STABLE ISOTOPIC ANALYSIS AT THE ANCESTRAL OHLONE SITE OF *YAKMUY ‘OOYÁKMA-TKA* (“PLACE OF THE EAST RIDGE SITE”): A COMPARATIVE STUDY OF “PREHISTORIC” DIETARY VARIATION

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We examine how Late Holocene people living at the ancestral Ohlone site of Yakmuy ‘Ooyákma-tka (“Place of the East Ridge Site” [CA-SCL-215]) interacted with their environment based on the foods they consumed. We examine dietary variation among 32 individuals buried at the site, located within the current city of San Jose. Radiocarbon dates indicate that Yakmuy ‘Ooyákma-tka spans the M4 phase of the Middle Period through the first half of the Middle to Late Period Transition (870 and 1170 ACE). This study examines carbon and nitrogen isotopes to provide insight into dietary variation, focusing especially on differences by sex and age. We show that Yakmuy ‘Ooyákma-tka inhabitants consumed mainly low trophic level resources, consistent with an almost entirely vegetarian based diet. Dietary variation among males and females follows a distinct life history pattern wherein dietary proteins increased markedly in females during their reproductive years and declined in their older years.

The San Francisco Bay Area was densely populated during the Late Holocene (ca. 3,000-200 cal BP). Because of construction projects and loss of native lands, many Ohlone burial grounds and spiritual sites have been disturbed and/or removed. The Ohlone *Yakmuy ‘Ooyákma-tka* site (CA-SCL-215; Figure 1), located in the Santa Clara Valley, was excavated due to a gated community housing development expansion. The Muwekma Ohlone are a previously federally recognized tribe affiliated with the site (Arellano et al. 2021; Field 1992; Milliken 2009). Excavations at this site took place under the direction of the Muwekma Ohlone Tribe, the State-assigned Most Likely Descendant Tribe (MLD). Preliminary osteological analysis was conducted by San Jose State University graduate students and Muwekma field osteologists. The dentition

