nicolas Island individuals, indicated by dashed circle, exhibit values that fall outside of the model parameters. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4

Proportions of food contributions in human diets grouped by primary geographic location. Median = 50% quantile, Range = 95% Bayesian credible intervals.

Location	Marine high		Marine low		Plants		T.Mammal	
	Median	Range	Median	Range	Median	Range	Median	Range
Inland	0.13	0.03–0.22	0.10	0.01–0.27	0.26	0.14–0.4	0.51	0.31–0.67
Coastal	0.40	0.22–0.55	0.22	0.06–0.44	0.13	0.04–0.26	0.24	0.09–0.36
Island	0.53	0.36–0.71	0.29	0.09–0.49	0.05	0.01–0.16	0.11	0.02–0.22

5. Discussion

5.1. Geographic differences

Using our new baseline stable isotope database for southern Californian foods, we conducted Bayesian modeling of ancient human dietary practices in southern California using previously published isotope values from over 346 burials from across the region (Fig. 2). This analysis allows us to determine both temporal and spatial variability in types of food consumed and gives us a more nuanced perspective on ancient dietary practices in southern California. A depiction of

differences in food categories between geographic regions can be found in Table 4. In general, our model shows a diet high in plant foods and terrestrial mammals at inland sites (CI: 31–67%), high in marine foods on island sites (CI: 36–71%), and a fairly mixed diet between terrestrial and marine resources at coastal sites (Fig. 6). Similar patterns have been observed by Walker and DeNiro (1986) and Goldberg (1993).

5.2. Northern channel island diets

Shifts in relative protein consumption from different food groups through time are displayed in Fig. 6. The posterior distributions of the

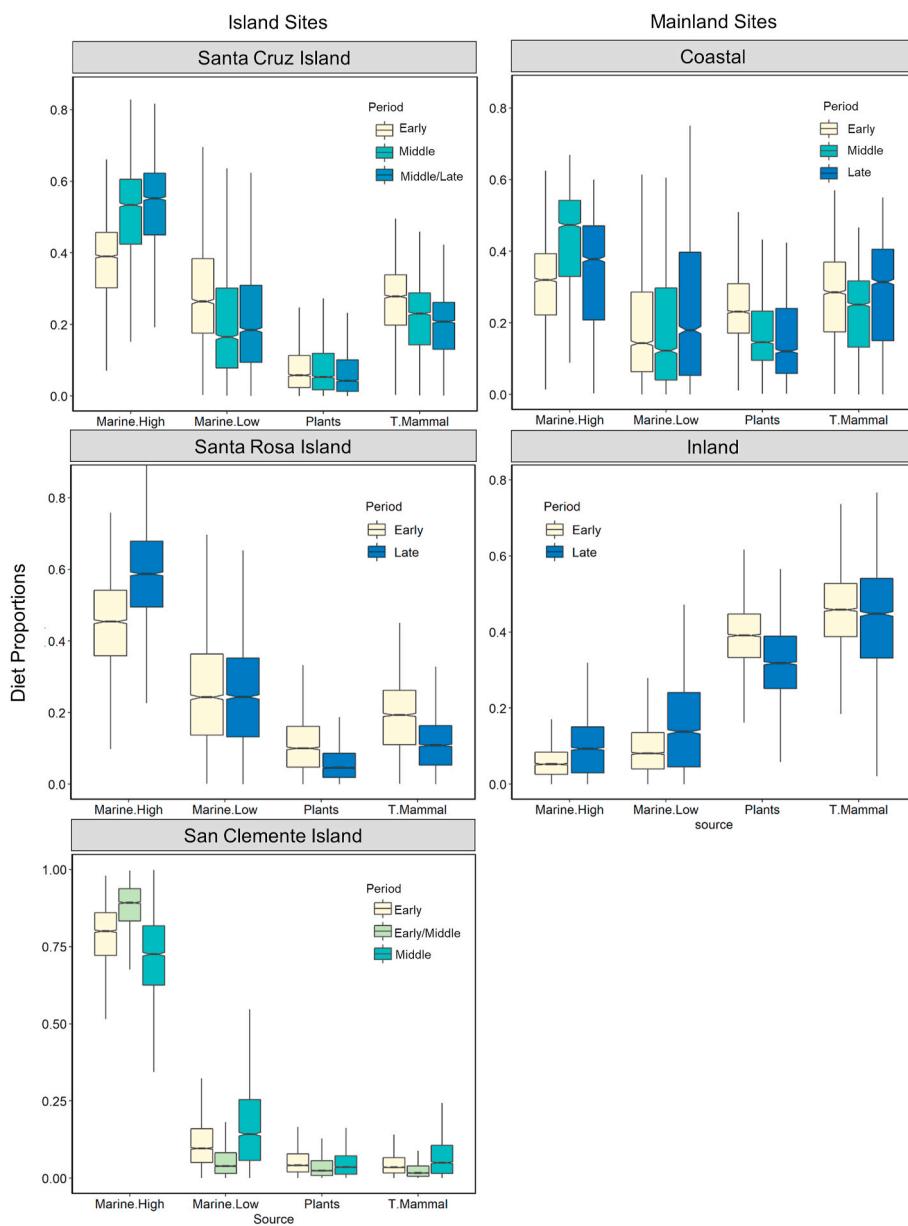


Fig. 6. (Color). Boxplots displaying the probability distributions of calculated proportions of food sources in human diets at each southern California site location over time. Horizontal lines represent median values; boxes represent the interquartile range; and lines display 1.5 times length of the interquartile range above and below the first and third quartiles. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Bayesian mixing model demonstrate a clear pattern of dietary change through time among human populations of the Northern Channel Islands where finfish or pinniped (marine high) consumption increased relative to invertebrate (marine low) consumption. On Santa Rosa Island, the proportion of marine high foods in human diet increased from a median value of 45% (CI: 20–63%) during the Early Period to a median of 59% (CI: 34–81%) during the Late period (Supplemental Table 1). Similarly at Santa Cruz Island, human consumption of marine high foods increased from a median of 39% (CI: 13–56%) during the Early Period to a median of 55% (CI: 26–72%) during the Middle Period. During the mixed Middle/Late Period at Santa Cruz Island, human consumption of marine high foods remained similar to the Middle Period with a median of 53% (95% CI: 21–71%; Supplemental Table 1).

