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REPORTS

The Importance of Fish, Cyclical Dietary Shifts, and the Antiquity of Northern Side-Notched Points: New Stable Isotope and Radiocarbon Data from Lassen and Modoc Counties, Northeastern California

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We report new stable isotope and radiocarbon data on a small set of human remains representing seven individuals from three archaeological sites in northeastern California, CA-MOD-205 (Franklin Creek site; n = 2), CA-LAS-989 (Bare Cave; n=4), and an unrecorded site near Honey Lake (n =1). Results reveal several points of interest for dietary reconstructions, mobility patterns, and the antiquity of Northern Side-Notched points. First, one of the samples from LAS-989 produced a calibrated radiocarbon date in excess of 7,800 cal B.P., one of the oldest human bones dated in northern California. This sample is associated stratigraphically with Northern Side-Notched projectile points, demonstrating the antiquity of this point style. The other samples consistently dated to the Late Holocene (2,200 to 1,200 cal B.P.). Second, dietary isotopes indicate that all individuals had a mixed diet, including C_3 plants and large game, as expected, but they also consumed significant quantities of fish, including varying quantities of a ^{13}C-enriched food, likely salmon or Tahoe sucker. Third, serial samples of dentin collagen from one woman near Honey Lake indicate that she was weaned between 3.1 and 3.7 years of age, and had periodic and fluctuating access to this ^{13}C-enriched food resource during later childhood and teenage years, with a periodicity around 3–4 years. We attribute this to either a residentially mobile settlement system with exploitation of a key and periodically-abundant resource, or to a structured fiesta system involving regular visits to a location on a major river. Finally, sulfur and oxygen isotopes suggest that most individuals had been living in northeastern California (i.e., were local) for a number of years prior to their deaths.

Dietary reconstruction and settlement pattern analyses have been a mainstay in California and Great Basin archaeological research and have provided important insights into ancient human behavior and behavioral changes (e.g., Basgall 1987; Bettinger 1999; Broughton 1994, 1997; Hildebrandt and Hayes 1993; Wohlgemuth 1996). Typically these studies rely on analysis of artifact morphology, identification of faunal and botanical remains, and analysis of site structure and location.

In this paper we employ new archaeometric techniques and examine isotopic signatures of human remains to provide additional insight into ancient human diet and mobility in northeastern California. We use existing collections, excavated and/or collected in the 1960s and 1970s, that have sat relatively unanalyzed in the ensuing 40–50 years. In the process of providing the new isotopic information about human behavior, we simultaneously point out the tremendous value of the curation of archaeological materials. As new analytical methods are developed, such as stable isotopes, proteomics, and ancient DNA, we can revisit older collections and open new windows on understanding ancient human behavior and reconnect with people from the past.

This study focuses on three sites in northeastern California, two in Lassen County (CA-LAS-989 and Honey Lake) and one in Modoc County (CA-MOD-305) (Fig. 1). The sites are located in the territory of Washo and Northern Paiute peoples. In pre-contact times, people in this region were residentially-mobile hunter-gatherers following seasonally-available resources, with technologies and social systems that were fine-tuned to making a living in this arid landscape (Freed 1960; Lowie 1939).

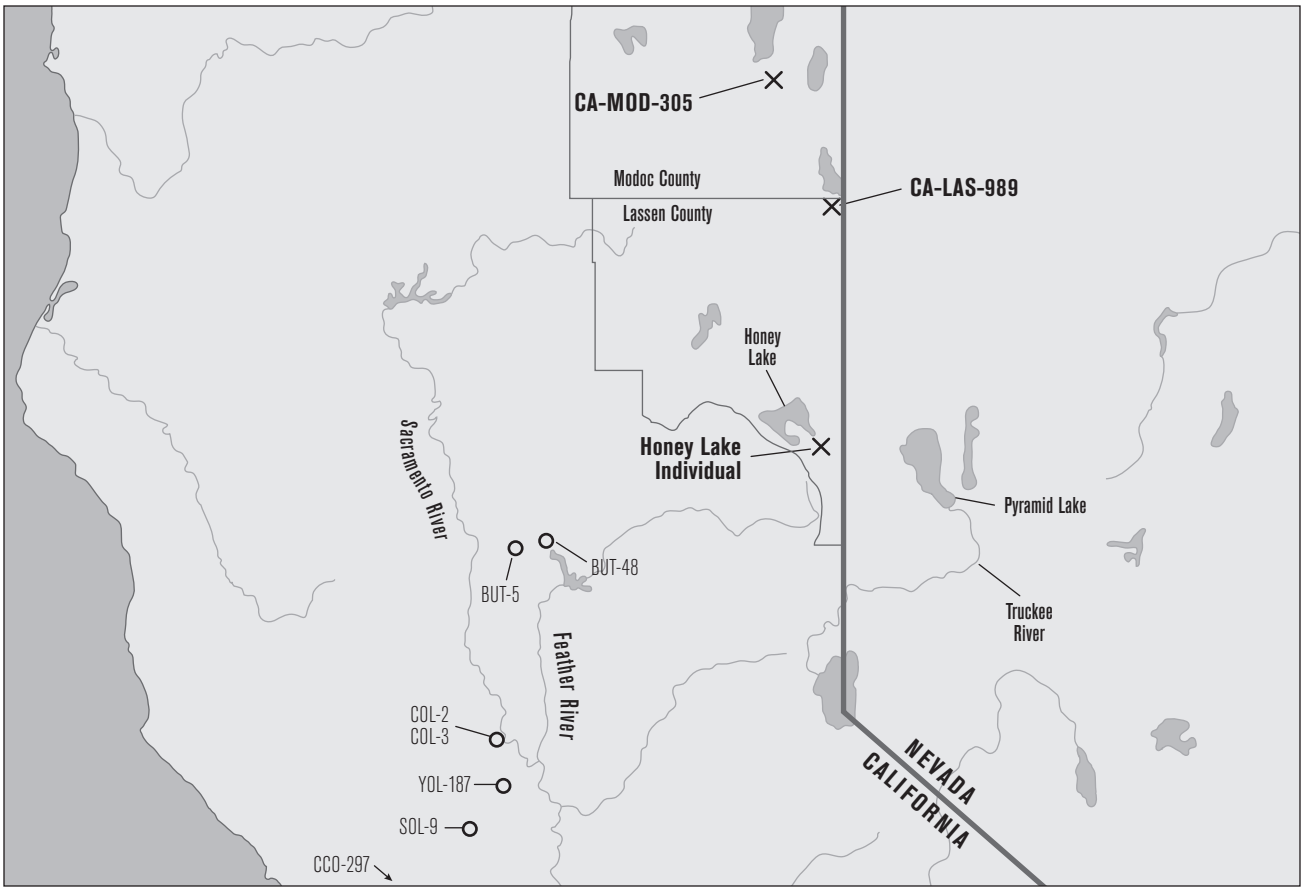

Figure 1 Map of Northern California and location of sites included in this study (X's) and locations of comparative samples (small O's).