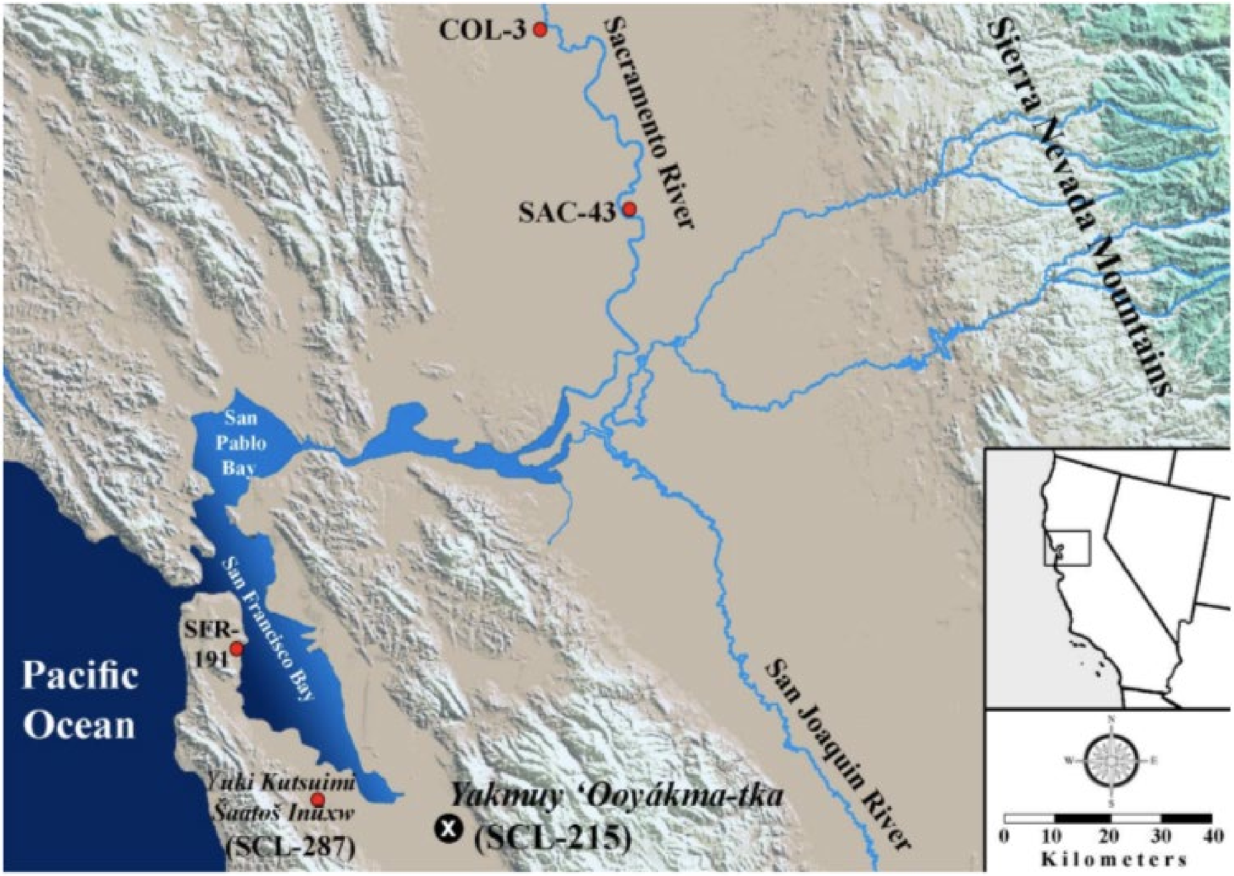

Figure 1. Map showing the location of Yakmuy 'Ooyákma-tka (CA-SCL-215) (from Eerkens et al. 2022).

of the burials was analyzed by Dave Grant from D&D Osteological Services in San Jose. Burial associations and faunal remains were revealed with some of the recovered burials. Radiocarbon dates place the site within the Middle to Late Period Transition of Central California chronology (1,300-1,000 cal BP; see Groza et al. 2011 [Dating Scheme D2]). For the current research, we focus on stable carbon and nitrogen isotope analysis of human bones and teeth to reconstruct adult and juvenile dietary patterns at the site.

A SANTA CLARA VALLEY ANCESTRAL OHLONE PALEO-MENU

The Santa Clara Valley is home to a wide variety of plants and animals, terrestrial and aquatic, many of which were economically important resources to precontact Ohlone. Terrestrial plant resources include acorns from coast live oak (*Quercus agrifolia*), tan oak (*Notholithocarpus densiflorus*), manzanita berry (*Arctostaphylos glauca*), nutsedge (*Cyperus rotundus*), common tule (*Schoenoplectus acutus)*, cluster-lilies (*brodiaea*), and yampah (*Perideridia*), among others. Terrestrial mammalian resources include elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), mule deer (*Odocoileus hemionus*), bobcat (*Lynx rufus*), raccoon (*Procyon lotor*), brush rabbit (*Sylvilagus bachmani*), and coyote (*Canis latrans*). Although the site is in the South Bay, individuals may have had intermittent access to bay resources such as marine mammals, marine and estuarine fishes, invertebrates, birds, and shellfish.

BACKGROUND AND SITE INFORMATION

Excavations at *Yakmuy 'Ooyákma-tka* resulted in the recovery of 22 Ohlone burials representing 30 individuals and partial remains recovered from non-grave contexts. The total sample represents 32 individuals, 16 of which had associated dentition (Eerkens et al. 2022). The most probable cause of commingled burials and remains from non-grave contexts at the site is disturbance from mechanical equipment prior to archaeological recordation. When possible, the archaeological team provided data on burial positions (flexed vs. extended), orientation as measured at the spinal column, as well as any associated grave goods determined to be connected to a defined burial. Data on the burial population are reported in Table 1.

Sex estimation was conducted using several methods (pelvis, skull, and long bone measurements), depending on which skeletal elements were available. Six of the individuals were sexed as female and ten as male. Sex could not be estimated for the remainder of the sample due to the absence of diagnostic skeletal elements (DeOrnellas and Grant 2019) or because the remains were juvenile. Age at death was estimated using several different criteria, including the pubic symphysis, auricular surface, cranial sutures, epiphyseal union, and dentition.

This article examines dietary variation within *Yakmuy 'Ooyákma-tka*, including variation by sex and age. Stable carbon and nitrogen isotopes of human bone and dentinal collagen were used to reconstruct diet, including breastfeeding and weaning patterns. Previous research on another ancestral Muwekma heritage site in the Santa Clara Valley (Yukisma Mound [CA-SCL-38]) found that most precontact Ohlone individuals consumed terrestrial resources and that children were typically weaned between 1.5 and 2.0 years of age (Gardner et al. 2011, 2018). The study also found that complete cessation of breastmilk occurred by 3 to 3.5 years of age. We also compare dietary patterns between *Yakmuy 'Ooyákma-tka* and Yukisma Mound.

Stable isotope data provide unique insight on native uses of the landscape, including information on the types of resources consumed and the ecological zones accessed. These data provide information that helps link the Ohlone peoples to their native landscapes and demonstrate ancient dietary practices, including both cultural changes and continuity through time. This is an important consideration, as the Ohlone are no longer federally recognized. For these reasons, the Muwekma Ohlone gave permission to conduct this research and to serve as research collaborators.