For the purposes of the following discussion we assume that the primary foods consumed within the marine high and marine low categories were finfish and shellfish (rather than pinnipeds or urchins), respectively based on the faunal record of the region (e.g. Colten, 2001;

Kennett, 2005). The pattern of increasing finfish relative to shellfish consumption through time among human populations at sites from the two northern Channel islands, Santa Rosa and Santa Cruz, matches similar trends identified in the faunal record on the islands (Braje et al., 2007; Colten and Arnold, 1998; Erlandson et al., 2009; Glassow, 1993; Jazwa et al., 2020; Kennett, 2005; Rick et al., 2005; Porcasi, 2011). Possible explanations for this shift include (1) overharvesting of local shellfish patches over time, (2) human population growth, which would have strained local resources (Raab et al., 2009:159–169; Porcasi et al., 2000; Hildebrandt and Jones, 1992), and (3) new technological innovations of watercraft and fishhooks (Colten and Arnold, 1998; Erlandson et al., 2009; McKenzie, 2007; Rick, 2007; Rick et al., 2002). Our model shows this pattern as being manifested slightly differently on Santa Rosa Island compared to Santa Cruz Island. While finfish consumption increases through time on both islands, Santa Cruz shows a slight decrease in shellfish consumption between the Early and Middle Periods, while on Santa Rosa Island shellfish consumption stays fairly

constant through time (Fig. 6). It is notable that on Santa Cruz Island the biggest changes in diet seem to have occurred during the Middle Period, suggesting that the major changes for island life associated with the Late Period may have started slightly earlier for island populations.

5.3. Southern channel island diets

San Clemente Island shows a striking dominance of marine high resources through time (Fig. 6e). Considering the faunal record of the Southern Channel Islands, it is likely that this signature represents heavy consumption of fish, pinnipeds, and cetaceans. Indeed, much of our data for San Clemente Island comes from Eel Point, which has a dense faunal record of pinniped and dolphinidae consumption during the Early Period (Porcasi et al., 2000; Raab et al., 2009). It is possible that decreases in pinniped and cetacean consumption through time were offset by increases in fishing, leading to the fairly constant pattern of marine high consumption shown in our results. Overall, it is clear from our results that higher trophic level marine resources were a much larger component of ancient diets on San Clemente Island than on Santa Cruz or Santa Rosa. This finding is an agreement with the conclusions drawn by Goldberg (1993) from the stable isotope data alone.

The human bone collagen stable isotope data from San Nicolas Island fell outside of the parameters of the Bayesian mixing model, and the dietary proportions were thus not calculated for sites at this location. To attempt to interpret the dietary practices, we plotted individual human values in reference to all marine organisms (Fig. 7). The human values

plot between many possible food source categories, with the rock crabs, spiny lobsters, otters, sea urchins, and tuna fish being the closest possible marine dietary inputs. Generally, residents of San Nicolas Island appear to have consumed a wide variety of marine organisms with a focus on species of the kelp forest, a pattern which would explain their significantly higher $\delta^{13}\text{C}$ values compared to other island and mainland sites.

5.4. Coastal diets

Dietary changes through time among human populations at coastal sites display a somewhat different pattern than on the islands. As can be seen from Fig. 6, our model indicates that consumption of shellfish (marine low) stayed relatively constant through time at coastal settlements, although it decreased slightly during the Middle Period and increased during the Late Period. Consumption of finfish (marine high) also seems to decrease slightly during the Late Period (compared to the Middle Period). These results suggest that Late Period coastal populations may not have intensified their procurement of fish to the same degree as their neighbors on the Channel Islands. Faunal analysis from the coastal sites included in our data set indicate that marine vertebrates including ethnohistorically high-valued pelagic fish were consumed at all of these coastal sites (Curtis, 1963; Follett, 1963; Bernard, 2005; Roeder, 1987). Shellfish remains, however, are also abundant. Overall, our model for coastal populations indicates a fairly broad dietary pattern combining both marine and terrestrial resources.