STABLE ISOTOPE APPROACHES TO PALEOECOLOGY

Palaeoecological models commonly use stable isotope signatures in bone and teeth to reconstruct dietary and migrational behavior of target individuals or species (e.g., Bocherens et al. 1994; Cormie and Schwarcz 1994; Miller et al. 2011; Newsome et al. 2010). The rationale behind such studies is that water and dietary macronutrients are routed to sites of bone and teeth to both synthesize and repair skeletal tissues. Due to fractionation processes in environmental and biological systems, isotopes of different elements tend to become enriched or depleted relative to others (Ambrose 1991; DeNiro and Epstein 1978, 1981; O'Leary 1988; Schoeninger 1985; Schwarcz and Schoeninger 1991). Their presence in the enriched or depleted state in organisms can indicate ingestion of food or water from those sources. While some elements with more global source pools (i.e., air) are better for tracing certain aspects of diet (e.g., C, N), others have more localized source-pools in water and soils, and are more strongly tied to geography (e.g., O, S, Sr). For example, $\delta^{18}O$ in bone and teeth is strongly correlated with sources of water for an individual. While the isotopic composition of water can change from season to season and year to year, an individual that consistently drinks from the same water source should show a limited range of variation in $\delta^{18}O$ (Buzon et al. 2011; Dupras and Schwarcz 2001; Levinson et al. 1987; Luz et al. 1984; Mant et al. 2016;). By contrast, $^{87}Sr/^{86}Sr$ and $\delta^{34}S$ are more strongly tied to underlying geological formations and soils (Ericson 1985; Oelze et al. 2012; Price et al. 2000; Richards et al. 2001). These elements are absorbed by plants and passed up the food chain relatively unaltered, and as such, indicate where individuals were acquiring their food. Again, individuals consuming foods across the same geological substrates ought to show similar $^{87}Sr/^{86}Sr$ and $\delta^{34}S$ in

their skeletal tissues. In this study, we focus on isotopes of C, N, O, and S.

Palaeoecological studies tend to focus on two components of bone that are preserved in ancient samples, collagen and bioapatite. Controlled feeding experiments with non-human mammals show that collagen is synthesized in the body using dietary protein primarily. More specifically, Fernandes et al., (2012) estimate that 74% of the carbon and nitrogen in bone collagen is routed from dietary protein, with the remainder coming from lipids and carbohydrates. This suggests that isotopic values in collagen reflect mainly, though not exclusively, the sources of dietary protein. By contrast, bone bioapatite (the inorganic, mineral component of bone) is synthesized more from the whole diet (i.e., a mix of protein, lipids, and carbohydrate). Comparing isotopic values in collagen with bioapatite allows researchers to parse out the sources of different macronutrients in the diet (Froehle et al. 2010; see also Eerkens et al. 2013 for an example from California).

In humans, bone collagen and apatite are slowly repaired and updated over time, resulting in a turnover of isotopic signatures as an individual ages (Fahy et al. 2017; Sealy et al. 1995; Stout and Lueck 1995; White et al. 2012). The amount of time represented by bone tissues depends on both the age of the individual (younger individuals have more rapid turnover) and the particular bone element (denser bone turns over more slowly). By contrast, teeth form early in life, and although some tissues can backfill the pulp chamber and root canal (secondary dentin) and coat the outside of the root (cementum), the primary tissues in enamel and dentin are not remodeled or updated later in life. As a result, bone isotopes in humans tend to record dietary or geographic information for the most recent years in an individual's life, typically the last 5–20 years depending on the bone type, while teeth record such information from earlier years (birth through adolescence). Furthermore, because dental tissues grow in layers over a number of years while the tooth is forming, it is possible to isolate particular portions of a tooth to record such information over more restricted time frames. Together, analysis of teeth and bone can provide a sort of isotopic life history, or an isobiography, of an individual.

For one individual in this study, we analyzed collagen from the dentin of both a first and third molar, following the methods established in previous research in California (Eerkens et al. 2011, 2016a; Eerkens and Bartelink 2013). One half of each tooth, from the occlusal surface to the apical root tip, was isolated and sectioned into 12 serial samples. These serial samples provide a diachronic record of diet over the time period the tooth grew. For the first molar, this is from approximately age 0 through age 9.5, and for the third molar, between age 8.5 through 21.5 years (Hillson 1996). The portion of the tooth representing the earlier part of the dietary signal was not present due to extensive occlusal wear that removed the enamel and exposed the underlying dentin, common in older adult individuals before A.D. 1800. For the individual in question, the remaining dentin from the first molar represents diet from about age 1.4 years through age 9.5 years, while the third molar records diet from age 11 through age 21.5 years.

AN ISOTOPIC FOODWEB MODEL FOR NORTHEASTERN CALIFORNIA

In ecological and paleodietary studies, carbon isotopes often provide an estimate of the consumption of C_3 vs. C_4 plants. The majority of plants around the world are C_3 photosynthesizers, producing a three-carbon molecule during the fixation of atmospheric carbon. This method of photosynthesis discriminates against the heavier ^{13}C, resulting in $\delta^{13}C$ values in plants between –30‰ and –22‰. By contrast, a small number of plants produce a four-carbon molecule (C_4) and have tissues with $\delta^{13}C$ values typically between –16‰ and –10‰. While the number of C_4 photosynthesizers is low, several important crop plants, such as maize, millet, sugar cane, and sorghum, fall in this category, allowing archaeologists to estimate their importance in local diets where those foods were regularly consumed (Schwarcz and Schoeninger 1991).