RESEARCH METHODS

The bone samples for this project were prepared at the Stable Isotope Preparation Lab (SIPL) at California State University, Chico. The SIPL prepared the samples for isotopic analysis of bone collagen and bioapatite (Table 2). All samples were mechanically cleaned using a diamond studded rotary drill and sonicated using DH_2O and 190+ proof ethanol. Once we removed trabecular bone and any dirt, we began chemical processing.

For the collagen preparation, we first soaked the samples in a 0.25M hydrochloric acid solution to demineralize, followed by a 24 hour 0.125M sodium hydroxide solution treatment to remove humics and other contaminants from the burial environment. Then we solubilized the sample pseudomorphs in $pH \approx 3$ water for three 24-hour cycles. After the collagen solubilization and extraction were complete, the liquid collagen was frozen and then freeze-dried for 24 hours. The collagen samples were submitted to the U.C. Davis Stable

Table 1. Demographic Information, Mortuary Data, and Elements Analyzed for Individuals from Yakmuy ‘Ooyákma-tka Included in this Study.

Individual	**Sex**	**Age**	**Position**	**Orientation**	**Grave Goods**	**Elements Analyzed**
1A	Female	40+ years	Indet.	Indet.	--	Mandible, LLM1, LLM3
2	Indet.	Indet.	Seated	38	--	Long bone fragment
3	Indet.	Indet.	Indet.	Indet.	--	Femur fragment
4	Indet.	40+ years	Flexed	0	--	Fibula LLM1, LLM2
5	Indet.	6-9 years	Indet.	Indet.	--	Mandible and Femur
6A	Indet.	3-5 years	Indet.	Indet.	--	Mandible
6B	Indet.	0-3 years	Indet.	Indet.	--	Cranium and Rib
6C	Indet.	Juvenile	Indet.	Indet.	--	Cranium
7	Female	40+ years	Indet.	Indet.	--	Mandible, ULM1, LLM3
8	Male	30-39 years	Flexed	355	--	Mandible, LLM1
9	Male	20-29 years	Flexed	180	--	Mandible LRM1, URM3
10	Female	Adult	Flexed	Indet.	--	Humerus
11	Male	30-39 years	Flexed	180	2 G2a beads; 18 Abalone	Fibula, ULM1, URM3
12	Male	30-39 years	Flexed	240	--	Mandible LLM1, LLM3
13	Female	40+ years	Flexed	Indet.	--	ULM1, Unsided M3
14A	Male	20-30 years	FD Ext.	270	5 G2 beads	Mandible, LLM1, LLM3
14B	Male	25-34 years	FD Ext.	270	--	Mandible, LLM1, LLM3
15	Female	40+ years	Flexed	355	8 G-series beads	Mandible, LRM1, LRM3
16	Male	55+ years	Flexed	220	--	Mandible, ULM1
17	Female	30-39 years	Indet.	Indet.	2 Dart points	Maxilla, ULM1, ULM3
18	Male	40+ years	Flexed	225	--	Mandible, LLM1, ULM3
19A	Indet.	40+ years	Indet.	Indet.	--	Lower Long Bone
19B	Indet.	Indet.	Indet.	Indet.	--	Lower Long Bone
20	Male	30-39 years	Flexed	290	--	Rib, LRM1, LLM3
21	Male	30-39 years	Flexed	270	--	Rib, URM3
22	Indet.	Newborn	Indet.	Indet.	--	Rib
ISO10/	Indet.	Adult	Indet.	Indet.	--	Humerus
ISO1	Indet.	Adult	Indet.	Indet.	--	Ulna
ISO2	Indet.	Adult	Indet.	Indet.	--	Long Bone
ISO3	Indet.	Adult	Indet.	Indet.	--	Femur
ISO4	Indet.	Adult	Indet.	Indet.	--	Cranium
ISO8	Indet.	Adult	Indet.	Indet.	--	Long Bone
ISO9	Indet.	Juvenile	Indet.	Indet.	--	Humerus

Note: ISO = isolated element; FD Ext. = face down extended; Indet. = indeterminate.

Isotope Facility for isotope analysis. The δ^{13}C and δ^{15}N values were measured on a PDZ Europa ANCAGSL elemental analyzer, interfaced to a PDX Europa 20–20 isotope ratio mass spectrometer (long-term reference precision ±0.2‰ for δ^{13}C and ±0.3‰ for δ^{15}N). All C/N ratios fell between 2.9 and 3.6, reflecting good quality collagen (DeNiro 1985). Collagen from eight burials was also submitted to DirectAMS in Bothell, Washington, for radiocarbon dating.