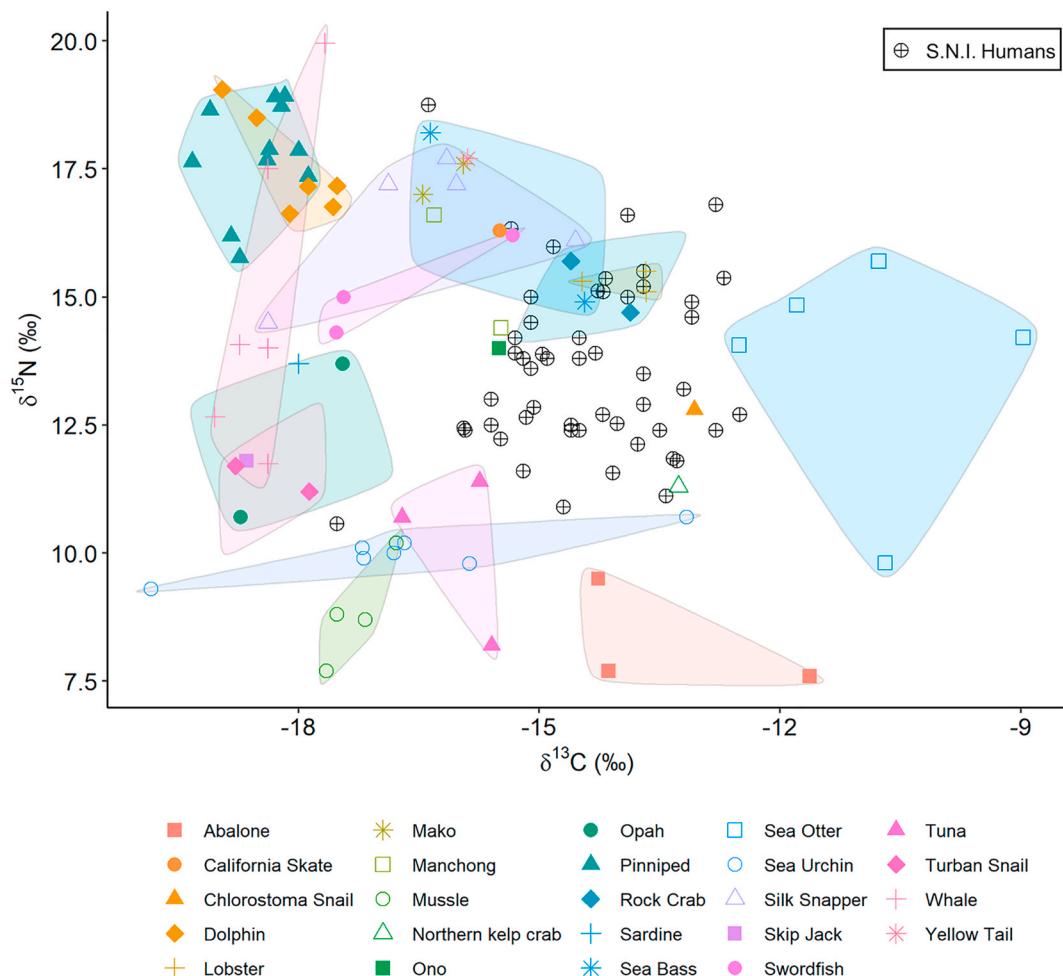


Fig. 7. (Color). Scatterplot of human stable carbon and nitrogen isotope values from San Nicolas Island (circles with cross marks) plotted against values of marine fish and invertebrates from the Southern California Bight region. The human values were adjusted for trophic discrimination factors ($\Delta^{13}\text{C} = -4\text{\textperthousand}$; $\Delta^{15}\text{N} = -4\text{\textperthousand}$). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

5.5. Inland diets

The three inland sites included in this study also display considerably different dietary patterns than populations on the coast and islands (Fig. 6). In both the Early and Late Periods, the largest source of dietary protein consumed by inland populations was from terrestrial mammals (median = 45% (CI: 20–66%)). The Late Period data, however, suggest an increase in the consumption of marine high and low resources compared to the Early Period. Although pelagic fish remains have been reported at both of these Late Period inland sites (Bernard, 2005; Follett, 1963), our model suggests that the importation of such high-valued fauna was less significant than the transport of low marine resources such as shellfish. Both sites (LAN-243 and LAN-227) are situated approximately 16 km from the coast (See Fig. 2). Although harvesting efficiency varies considerably by shellfish type and location, this distance is within the one-way travel threshold for extremely heavy mussel loads calculated by Bettinger et al. (1997:896). Shellfish at these sites could thus have been procured directly via travel to the coast, but could also have been acquired through trade with neighboring coastal populations. The increase in marine resource consumption at inland sites during the Late Period may be indicative of increased regional trade during this time.

5.6. Social implications of dietary data

One of the most interesting patterns resulting from our models concerns the lower relative contribution of plant protein to human diets on the Northern Channel Islands compared to the mainland coast. It is notable that our model depicts a slight decrease in plant consumption on Santa Rosa Island from the Early Period (median = 10% (CI: 0–27%)) to the Middle Period (median = 5% (CI: 0–18%)), contrary to what would be expected if inter-island transport of food goods was increasing during this time. On Santa Cruz Island plant consumption remained constant through time, with a noticeable but insignificant decrease during the Late Period. These results are not in accordance with suggestions that Late Period islanders intensified the importation of plant foods from the mainland (e.g. Arnold and Martin, 2014), and support models that emphasize the consumption of local food resources on the Northern Channel Islands (Fauvelle and Perry, 2019; Gill et al., 2019). Nevertheless, because the stable isotope values in bone collagen are heavily biased towards dietary protein sources, the consumption of low-protein plant food sources may be underrepresented in our model, and any conclusions about plant food consumption must remain tentative.

5.7. Limitations

Our Bayesian modeling complements traditional approaches to studying dietary change in southern California, such as faunal analysis and paleoethnobotany. Despite its advantages, there are several limitations to our approach. Probability estimates based on baseline isotopic values lump together species that consume similar food types. This means that our analysis groups together several fairly different species for the purposes of analysis. Faunal analysis, for example, suggests that finfish and pinnipeds were consumed at different levels across time and space in southern California (Colten and Arnold, 1998; Erlandson et al., 2009; Hildebrandt and Jones, 1992; Raab et al., 2009). Our analysis, however, requires us to combine these marine categories into one. Additionally, some food sources were not available for analysis as part of this study, such as sea birds, and they are thus not accounted for in the model, despite the fact that they were surely consumed by ancient inhabitants of the California Bight region. Nonetheless, the stable isotope mixing model techniques applied in this paper provide a well-informed and quantitative interpretation of the existing stable isotope data and add to our growing understanding of human-environmental relationships in ancient Southern California.