In California, there are few native C_4 plants, and the majority of those were not important dietary staples prior to contact (Bartelink 2009). Instead, C_3 plants dominated the ancient human diet, leading to the expectation that people gaining a large fraction of their dietary protein from plants, or terrestrial animals that consume these plants, ought to display low $\delta^{13}C$ values. On the other hand, aquatic ecosystems can include foods that are enriched in $\delta^{13}C$. Carbon enters marine systems through exchange with atmospheric CO_2 and through photosynthesizing phytoplankton. The $\delta^{13}C$

values of marine foods typically overlap with those of C_4 plants. Note that this includes some food resources that may be acquired in non-marine settings, most notably salmon, sturgeon, and other anadromous fishes that spend significant time eating in oceans. As a result, these fishes develop a marine isotopic signature in their tissues which persists even when they migrate back to freshwater inland streams. Humans who then capture and consume these fishes subsequently incorporate that marine-derived carbon into their own skeletal tissues.

Nitrogen isotopes are strongly correlated with the trophic level of consumed foods (Schoeninger and DeNiro 1984). Nitrogen fractionates during the digestion of food, formation of urea, and synthesis of new biological tissues in animals, favoring the retention of the heavier ^{15}N isotope for the latter. As a result, $\delta^{15}N$ increases by about 3–4‰ with each trophic level. In terrestrial systems in California, there are essentially three trophic levels: plants, browsers (vegetarians), and carnivores. In aquatic environments there are more trophic levels, resulting in greater enrichment of $\delta^{15}N$ at the top of the food chain (typically in large fish, predatory birds, and aquatic mammals).

Humans are complex omnivores and use a wide range of technologies to render plants and animal products into food. As a result, it is typically not possible to pinpoint particular food items as being in or out of the diet using isotopic data alone. Instead, stable isotope data are used to estimate general classes of foods with distinctive underlying isotopic profiles, and their relative proportion in the diet of individuals.

In this study, we are interested in contrasting the importance of four general classes of food in Northeastern California: C_3 plants (represented by acorns); large herbivores (represented by antelope, deer, and elk); anadromous fishes of the Sacramento River watershed; and freshwater fishes of the Truckee River system. We assembled $\delta^{13}C$ and $\delta^{15}N$ data for these four resource groups from either published literature or our own unpublished isotopic analyses of archaeological faunal remains. We treat these four resource groups as end points for a dietary model in the region. This dietary model is highly simplified, of course, and we recognize that (1) these foods can vary in their isotopic composition depending on local ecological conditions, especially aquatic ones; (2) that people would have consumed a mix of these foods in varying proportions throughout the year; and (3) that other foods, perhaps with intermediary isotopic compositions, were also a component of the diet.

We use $\delta^{13}C$ and $\delta^{15}N$ data published by Hopkins and Ferguson (2012) on modern acorns from Yosemite National Park as representative of C_3 plant signatures. To correct for the Suess effect in modern atmospheric carbon we add 1.5‰ to the acorn $\delta^{13}C$ values to bring them into line with ancient atmospheric carbon (Keeling 1979). To represent the isotopic signature of large herbivores, we use data for tule elk (*Cervus elaphus nannodes*) published by Broughton et al. (2013) from Emeryville Shellmound (CA-ALA-309), and $\delta^{13}C$ and $\delta^{15}N$ bone collagen data on a series of antelope (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), and elk (*Cervus* sp.) samples from archaeological sites along the Feather River in Butte County (data from Morales et al. 2018). To account for isotopic differences between ungulate bone collagen and muscle meat, we subtract 2.4‰ from the bone collagen $\delta^{13}C$ values (DeNiro and Epstein 1978). We use unpublished $\delta^{13}C$ and $\delta^{15}N$ data from archaeological bones identified as chinook salmon (*Oncorhynchus tshawytscha*) from sites on the Sacramento River, and data published by Sydeman et al. (1997) on modern chinook salmon, as representative of salmon in the Sacramento River. To account for isotopic differences between bone collagen and muscle meat, we subtracted 3.7‰ from the $\delta^{13}C$ values and also correct for the Suess effect on the modern sample. Finally, we use $\delta^{13}C$ and $\delta^{15}N$ data published in Estep and Vigg (1985) from modern freshwater fish muscle, including Tahoe sucker (*Catostomus tahoensis*), Tui chub (*Gila bicolor*), Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), and Cui-ui (*Chasmistes cujads*), to represent freshwater fishes of the Truckee River system. We correct the carbon values for the Suess effect. Figure 2 plots the isotopic data for these four categories of food and thus, represents a simplified isotopic foodweb for human consumers in northeastern California.

As seen in Figure 2, the different food groups plot in distinctive regions of isotopic space. As expected, C_3 plants are systematically low in $\delta^{15}N$, but do show some variation in $\delta^{13}C$. Some of this variation in carbon may be due to differences between particular trees and access to water, as water stress is known to increase $\delta^{13}C$ in plant tissues (e.g., Arens et al. 2000; Cernusak et al. 2013; Unger

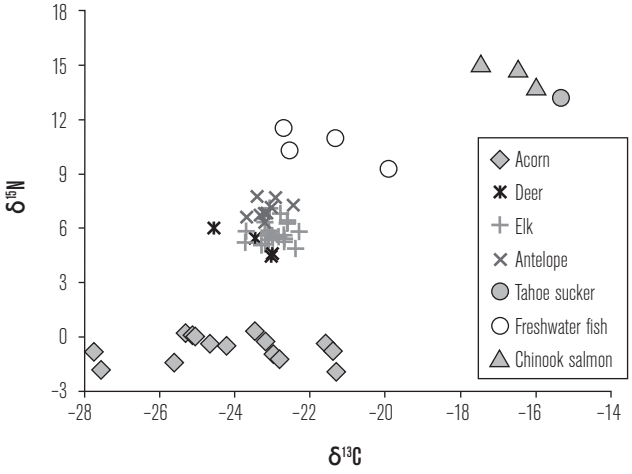

Figure 2. Simplified $\delta^{13}C$ and $\delta^{15}N$ foodweb model for northeastern California.