6. Conclusions

This paper has presented new baseline isotope values for food resources in southern California, expanding the coverage of important marine resources compared to previous studies (e.g. Goldberg, 1993; Newsome et al., 2004). Using our baseline values, we reevaluated previously published human isotope data (Goldberg, 1993; Harrison and Katzenberg, 2003), and constructed Bayesian stable isotope mixing models to evaluate temporal and spatial differences across four different food categories: marine high (finfish and pinnipeds), marine low (mollusks and urchins), terrestrial plants, and terrestrial mammals (see Table 2). Our results demonstrate a shift through time in the Northern Channel Islands towards greater reliance on finfish relative to shellfish. Notably, this process was coeval with increasing human populations on the islands and technological innovations that would have facilitated higher yields from fishing (see Fig. 6).

Our data suggest that increases in fishing during the Middle and Late Periods were more pronounced on the Northern Channel Islands than on the mainland coast, where ancient populations had diets that were more equally spread between fish, shellfish, and terrestrial plant and animal resources. San Clemente Island populations displayed a strikingly different pattern, with finfish and pinnipeds being the dominant source of protein across all periods of occupation. As expected, interior populations consumed higher proportions of terrestrial resources, with a marked increase in importation of marine resources during the Late Period. Across all time periods, island populations seem to have consumed less protein from plant resources relative to their mainland neighbors, displaying a slight decrease in plant consumption during the Late Period. High degrees of variation in dietary patterns between the islands and coasts of southern California suggest that Late Holocene shifts in diet were likely contingent on multiple local processes in addition to regional prime-movers. Together, our data present a dynamic picture of dietary change through time in southern California, showing how different local populations shifted their food procurement strategies as regional populations rose and many island and coastal groups adopted more socially and economically complex ways of life.

Data availability

Baseline stable isotope values for southern California can be found in the companion data article to this paper (Fauvelle and Somerville, 2021). Human isotope values were drawn from Goldberg (1993) and Harrison and Katzenberg (2003).

CRediT authorship contribution statement

Mikael Fauvelle: Conceptualization, Investigation, Resources, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Andrew D. Somerville:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The research presented in this paper was supported by a grant from the University of California Pacific Rim Research Program (DG-14-27). Laboratory analysis was conducted at the Paleodiet Laboratory at the University of California, San Diego, directed by Dr. Margaret Schoeninger. We thank Mia Muscio for assisting with the collection of plant

samples used in this study. We also thank Andre Colonese and one anonymous reviewer for their helpful comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quaint.2021.06.025>.