et al. 2010; Yakir et al. 1990). By contrast, large game animals are enriched in $\delta^{15}N$ over C_3 plants by about 4–7‰, but are also less variable in $\delta^{13}C$. Most freshwater fishes of the Truckee River system plot another 2–4‰ higher on $\delta^{15}N$ and are also slightly enriched in $\delta^{13}C$ relative to large game. One notable exception are Tahoe suckers, which are enriched even further in $\delta^{15}N$ and especially $\delta^{13}C$, and plot with the anadromous fishes of the Sacramento River. A similar effect has been noted in Lake Tahoe, where although all fishes are systematically lower in $\delta^{15}N$ and δ13C compared to fishes in the Truckee River, suckers are significantly enriched in $\delta^{13}C$ relative to pelagic species of the lake (Vander Zanden et al. 2003). Sacramento River salmon show the highest $\delta^{13}C$ and $\delta^{15}N$ values, as expected of higher-order predators from marine environments. Together, the data suggest that individuals emphasizing the consumption of foods from these particular food groups should display distinctive isotopic signatures in their own skeletal tissues.

SITES AND MATERIALS

Site CA-MOD-305, also known as the Franklin Creek site, is an open-air occupation site just south of Goose Lake. The site was excavated in 1975 as part of a U.C. Davis field school under the direction of Richard Hughes. Prior to the radiocarbon dates obtained as part of this study, little chronological information was available for the site. The site includes a moderately dense midden, including significant amounts of lithic debris, as well as fire-cracked rock, groundstone, and a range of faunal remains. One burial was encountered, but was not excavated. However, a small number of disassociated human remains (n=16) were misidentified as faunal remains in the field and were transported to the lab. These bones were later identified as human in the museum. Two fragments from different units were sampled as part of the current study (see Table 1). Based on horizontal and vertical differences in the locations of the two samples, we believe they represent remains from two different individuals, and labeled them Individual #1 and Individual #2.

Table 1

PROVENIENCE AND DESCRIPTION OF SAMPLES INCLUDED IN THIS STUDY

Site	Individual #	Element	Unit	Depth
CA-MOD-305	1	Cranium	8S 37W North	30–40 cm.
CA-MOD-305	2	Calcaneous	8S 35W	20–30 cm.
CA-LAS-989	1 (6-4303)	Right fibula	Rear Alcove 1	12–36 in.
CA-LAS-989	2 (6-4259)	Fibula	B12	30–36 in.
CA-LAS-989	3 (6-4233)	Right ulna	B10	24–30 in.
CA-LAS-989	4 (6-4312)	Right tibia	Rear Alcove 3	12–18 in.
Honey Lake	1	Left humerus, LRM1, LRM3	N/A	Unknown

Site CA-LAS-989, or the Bare Cave site (the site has also been referred to by the trinomial CA-LAS-202), is a small rockshelter overlooking Bare Creek in southern Surprise Valley. The site was excavated by Martin Baumhoff in the early 1960s as part of a U.C. Davis field school. Ten units were excavated to a maximum depth of 2 meters and revealed several natural stratigraphic layers, as well as significant quantities of chipped stone artifacts, lithic flaking debris, groundstone fragments, and faunal dietary refuse. Smaller numbers of pipes, beads, and bone tools were also recovered. Projectile point styles include Desert Side-Notched, Rosegate, Elko series, Humboldt, Gatecliff, and Northern Side-Notched, indicating a long period of use, from at least the Middle Holocene to the latest pre-contact periods in the Late Holocene (Hughes 1986). Although no intact burials were discovered, small numbers of disassociated human bone were identified. Four of these elements, chosen from different site locations and depths to increase the likelihood that each bone represented a unique individual, were included in the current analysis (Table 1).

The final set of materials are derived from a single individual, an older adult female, given to the U.C. Davis Department of Anthropology in 1974 by the U.C. Davis Police Department. The circumstance under which the Police Department acquired the remains are not well documented. The remains were collected either in Mud Flat or Herlong; however, both locations are near Honey Lake in Lassen County. For this study, a small fragment of the left humerus and the permanent lower right first (LRM1) and third molars (LRM3) were analyzed. The occlusal surfaces of both teeth were highly worn, resulting in removal of enamel and a significant portion of the early-growing dentin. We estimate that the dentin that would have formed between age 0 and approximately 1.4 years for the first molar, and 9 to 11 years for the third molar, were lost during the lifetime of the woman due to heavy occlusal wear.

METHODS

To isolate collagen for analysis, we followed a modified Longin procedure (Longin 1971) similar to that outlined in Schwarcz and Schoeninger (1991). For bone samples, approximately 1 g. of cortical bone was cleaned of any surface contamination by burring exposed surfaces with a hand-held drill and then sonicating the sample in deionized H_2O (three five-minute baths, with the dH_2O replaced after each bath). For teeth, one longitudinal half (crown to root) was cleaned in a similar manner, removing any remaining enamel and cementum. The sample was left in an open container until completely dry, then weighed and placed in a 0.5 M. hydrochloric acid (HCl) solution to demineralize. HCl was changed every other day until the sample was completely demineralized (approximately 2 weeks). The sample was then washed with deionized water and soaked in 0.125 M. NaOH (sodium hydroxide) for 24 hours to remove humic acids. Slightly acidic pH3 water was added to the vial and the sample placed in a 70°C oven to solubilize collagen. The sample was then placed in a freeze-dryer to remove all remaining water, isolating the collagen fraction.

Approximately 1 mg. of collagen is needed to simultaneously analyze carbon and nitrogen. Collagen total C, total N, $\delta^{13}C_{col}$, and $\delta^{15}N$ were measured by continuous-flow mass spectrometry on a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (IRMS) at the Stable Isotope Facility (SIF), University of California, Davis. Carbon isotopes ratios ($\delta^{13}C$) are reported expressed in per-mil notation (parts per thousand) relative to the PeeDee Belemnite standard (arbitrarily set at 0‰), while N isotope ratios ($\delta^{15}N$) are expressed against N_2 in modern atmospheric air (arbitrarily set to 0‰). Separate collagen samples were submitted to the SIF for sulfur isotopes, which were measured on an Elementar vario ISOTOPE cube interfaced to a SerCon 20-22 IRMS. Approximately 10 mg. of collagen are required to measure sulfur isotopes. Final $\delta^{34}S$ values are reported relative to the Vienna-Canyon Diablo Troilite (VCDT) standard (arbitrarily set to 0‰). The SIF reports long-term reproducibility on standards for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ as 0.2‰, 0.3‰, and 0.4‰, respectively.

Bioapatite preparation started with the same cleaned bone, which was powdered in an agate mortar and pestle. Approximately 0.04 g. of bone powder was placed in a weighed centrifuge vial. Organics were removed by adding a 1.5% sodium hypochlorite at a ratio of 0.04 ml. solution/mg. sample. After 24 hours the sample was centrifuged and the solution replaced. After a second 24 hours the solution was discarded and the sample was washed three times with dH_2O. For the next 8–12 hours the sample was placed in a diagenetic wash composed of a 1 M. acetic acid solution (at the same ratio of 0.04 ml. solution/mg. sample) which was replaced after 12 hours. The sample was then rinsed three times with dH_2O and any remaining water pipetted off. The sample was left in the container with no cap until completely dry. Apatite samples were analyzed on a GVI Optima Stable Isotope Ratio Mass Spectrometer at the Stable Isotope Lab (SIL) at University of California, Davis. The carbonate component of bone apatite was used to simultaneously measure $\delta^{13}Cap$ and $\delta^{18}O$. Long-term reproducibility for standards on the instrument is 0.1‰ for $\delta^{13}C$ and 0.2‰ for $\delta^{18}O$.

RESULTS

Table 2 presents results of the isotopic analyses of human bone. All samples were measured for $\delta^{13}C$ and $\delta^{15}N$ in collagen and $\delta^{13}C$ and $\delta^{18}O$ in apatite. C/N ratios were in the expected range for all seven samples, indicating good collagen preservation (DeNiro 1985). Only five of the

Table 2

RESULTS SHOWING BONE STABLE ISOTOPES AND RADIOCARBON DATES

Site	Indiv. #	Collagen Yield	C/N	δC_{col}	$\delta^{15}N$	$\delta^{34}S$	$\delta^{13}C_{ap}$	$\delta^{18}O_{ap}$	^{14}C Age
MOD-305	1	8.70%	3.4	–19.2	11.4		–13.3	–15.2	1,260 ± 25
MOD-305	2	12.00%	3.2	–19.6	11.4	6.3	–15.2	–10.0	1,360 ± 25
LAS-989	1 (6-4303)	6.90%	3.3	–19.3	11.3	5.5	–13.9	–9.8	7,120 ± 110
LAS-989	2 (6-4259)	n/a	3.2	–18.9	11.3		–14.9	–12.1	
LAS-989	3 (6-4233)	17.00%	3.3	–19.1	9.0	6.1	–13.6	–4.9	2,140 ± 30
LAS-989	4 (6-4312)	13.00%	3.3	–18.4	10.8	5.8	–13.2	–9.3	2,060 ± 25
Honey Lake	1	17.00%	3.2	–17.6	10.5	6.9	–13.4	–9.7	1,840 ± 20

Note: We were unable to determine collagen yield for Individual 2 at CA-LAS-989 due to a measurement error.

Table 3

$\delta^{13}C$ AND $\delta^{15}N$ VALUES IN LRM1 AND LRM3 SERIAL SAMPLES FROM HONEY LAKE WOMAN

LRM1					LRM3				
Sec#	Age	C/N	$\delta^{13}C$	$\delta^{15}N$	Sec#	Age	C/N	$\delta^{13}C$	$\delta^{15}N$
L	1.8	3.2	–18.3	14.7	L	11.8	3.2	–16.6	14.0
K	2.4	3.2	–18.3	14.6	K	12.9	3.2	–17.2	13.2
J	3.1	3.2	–17.6	13.3	J	13.6	3.2	–17.5	11.6
I	3.7	3.2	–18.0	13.1	I	14.4	3.2	–17.2	12.1
H	4.3	3.2	–18.0	13.1	H	15.1	3.2	–16.2	13.1
G	4.9	3.2	–17.8	13.2	G	15.9	3.2	–16.3	12.7
F	5.5	3.2	–18.0	13.1	F	16.6	3.2	–17.0	12.1
E	6.1	3.2	–17.6	13.2	E	17.4	3.2	–17.0	10.4
D	6.7	3.2	–16.9	13.6	D	18.1	3.2	–17.4	11.0
C	7.4	3.2	–16.3	13.6	C	18.9	3.2	–17.3	12.3
B	8.0	3.2	–15.6	13.3	B	19.6	3.2	–17.6	11.3
A	8.9	3.2	–17.2	11.5	A	20.8	3.2	–18.0	11.4

seven samples produced enough collagen by volume for $\delta^{34}S$ analysis.

AMS radiocarbon dates were obtained on collagen from six of the seven individuals. The AMS dates reveal one early Holocene date in excess of 7,000 years, with the remainder falling in the late Holocene between 2,200 and 1,200 B.P.

Table 3 presents $\delta^{13}C$ and $\delta^{15}N$ from serial samples of dentinal collagen from the woman from Honey Lake. C/N ratios were homogenous for all sections and within the accepted range for human collagen. An estimated median ontogenetic age is also given in the table for each section.

Figure 3 plots the serial samples for nitrogen (upper line; left Y-axis) and carbon (lower line; right Y-axis) across the serial samples, with age plotted on the X-axis. Each tooth crown had heavy occlusal wear that resulted in removal of earlier-growing dentine. Dotted black lines are drawn connecting the first molar series with the third molar series. As well, adult bone collagen values are plotted on the far right of the graph and are connected to the third molar serial samples with dotted lines.

The nitrogen curve in the first molar shows an expected "weaning signature," wherein $\delta^{15}N$ drops by 2–4‰ from the earliest sections into later sections, while $\delta^{13}C$ shows only minor changes. Based on the

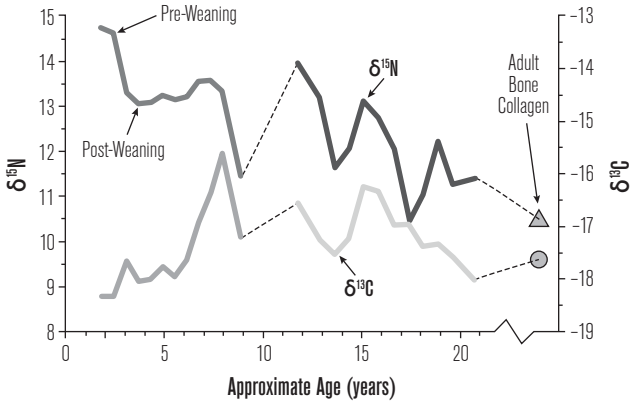

Figure 3. Serial δ13C (lower line) and δ15N (upper line) values for one individual from Honey Lake showing marked fluctuations in diet across childhood and teenage years.