References

- Ainis, A.F., Erlandson, J.M., Gill, K.M., Graham, M.H., Vellanoweth, R.L., 2019. The potential use of seaweeds and marine plants by Native peoples of Alta and Baja California. In: Gill, K.M., Fauvelle, M., Erlandson, J.M. (Eds.), *An Archaeology of Abundance: Reevaluating the Marginality of California's Islands*. University Press of Florida, Gainesville, pp. 135–170.
- Ames, K.M., 2002. Going by boat: the forager-collector continuum at sea. In: Fitzhugh, Ben, Habu, Junko (Eds.), *Beyond Foraging and Collecting: Evolutionary Change in Hunter-Gatherer Settlement Systems*. Kluwer Academic/Plenum Publishers, New York, pp. 19–52.
- Ambrose, S.H., Buikstra, J., Krueger, H.W., 2003. Status and gender differences in diet at Mound 72, Cahokia, revealed by isotopic analysis of bone. *J. Anthropol. Archaeol.* 22 (3), 217–226.
- Ambrose, S.H., Norr, L., 1993. Isotopic composition of dietary protein and energy versus bone collagen andapatite: purified diet growth experiments. In: Lambert, J.B., Grupe, G. (Eds.), *Molecular Archaeology of Prehistoric Human Bone*. Springer, Berlin, pp. 1–37.
- Arnold, J.E., 1995. Transportation innovation and social complexity among maritime hunter gatherer societies. *Am. Anthropol.* 97 (4), 733–747.
- Arnold, J.E., 2001. The chumash world and regional perspectives. In: Arnold, J.E. (Ed.), *The Origins of a Pacific Coast Chiefdom: the Chumash of the Channel Islands*, 1–19. University of Utah Press, Salt Lake City.
- Arnold, J.E., Martin, L.S., 2014. Botanical evidence of paleodietary and environmental change: drought on the Channel islands, California. *Am. Antiq.* 79 (2), 227–248.
- Arnold, J.E., Munns, A., 1994. Independent or attached specialization: the organization of shell bead production in California. *J. Field Archaeol.* 21 (4), 473–489.
- Bartelink, E., 2009. Late holocene dietary change in the san francisco bay area. *Calif. Archaeol.* 1 (2), 227–251.
- Bartelink, E., Beasley, M., Eerkens, J.W., Gardner, K.S., Wiberg, R.S., Garibay, R., 2020. Stable isotope evidence of diet breadth expansion and regional dietary variation among Middle-to-Late Holocene Hunter-Gatherers of Central California. *J. Archaeol. Sci.: Reports* 29, 102182.
- Beasley, M.M., Martinez, A.M., Simons, D.D., Bartelink, E.J., 2013. Paleodietary analysis of a San Francisco Bay Area shellmound: stable carbon and nitrogen isotope analysis of late Holocene humans from the Ellis Landing site (CA-CCO-295). *J. Archaeol. Sci.* 40 (4), 2084–2094.
- Ben-David, M., Flynn, R.W., Schell, D.M., 1997. Annual and seasonal changes in diets of martens: evidence from stable isotope analysis. *Oecologia* 111, 280–291.
- Bennyhoff, J.A., Hughes, R.E., 1987. Shell Bead and Ornament Exchange Networks between California and the Western Great Basin. The American Museum of Natural History, New York.
- Bernard, J., 2005. The origins of large-species fishing among the chumash. *Found. Chumash Complex.* 7, 25.
- Bettinger, R.L., Malhi, R., McCarthy, H., 1997. Central place models of acorn and mussel processing. *J. Archaeol. Sci.* 24 (10), 887–899.
- Binford, L.R., 1990. Mobility, housing, and environment: a comparative study. *J. Anthropol. Res.* 46 (2), 119–152.
- Bocherens, H., Drucker, D., 2003. Rophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *Int. J. Osteoarch.* 13, 46–53.
- Bocherens, H., Drucker, D.G., Germonpré, M., Lázníčková-Galeťová, M., Naito, Y.I., Wissing, C., Brůžek, J., Oliva, M., 2015. Reconstruction of the Gravettian food-web at Předmostí I using multi-isotopic tracking (^{13}C , ^{15}N , ^{34}S) of bone collagen. *Quant. Int.* 359–360, 211–228.
- Braje, T.J., Kennett, D.J., Erlandson, J.M., Culleton, B.J., 2007. Human impacts on nearshore shellfish taxa: a 7,000 year record from Santa Rosa Island, California. *Am. Antiq.* 735–756.
- Cheung, C., Szpak, P., 2020. Interpreting past human diets using stable isotope mixing models. *J. Archaeol. Method Theor.* 1–37.
- Colten, R.H., 2001. Ecological and economic analysis of faunal remains from Santa Cruz Island. *The Origins of a Pacific Coast Chiefdom: the Chumash of the Channel Islands*. University of Utah Press, Salt Lake City, pp. 199–219.
- Colten, R.H., Arnold, J.E., 1998. Prehistoric marine mammal hunting on California's northern Channel Islands. *Am. Antiq.* 63 (4), 679–701.
- Commendador, A.S., Finney, B.P., Fuller, B.T., Tromp, M., Dudgeon, J.V., 2019. Multiproxy isotopic analyses of human skeletal material from Rapa Nui: evaluating the evidence from carbonates, bulk collagen, and amino acids. *Am. J. Phys. Anthropol.* 169 (4), 714–729.
- Crittenden, A.N., Schnorr, S.L., 2017. Current views on hunter-gatherer nutrition and the evolution of the human diet. *Am. J. Phys. Anthropol.* 162, 84–109.
- Crowley, B.E., Carter, M.L., Karpany, S.M., Zihlman, A.L., Koch, P.L., Dominy, N.J., 2010. Stable carbon and nitrogen isotope enrichment in primate tissues. *Oecologia* 164, 611–626.
- Curtis, F., 1963. Arroyo sequit-LAn-52 :archeological investigations in leo carillo beach state park, los angeles county, California/ (Sacramento, Calif.).
- DeNiro, M.J., Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochem. Cosmochim. Acta* 45, 341–351.
- DeNiro, M.J., Epstein, S., 1978. Influence of diet on the distribution of carbon isotopes in animals. *Geochem. Cosmochim. Acta* 42, 495–506.
- Eide, M., Olsen, A., Ninnemann, U.S., Eldevik, T., 2017. A global estimate of the full oceanic ^{13}C Suess effect since the preindustrial. *Global Biogeochem. Cycles* 31, 492–514.