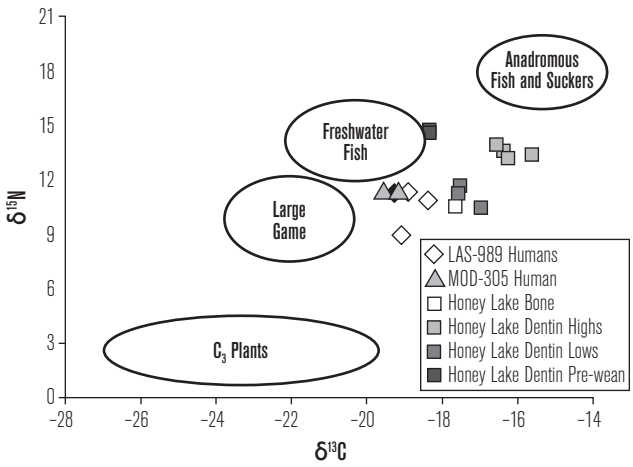

Figure 4. Comparison of human bone and dentinal collagen values relative to adjusted food group reference samples.

location of this decrease within the first molar sections, we estimate this woman was fully weaned between 3.1 and 3.7 years of age. In general, there is tremendous inter-individual and inter-site variation in the age of weaning in archaeological populations in California. The age of weaning recorded here is well within the range recorded in other pre-contact individuals we have measured in the state (Eerkens and Bartelink 2013; Eerkens et al. 2016b; Greenwald et al. 2016).

Around 6 years of age, $\delta^{15}N$ and $\delta^{13}C$ begin to co-vary and show a series of significant cyclical fluctuations that continue through the woman's teenage years. These fluctuations indicate a shifting diet with episodic and significant variations in an item high in $\delta^{15}N$ and $\delta^{13}C$, followed by periods where foods with lower isotopic values were the main source of protein. The periodicity on these fluctuations is 3–4 years.

Figure 4 plots the human $\delta^{13}C$ and $\delta^{15}N$ collagen values relative to the four food groups discussed earlier. To make the faunal data comparable to human bone collagen, we have added 1‰ to $\delta^{13}C$ and 4‰ to $\delta^{15}N$ values from those shown in Figure 2. This addition accounts for trophic level differences between the food resources themselves and the humans who would have been consuming them (Bocherens and Drucker, 2003; Schoeninger 1985; however, see O'Connell et al. 2012 who suggest a 6‰ offset for $\delta^{15}N$). In addition to bone collagen, we also plot values from the dentinal collagen of the Honey Lake woman, including her pre-weaning values, the high $\delta^{15}N$ and $\delta^{13}C$ points shown in Figure 3, and the low $\delta^{15}N$ and $\delta^{13}C$ points. As shown in Figure 4, none of the bone or dentine collagen values falls directly within one of the ellipses associated with the four food groups. As discussed below, this likely indicates a mixing of different food groups, leading to the archaeologically-observed collagen values, as would be expected of a human omnivore.

Figure 5 compares the five individuals in this study for whom we measured both $\delta^{34}S$ from collagen and $\delta^{18}O$ from apatite. As discussed earlier, these isotopic systems are better than carbon and nitrogen at tracking the geographic location of an individual. The figure compares the individuals here to individuals from a range of other archaeological sites in Central and Northern California for which we have data (see Fig. 1 for locations, except for CCO-297, which is located on San Francisco Bay off the bottom of the map). The comparison is not systematic, but is simply meant to show some of the isotopic variation across the northern part of the state. As shown, four of the five individuals from this study cluster close together in $\delta^{34}S$ and $\delta^{18}O$ isotopic space, near the bottom center of Figure 5. Individuals from BUT-4 and BUT-48 in nearby Butte County also plot in this area of the graph. One individual (#3) from LAS-989 is similar to the others for $\delta^{34}S$, but is notably higher in $\delta^{18}O$. Note specifically that the Lassen and Modoc individuals are distinct from others in Contra Costa, Yolo, Solano, and Colusa counties, to the south and west of the study area. We currently lack analogous data from humans to the north and east of the study area.

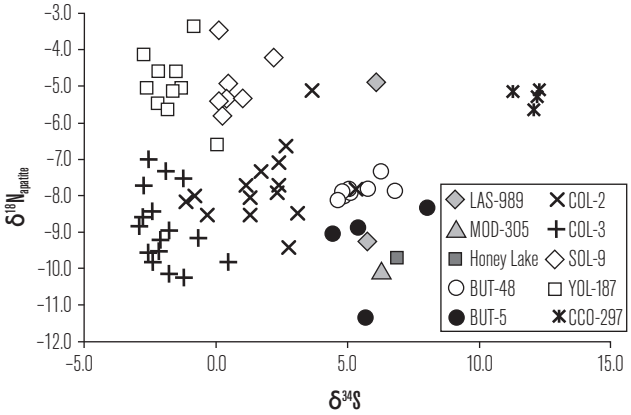

Figure 5. $\delta^{34}S$ vs. $\delta^{18}O$ in human bone for individuals in this study versus a selection of individuals from other regional sites.

DISCUSSION

Direct AMS radiocarbon dates on the majority of individuals in this study fall within the Late Holocene (ca. 2,030–1,220 cal B.P.), and more specifically within the late Elko to early Rose Springs periods (Bettinger and Taylor 1974; Heizer and Hester 1978; Thomas 1981). For LAS-989 and MOD-305, this is consistent with many of the types of projectile points recovered at the site (i.e., Elko and Rosegate).

One radiocarbon date from Bare Cave has a median calibrated age of 7,940 cal B.P. (2-sigma 8,170–7,720 cal B.P.), assuming no marine carbon is present. Even assuming 20% of the carbon in this bone collagen is from marine sources (e.g., anadromous fishes), the median calibrated date is 7,830 cal B.P. (2-sigma 8,020–7,620 cal B.P., using a marine reservoir ΔR of 265±50). To our knowledge, this is the oldest directly-dated human bone at an interior site in Northern California (e.g., Erlandson et al. 2007). Furthermore, this date confirms the antiquity of Northern Side-Notched points which are associated stratigraphically with the human bone (see Hughes 1986:208–213).

As shown in Figure 4, bone collagen $\delta^{15}N$ and $\delta^{13}C$ values from all seven individuals in this study indicate a diet that falls isotopically between a range of terrestrial foods and fish. No single food group can explain the range of $\delta^{15}N$ and $\delta^{13}C$ values we observed. For the six LAS-989 and MOD-305 individuals, a combination of C_3 plants, large game, and at least some freshwater fish is necessary to fully explain the $\delta^{15}N$ and $\delta^{13}C$ values. This is consistent with the ethnographic accounts of a highly mobile lifestyle in pursuit of seasonally-available resources that included pine nuts, acorns, game drives, and inland fishing. For the Honey Lake woman, bone collagen (particularly her $\delta^{13}C$) can only be explained by the incorporation of these foods, and by the addition of anadromous fishes or freshwater suckers. To explain the elevated levels, the protein component of her diet may have included up to 40–50% of these ^{13}C-enriched fishes. Compared to other pre-contact Californian populations, the seven Modoc and Lassen county individuals compare favorably on $\delta^{15}N$ and $\delta^{13}C$ to groups living on the Sacramento River and/or on the edges of Suisun Marsh, but are quite unlike groups living away from major rivers, those living on the Pacific coast, and those living on San Francisco Bay (cf. Eerkens et al. 2013). Isotopic values for the individuals in this study are consistent with a diet rich in fishes and both terrestrial and aquatic plants, supplemented by large game. Studies have shown that isotopic values of pine nuts are enriched in $\delta^{13}C$ (e.g., Hull et al. 2018). The inclusion of pine nuts as a staple food source in the diet of these individuals, coupled with exploitation of inland fisheries, explains the rightward shift in $\delta^{13}C$ values in isotopic space (i.e., enrichment) and similarities to higher trophic riverine signatures found along the Sacramento River.

Serial sampling from the first and third molars of the Honey Lake woman reveals additional details on diets in the region. As expected, there was a large drop in $\delta^{15}N$ combined with relatively stable $\delta^{13}C$ across the early-growing tissues of the first molar. This pattern is consistent with weaning from breastmilk (Eerkens et al. 2011). In this case, we estimate that she was weaned between 3.1 and 3.7 years of age. More surprising, however, are the large fluctuations in $\delta^{15}N$ and $\delta^{13}C$ across the later-growing sections of the first molar, and all sections of the third molar. As shown in Figure 3, notable increases in $\delta^{15}N$ and $\delta^{13}C$ with a periodicity of approximately 3–4 years are visible. Relative to the low points, the high $\delta^{15}N$ and $\delta^{13}C$ values plot close to the anadromous/sucker food group.

We interpret this fluctuating curve as a signal of seasonal and episodic pulses of fish protein in her diet. Honey Lake is an internally-draining basin, is seasonally dry, and does not support an extensive fishery. In light of the isotopic data from fish, we see two possibilities.

First, the basin is not far from the upper reaches of the Sacramento River watershed. Tributaries of the Northern and Middle forks of the Feather River lie less than 40 km. west of where the woman was buried. She could have made periodic residential moves to these areas to harvest and consume Chinook salmon during certain years. Alternatively, the shores of Pyramid Lake are less than 40 km. to the east of where the woman was found. It is possible that she periodically visited Pyramid Lake or the Truckee River to harvest Tahoe suckers during certain years. Ethnographically, peoples living in this area would fish at Lake Tahoe in the spring and summer, travel west in the fall for acorn gathering, and winter in the mountains to harvest their most economically important food, pine nuts (Lowie 1939). In years when the pine nut harvest failed, they returned to lakes to fish (Freed 1960).

Our sampling approach did not allow us to reconstruct seasonality information that could be correlated to these peaks and valleys in $\delta^{15}N$ and $\delta^{13}C$. However, future studies and sampling of teeth from this or additional individuals in the region might allow cross-correlation of these dietary isotopic systems (carbon and nitrogen), with $\delta^{18}O$ or other isotopic systems that are more closely tied to seasons of the year. For example, pairing $\delta^{13}C$ with $\delta^{18}O$ across serial samples in the enamel or dentine portions of teeth could provide additional information linking diet to season (e.g., see Eerkens et al. 2016b).

The 3–4 year cyclical pattern is particularly interesting from a life-history perspective. We see three possible explanations for this pattern. First, it is possible that individuals in this society were involved in a cyclical pattern of feasting at different villages (i.e., a fiesta system). The cyclical pattern in her isotopes starting around age 7 may reflect seasonal visits to a village close to a productive salmon or sucker fishing spot. This particular village may have hosted such a feast approximately one in every three to four years. Younger children under age 7 years may not have been able to participate in such events, especially if they involved extensive walking, thus explaining the lack of such a cyclical pattern in her first molar. As well, the lower $\delta^{13}C$ in her bone collagen is consistent with more limited residential mobility during her later adult years, as she aged and stayed closer to the Honey Lake region.

Second, it is possible that staple resource productivity (i.e., pine nuts or salmon/sucker) waxed and waned in local environments. As part of a residentially-mobile settlement strategy, it is possible that this woman spent certain years near productive fisheries consuming salmon and/or suckers, but ate fewer fish in other years when staple foods like pine nuts were more bountiful. Alternatively, fish may have been a fallback food resource only exploited when pine nuts and other more local resources failed, leading to some cyclicity in the stable isotope signature. In any case, ethnographic accounts indicate that only able-bodied men and women would travel for fishing expeditions (Freed 1960). This line of reasoning could also explain why the woman lacks a cyclical pattern in her first molar (as above, she was too young to walk the long distance to the fishing locale), and why the bone $\delta^{13}C$ was low (as above, in her old age she stopped visiting the fishing locale). In this regard, it is intriguing that 3–4 years coincides with the average life cycle of the Chinook salmon (Sturrock et al. 2015; Williams 2006; Willmes et al. 2018). There are events (drought, floods, temperature changes, etc.) that happen at multiple scales from global to the individual stream level that affect salmon abundance in California streams (e.g., Brands and McLain 2001). We are unaware of ethnographic accounts or ecological data indicating that spawning grounds were only used by particular cohorts of salmon (i.e., that particular spawning grounds were only productive every third or fourth year). However, if such a pattern existed in pre-contact times, it is possible that the woman was exploiting these productive spawning grounds only during certain years when a particular cohort returned to spawn.