- Erlandson, J.M., 1991. Early Hunter-Gatherers of the California Coast. Plenum Press, New York.
- Erlandson, J.M., Fitzpatrick, S.M., 2006. Oceans, islands, and coasts: current perspectives on the role of the sea in human prehistory. *J. I. Coast Archaeol.* 1 (1), 5–32.
- Erlandson, J.M., Graham, M.H., Bourque, B.J., Corbett, D., Estes, J.A., Steneck, R.S., 2007. The kelp highway hypothesis: marine ecology, the coastal migration theory, and the peopling of the Americas. *J. I. Coast Archaeol.* 2 (2), 161–174.
- Erlandson, J.M., Rick, T.C., Braje, T.J., Casperson, M., Culleton, B., Fulfrost, B., Garcia, T., Guthrie, D.A., Jew, N., Kennett, D.J., Moss, M.L., Reeder, L., Skinner, C., Watts, J., Willis, L., 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California's Channel Islands. *Science* 331 (6021), 1181–1185. <https://doi.org/10.1126/science.1201477>.
- Erlandson, J.M., Rick, T.C., Braje, T.J., 2009. Fishing up the food web?: 12,000 Years of maritime subsistence and adaptive adjustments on California's Channel islands. *Pac. Sci.* 63 (4), 711–724.
- Fauvelle, M., 2011. Mobile mounds: asymmetrical exchange and the role of the tomol in the development of chumash complexity. *Calif. Archaeol.* 3 (2), 141–158.
- Fauvelle, M., 2013. Evaluating cross-channel exchange in the Santa Barbara region: experimental data on acorn processing and transport. *Am. Antiq.* 78 (4), 790–798.
- Fauvelle, M., 2014. Acorns, asphaltum, and asymmetrical exchange: invisible exports and the political economy of the Santa Barbara Channel. *Am. Antiq.* 79 (3), 573–575.
- Fauvelle, M., Esch, E., Somerville, A., 2017. Climate change and subsistence exchange in southern California: was western sea-purslane a Channel island trade good? *Am. Antiq.* 82 (1), 183–188.
- Fauvelle, M., Perry, J., 2019. Material conveyance and trade in the Channel region. In: Gill, Kristina M., Fauvelle, Mikael, Erlandson, Jon M. (Eds.), *An Archaeology of Abundance: Re-evaluating the Marginality of California's Islands*. University Press of Florida, Gainesville, pp. 191–225.
- Fauvelle, M., Somerville, A., 2021. Surf and Turf: Southern California Baseline Stable Isotope Dataset. Data in Brief. Submitted for publication.
- Fernandes, R., Millard, A.R., Brabec, M., Nadeau, M.-J., Grootes, P., 2014. Food reconstruction using isotopic传递 signals (FRUITS): a bayesian model for diet reconstruction. *PLoS One* 9, e87436.
- Fernandes, R., Nadeau, M.-J., Grootes, P.M., 2012. Macronutrient-based model for dietary carbon routing in bone collagen and bioapatite. *Archaeol. Anthropol. Sci.* 4, 291–301.
- Follett, W.I., 1963. Fish remains from arroyo sequit shellmound (LAN-52), los angeles county, California. *Arroyo Sequit-LAn 52*, 113–121.
- Froehle, A.W., Kellner, C.M., Schoeninger, M.J., 2010. FOCUS: effect of diet and protein source on carbon stable isotope ratios in collagen: follow up to Warinner and Tuross (2009). *J. Archaeol. Sci.* 37, 2662–2670.
- Fry, B., 2007. *Stable Isotope Ecology*. Springer, Baton Rouge.
- Gamble, L.H., 2002. Archaeological evidence for the origin of the plank canoe in North America. *Am. Antiq.* 301–315.
- Gamble, L.H., 2008. *The Chumash World at European Contact: Power, Trade, and Feasting Among Complex Hunter-Gatherers*. University of California Press, Berkeley.
- Gamble, L.H., 2011. Structural transformation and innovation in emergent political economies of southern California. In: Sassaman, K.E., Jr Holly, D.H. (Eds.), *Hunter-gatherer Archaeology as Historical Process*. University of Arizona Press, Tucson, pp. 227–248.
- Gamble, L.H., 2020. The origin and use of shell bead money in California. *J. Anthropol. Archaeol.* 60, 101237.
- Gamble, L.H., Russell, G.S., King, C., Hudson, J., 1996. Distribution of Wealth and Other Items at the Malibu Site, CA-LAN-264. Report Prepared for the California Department of Parks and Recreation, Sacramento, California.
- Gamble, L.H., Walker, P.L., Russell, G.S., 2001. An integrative approach to mortuary analysis: social and symbolic dimensions of Chumash burial practices. *Am. Antiq.* 185–212.
- Gill, K.M., 2013. Paleoethnobotanical investigations on the Channel islands: current directions and theoretical considerations. In: Jazwa, Christopher S., Perry, Jennifer E. (Eds.), *California's Channel Islands: the Archaeology of Human-Environment Interactions*. University of Utah Press, Salt Lake City.
- Gill, K.M., 2015. *Ancient Plant Use and the Importance of Geophytes Among the Island Chumash of Santa Cruz Island, California*. University of California, San Diego.
- Gill, K.M., 2016. 10,000 years of geophyte use among the island chumash of the northern Channel islands. *Fremontia* 44 (3), 34–38.
- Gill, K.M., Erlandson, J.M., 2014. The island chumash and exchange in the Santa Barbara Channel region. *Am. Antiq.* 79 (3), 570–572.
- Gill, K.M., Erlandson, J.M., Niessen, K., Hoppa, K., Merrick, D., 2019. Where Carbohydrates Were Key: Reassessing the Marginality of Terrestrial Plant Resources on California's Islands. *An Archaeology of Abundance: Re-evaluating the Marginality of California's Islands*. University Press of Florida, Gainesville, FL.
- Gill, K.M., Fauvelle, M., Erlandson, J.M., 2019. An Archaeology of Abundance: Reevaluating the Marginality of California's Islands. University Press of Florida, Gainesville.
- Glassow, M.A., 1993. Changes in subsistence on marine resources through 7,000 years of prehistory on Santa Cruz Island. In: *Archaeology on the Northern Channel Islands*:

- Studies of Subsistence, Economics, and Social Organization, vol. 34. Coyote Press Archives of California Prehistory, pp. 75–94.
- Goldberg, C.F., 1993. The Application of Stable Carbon and Nitrogen Isotope Analysis to Human Dietary Reconstruction in Prehistoric Southern California. Unpublished Doctoral Dissertation, University of California, Los Angeles.
- Goldberg, C., Titus, M., Salls, R., Berger, R., 2000. Site chronology on San Clemente Island, California. *Pacific Coast Archaeol. Soc. Quart.* 36 (1), 31–40.
- Graven, H., Allison, C.E., Etheridge, D.M., Hammer, S., Keeling, R.F., Levin, I., Meijer, H.A.J., Rubino, M., Tans, P.P., Trudinger, C.M., 2017. Compiled records of carbon isotopes in atmospheric CO₂ for historical simulations in CMIP6. 10. Geoscientific Model Development.
- Greenwood, R.S., Foster, J.M., Romani, G.R., 1986. Archaeological Study of CA-VEN-110, Ventura, California. Greenwood and Associates Pacific Palisades CA.
- Gusick, A.E., Perry, J., Gill, K.M., Teeter, W., 2020. A trans-holocene approach to assess maritime development on the California Channel Islands archipelago: a case study from Eel Point, San Clemente Island. *Quat. Int.* 597, 37–49.
- Harrison, R.G., Katzenberg, M.A., 2003. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from Southern Ontario and San Nicolas Island, California. *J. Anthropol. Archaeol.* 22 (3), 227–244.
- Hedges, R.E.M., Reynard, L.M., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J. Archaeol. Sci.* 34, 1240–1251.
- Hesslein, R.H., Capel, M.J., Fox, D.E., Hallard, K.A., 1991. Stable isotopes of sulfur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie river basin, Canada. *Can. J. Fish. Aquat. Sci.* 48, 2258–2265.
- Hildebrandt, W.R., Jones, T.L., 1992. Evolution of marine mammal hunting: a view from the California and Oregon coasts. *J. Anthropol. Archaeol.* 11 (4), 360–401.
- Jackson, A.L., Inger, R., Parnell, A.C., Bearhop, S., 2011. Comparing isotopic niche widths among and within communities: SIBER—Stable Isotope Bayesian Ellipses in R. *J. Anim. Ecol.* 80, 595–602.
- Jansen, O.E., Aarts, G.M., Das, K., Leopold, G., Michel, L., Reijnders, P.J.H., 2012. Feeding ecology of harbour porpoises: stable isotope analysis of carbon and nitrogen in muscle and bone. *Mar. Biol. Res.* 8, 829–841.
- Jazwa, C.S., Joslin, T.L., Kennett, D.J., 2020. Fishing, subsistence change, and foraging strategies on western Santa Rosa Island, California. *Am. Antiqu.* 85 (3), 591–608.
- Johnson, J.R., Stafford Jr., T.W., Ajie, H.O., Morris, D.P., 2002. Arlington springs revisited. Santa Barbara Museum of Natural History, Santa Barbara, CA, pp. 541–545.
- Jones, T.L., 2008. Culture or adaptation: milling stone reconsidered. In: Monographs in California and Great Basin Anthropology—Avocados to Millingstones. Papers in Honor of DL True(5).
- Keeling, C.D., 1979. The Suess effect: 13C–14C interrelations. *Environ. Int.* 2, 229–300.
- Kelly, R.L., 2013. The Lifeways of Hunter-Gatherers: the Foraging Spectrum. Cambridge University Press.
- Kennett, D.J., 2005. The Island Chumash: Behavioral Ecology of a Maritime Society. University of California Press, Berkeley.
- King, C., 1976. Chumash inter-village economic exchange. In: Bean, L.J., Blackburn, T.C. (Eds.), Native Californians: A Theoretical Retrospective. Ballena Press, Socorro, pp. 289–318.
- King, C., 1990. Evolution of chumash society: a comparative study of artifacts used for social system maintenance in the Santa Barbara Channel region before A.D. 1804. In: Thomas, D.H. (Ed.), The Evolution of North American Indians. Garland Publishing, New York.
- Kintigh, K.W., Altschul, J.H., Beaudry, M.C., Drennan, R.D., Kinzig, A.P., Kohler, T.A., Limp, W.F., Maschner, H.D.G., Michener, W.K., Pauketat, T.R., 2014. Grand challenges for archaeology. *Am. Antiqu.* 79 (1), 5–24.
- Kohn, M.J., 2010. Carbon isotope compositions of terrestrial C₃ plants as indicators of (paleo)ecology and (paleo)climate. *Proc. Natl. Acad. Sci. Unit. States Am.* 107, 19691–19695.
- Lambert, P.M., 1993. Health in prehistoric populations of the Santa Barbara Channel Islands. *Am. Antiqu.* 59–522.
- Lambert, P.M., Walker, P.L., 1991. Physical anthropological evidence for the evolution of social complexity in coastal Southern California. *Antiquity* 65, 963–973.
- Lewis, M.C., Sealy, J.C., 2018. Coastal complexity: ancient human diets inferred from Bayesian stable isotope mixing models and a primate analogue. *PLoS One* 13, e0209411.
- Linderholm, A., Hendenstierna-Jonson, C., Svensk, O., Lidén, K., 2008. Diet and status in Birka: stable isotopes and grave goods compared. *Antiquity* 82 (316), 446–461.
- McKenzie, D.K., 2007. Simulated Prehistoric Fishing Methods on the Northern Channel Islands. University of California, Santa Barbara, California. Unpublished MA Thesis.
- Minagawa, M., Wada, E., 1984. Stepwise enrichment of ¹⁵N along food chains: further evidence and the relation between ¹⁵N and animal age. *Geochim. Cosmochim. Acta* 48, 1135–1140.
- Newsome, S.D., Bentall, G.B., Tinker, M.T., Oftedal, O.T., Ralls, K., Estes, J.A., Fogel, M.L., 2010. Variation in ⁸¹³C and ⁸¹⁵N diet–vibrissae trophic discrimination factors in a wild population of California sea otters. *Ecol. Appl.* 20, 1744–1752.
- Newsome, S.D., Phillips, D.L., Culleton, B.J., Guilderson, T.P., Koch, P.L., 2004. Dietary reconstruction of an early to middle Holocene human population from the central California coast: insights from advanced stable isotope mixing models. *J. Archaeol. Sci.* 31, 1101–1115.
- O'Leary, M.H., 1988. Carbon isotopes in photosynthesis. *Bioscience* 38, 328–336.
- Parnell, A.C., Inger, R., Bearhop, S., Jackson, A.L., 2010. Source partitioning using stable isotopes: coping with too much variation. *PLoS One* 5, e9672.
- Phillips, D.L., 2001. Mixing models in analyses of diet using multiple stable isotopes: a critique. *Oecologia* 127, 166–170.
- Phillips, D.L., Koch, P.L., 2002. Incorporating concentration dependence in stable isotope mixing models. *Oecologia* 130, 114–125.
- Phillips, D.L., Inger, R., Bearhop, S., Jackson, A.L., Moore, J.W., Parnell, A.C., Semmens, B.X., Ward, E.J., 2014. Best practices for use of stable isotope mixing models in food-web studies. *Can. J. Zool.* 92, 823–835.
- Porcasi, J.F., 2011. More on mollusks: trans-holocene shellfish exploitation on the California coast. *J. I. Coast Archaeol.* 6 (3), 398–420.
- Porcasi, J.F., Jones, T.L., Raab, M., 2000. Trans-Holocene marine mammal exploitation on San Clemente Island, California: a tragedy of the commons revisited. *J. Anthropol. Archaeol.* 19 (2), 200–220.
- Post, D.M., 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology* 83, 703–718.
- Post, D.M., Layman, C.A., Arrington, D.A., Takimoto, G., Quattrochi, J., Montana, C.G., 2007. Getting to the fat of the matter: models, methods and assumptions for dealing with lipids in stable isotope analyses. *Oecologia* 152 (1), 179–189.
- R Core Team, 2020. R: A Language and Environment for Statistical Computing. Foundation for Statistical Computing, Vienna.
- Raab, M.L., Cassidy, J., Yatsko, A., Howard, W.J., 2009. California Maritime Archaeology: A San Clemente Island Perspective. Alta Mira Press, Lanham.
- Rick, T.C., 2007. The Archaeology and Historical Ecology of Late Holocene San Miguel Island, vol. 8. ISD LLC.
- Rick, T.C., Culleton, B.J., Smith, C.B., Johnson, J.R., Kennett, D.J., 2011. Stable isotope analysis of dog, fox, and human diets at a Late Holocene Chumash village (CA-SRI-2) on Santa Rosa Island, California. *J. Archaeol. Sci.* 38 (6), 1385–1393.
- Rick, T.C., Erlandson, J.M., Vellanoweth, R.L., 2001. Paleoceanic marine fishing on the Pacific coast of the Americas: perspectives from Daisy Cave, California. *Am. Antiqu.* 595–613.
- Rick, T.C., Erlandson, J.M., Vellanoweth, R.L., Braje, T.J., 2005. From Pleistocene mariners to complex hunter-gatherers: the archaeology of the California Channel Islands. *J. World PreHistory* 19 (3), 169–228.
- Rick, T.C., Erlandson, J.M., Vellanoweth, R.L., Braje, T.J., Collins, P.W., Guthrie, D.A., Stafford Jr., T.W., 2009. Origins and antiquity of the island fox (*Urocyon littoralis*) on California's Channel Islands. *Quat. Res.* 71 (2), 93–98.
- Rick, T.C., Hofman, C.A., Reeder-Myers, L.A., 2019. Why translocate? Evaluating the evidence and reasons for ancient human introductions of wildlife to California's islands. *An Archaeology of Abundance: Reevaluating the Marginality of California's Islands*. University Press of Florida, Gainesville, pp. 248–272.
- Rick, T.C., Vellanoweth, R.L., Erlandson, J.M., Kennett, D.J., 2002. On the antiquity of the single-piece shell fishhook: AMS radiocarbon evidence from the southern California coast. *J. Archaeol. Sci.* 29 (9), 933–942.
- Roeder, M.A., 1987. Archaeological Study of CA-VEN-110, Ventura, California. *Fish Remains Supplement*. Greenwood and Associates, Pacific Palisades CA.
- Schoeninger, M.J., DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim. Cosmochim. Acta* 48, 625–639.
- Schoeninger, M.J., DeNiro, M.J., Tauber, H., 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220, 1381–1383.
- Schwarz, H.P., Schoeninger, M.J., 2011. Stable isotopes of carbon and nitrogen as tracers for paleo-diet reconstruction. In: Baskaran, M. (Ed.), *Handbook of Environmental Isotope Geochemistry*. Springer Berlin Heidelberg, pp. 725–742.
- Smith, C.F., 1976. Flora of the Santa Barbara Region, California: an Annotated Catalogue of the Native and Naturalized Vascular Plants of the Santa Barbara County Mainland and Nearby Channel Islands. Santa Barbara Museum of Natural History, Santa Barbara, CA.
- Smith, E., Fauvelle, M., 2015. Regional interactions between California and the southwest: the western edge of the North American continental system. *Am. Anthropol.* 17 (4), 710–721.
- Somerville, A.D., Fauvelle, M., Froehle, A.W., 2013. Applying new approaches to modelling diet and status: Isotopic evidence for commoner resiliency and elite variability in the Classic Maya lowlands. *J. Archaeol. Sci.* 40 (3), 1539–1553.
- Somerville, A.D., Froehle, A.W., Schoeninger, M.J., 2018. Environmental influences on rabbit and hare bone isotope abundances: implications for paleoenvironmental research. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 497, 91–104.
- Stock, B.C., Jackson, A.L., Ward, E.J., Parnell, A.C., Phillips, D.L., Semmens, B.X., 2018. Analyzing mixing systems using a new generation of Bayesian tracer mixing models. *PeerJ* 6, e5096.
- Stock, B.C., Semmens, B.X., 2013. MixSIAR GUI User Manual, version 1.0. <https://conserver.iugo-cafe.org/user/brice.semmens/MixSIAR>.
- Szpak, P., Orchard, T.J., McKechnie, I., Gröcke, D.R., 2012. Historical ecology of late Holocene sea otters (*Enhydra lutris*) from northern British Columbia: isotopic and zooarchaeological perspectives. *J. Archaeol. Sci.* 39, 1553–1571.
- Timbrook, J., 2007. Chumash Ethnobotany. Heyday Books, Berkeley.
- Walker, P.L., DeNiro, M.J., 1986. Stable nitrogen and carbon isotope ratios in bone collagen indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. *Am. J. Phys. Anthropol.* 71 (1), 51–61.