Third, 3–4 years is also the duration of birth spacing among natural-fertility populations (Howie and McNeilly 1982; Jones 1986). It is possible that the group to which this woman belonged normally ate fish on an annual basis, but that women abstained from these foods during pregnancy and/or early lactation. That this woman, herself, was weaned around 3.5 years of age is also in line with such an interpretation. Indeed, the slight increase in $\delta^{13}C$ in her first molar between the age of 2.4 to 3.1 years, just before she was fully weaned, would be consistent with her mother starting to eat more ^{13}C-enriched fish during the final stages of weaning. On the other hand, because the first decrease in $\delta^{13}C$ seems to happen around 9 years of age, this would imply that the Honey Lake woman had already become pregnant around this age or had begun

menses. Ethnographic accounts of the Washo indicate that a girl's puberty rite included abstaining from meat and fish for one month (Freed 1960). This explanation also does not account for why her bone collagen $\delta^{13}C$ is not enriched, as the woman should have resumed consumption of higher levels of fish after her child-rearing years. We believe this last scenario is less likely.

While $\delta^{15}N$ and $\delta^{13}C$ inform on paleodiet, $\delta^{18}O$ and $\delta^{34}S$ in bone are more strongly tied to the region in which an individual resides. The five individuals measured for both these isotopic systems show a narrow range of variation in $\delta^{34}S$, suggesting that they all lived in a similar geographic region during the time bone collagen tissues formed. Four of the five also show tightly constrained $\delta^{18}O$ in the –9‰ to –10‰ range, consistent with what would be expected of surface waters in northeastern California (Good et al. 2014; Kendall and Coplen 2001). One individual from Bare Cave (Individual #3), however, measured significantly lighter for $\delta^{18}O$ at –4.9‰, closer to what would be expected for an individual living further west; e.g., in the Sacramento Valley. It is possible this person was living during a window of time when $\delta^{18}O$ in surface waters was elevated (i.e., during a particularly wet period), or was obtaining water from a different location than the other individuals at Bare Cave, such as from groundwater or a natural spring. Alternatively, this person could have been a recent immigrant to the site from a location to the west but with similar underlying sedimentary $\delta^{34}S$. For example, our data from several pre-contact individuals buried in Butte County show slightly enriched $\delta^{18}O$ (ca., –7.5‰ to –9‰) but overlapping $\delta^{34}S$.

CONCLUSIONS

Stable isotope analyses of human remains in northeastern California provide new insights into diet and mobility at the individual level. The sample size is too small to make broad generalizations about diachronic patterns; however, the data do not reveal any marked differences in diet, as measured by $\delta^{15}N$ and $\delta^{13}C$ in bone collagen, from the early Holocene sample to the late Holocene. Instead, the one 7,800-year-old sample falls into the same general region of isotopic space as those dating between 2,200 and 1,200 years ago, indicating a similar diet in overall composition.

Prior to conducting these analyses, we had expected plants and large game animals to dominate the diets of individuals at these sites. Indeed, groundstone, projectile points, and animal bone were common midden constituents at LAS-989 and MOD-305, indicating the importance of these foods in local diets. Less expected was the importance of fish, as revealed by the stable isotope data. Fish bone and fishing tools are less well represented within these sites. In hindsight, much of this may be a sampling bias resulting from excavation techniques used in the 1960s and 70s, in that most fish bone will fall through 1/4-inch and even 1/8-inch mesh screens. Likewise, if nets were used to capture fish, this technology will not preserve under most archaeological conditions. Flotation and the sorting of micromaterials in the heavy fractions was also uncommon in the 60s and 70s and was not employed at these sites. In this respect, stable isotope analyses can provide important complementary data on diet, and furnish an independent line of evidence at the individual scale.

This study also points out the value of microsampling teeth for stable isotope analysis. While bone offers insight into diet over a 5–15 year period, we can gain insight into diet and dietary changes over much shorter intervals within the lifetime of an individual by virtue of the fact that teeth do not remodel. The age range for dental studies is limited to the first two decades of life, but as revealed in the case of the Honey Lake woman, a number of interesting dietary changes are evident within this window of time. Typically these dietary changes will include weaning, a unique early childhood period, and then later stability as an adult establishes a more permanent place of residence. In the case of the Honey Lake woman, however, we were able to document cyclical shifts between different food resources and provide new data to test hypotheses concerning ancient settlement patterns and/or life history strategies (e.g., food taboos during pregnancy). We believe these fine-scaled diachronic perspectives on diet and/or mobility will provide archaeologists with a range of novel data sets with which to examine ancient human behaviors.

Finally, we emphasize the value of older archaeological collections, and the importance of curation for future studies (e.g., Bartelink 2009; Eerkens et al. 2013). As shown in this study, we were able to generate a range of insights, some expected and some unexpected,

using existing and curated collections. As new methods are developed, typically outside of archaeology first, and only later applied within our discipline, there is tremendous value in analyzing collections for which a range of other contextual information is already available (e.g., stratigraphy, radiocarbon dates, faunal analyses, etc.). Without such existing collections, we need to excavate or generate new materials in order to apply a new technique, which will then also require the generation of new contextual information. Together, this increases the amount of time and money spent, increases impacts to a non-renewable archaeological record, and ultimately limits the reach and impact of our research to members of the public and ancestral communities. There are some short-term benefits to the reburial of artifacts immediately after lab work is completed in order to mitigate the archaeological "curation crisis" (Bawaya 2007; Kersel 2015), or long-term positive collaborative advantages to non-collection field methods (e.g., "catch and release;" see Gonzalez 2016; Lightfoot 2008). At the same time, as we show, there are also many long-term benefits for archaeology as a discipline when materials are curated in accessible and research-oriented museum collections.

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