For the bioapatite protocol, the cleaned bone samples were powderized using a M400 mixer mill. The powder was homogenized by being passed through a 600-micron screen. The powdered samples were combined with a 30% hydrogen peroxide solution to remove organic materials followed by a 1M buffered acetic acid treatment to remove contaminants. The processed bioapatite was sent to the University of Wyoming Stable Isotope Facility. δ^{13}C was measured using a Thermo Gasbench coupled with a Thermo Delta.

Table 2. Bone Collagen $\delta^{13}C$ and $\delta^{15}N$ Values for Individuals from Yakmuy ‘Ooyákma-tka.

Burial ID	**$\delta^{13}C_{col}$**	**$\delta^{15}N$**	**C/N**	**$\delta^{13}C_{ap}$**	**% Marine**	**AMS BP**	**Median calib AMS (95% CI)**
1A	-19.3	6.9	3.3	-14.5	14	1,243 ± 20	AD 934 (776-1010)
2	--	--	--	-11.7	n/a	--	--
3	-19.5	6.6	3.3	-11.5	13	--	--
4	-20.1	6.9	3.3	-12.9	9	1,158 ± 20	AD 971 (894-1022)
5	-18.3	9.1	3.3	-14.1	20	--	--
6A	-19.3	6.3	3.3	-12.3	14	1,009 ± 21	AD 1171 (1046-1225)
6B	-19.3	7.6	3.3	-12.7	14	--	--
6C	-19.4	7.0	3.3	-13.2	13	--	--
7	-19.4	6.6	3.3	-14.9	13	1,133 ± 20	AD 1019 (977-1150)
8	-19.7	7.1	3.3	-13.8	11	--	--
9	-19.5	7.5	3.3	-14.6	13	1,093 ± 29	AD 1087 (995-1158)
10	-19.7	7.2	3.3	-12.6	11	--	--
11	-19.5	7.5	3.3	-14.2	13	--	--
12	-20.0	7.9	3.3	-14.9	9	1,185 ± 20	AD 994 (886-1009)
13	-19.2	7.0	3.2	-15.1	14	--	--
14A	-19.2	7.0	3.3	-14.3	14	1,210 ± 25	AD 959 (891-1021)
14B	-19.9	6.9	3.3	-14.9	10	--	--
15	-19.9	6.2	3.4	-14.6	10	1,130 ± 30	AD 1003 (894-1119)
16	-19.2	7.6	3.3	-13.9	14		
17	-19.3	8.3	3.3	-13.6	14	1,260 ± 30	AD 919 (775-993)
18	-19.7	7.4	3.3	-14.4	12	1,265 ± 23	AD 883 (775-977)
19A	-19.1	7.6	3.3	-12.5	15	--	--
19B	-19.3	7.7	3.3	-13.3	14	--	--
20	-19.1	7.9	3.2	-14.4	15	1,186 ± 20	AD 996 (896-1034)
21	-19.4	8.5	3.3	-14.5	13	1,090 ± 19	AD 1089 (1021-1156)
22	-19.0	7.4	3.3	-13.8	16	--	--
ISO10/11	-20.2	6.2	3.2	-14.0	8	--	--
ISO1	-19.6	7.6	3.3	-14.2	12	--	--
ISO2	-19.4	7.9	3.3	-13.7	13	--	--
ISO3	-19.7	7.1	3.3	-13.5	11	--	--
ISO4	-19.4	7.6	3.3	-12.8	13	--	--
ISO8	-19.6	7.3	3.3	-13.2	12	--	--
ISO9	-18.9	7.7	3.3	-14.4	16	--	--

Note: ISO = isolated element; FD Ext. = face down extended; Indet. = indeterminate.

The dentin was prepared and analyzed at the University of California, Davis, following methods described in Eerkens et al. (2011). To reconstruct the approximate age at which each dentin layer was formed, the teeth were initially measured “from the occlusal surface to the dentin-enamel junction (DEJ), cement-enamel junction (CEJ), and apical root tip (ART)” (Eerkens et al. 2022).

RESULTS

Overall, the isotopic data show notably low $\delta^{13}C$ and especially low $\delta^{15}N$ values. This reflects a dietary emphasis on low trophic-level foods, such as plants, within the diets of ancestral Ohlone at this site (Eerkens et al. 2022). Low $\delta^{13}C$ values are consistent with terrestrial diets with little input from marine resources. The data are consistent with a predominantly vegetarian diet with a small contribution of animal protein, including shellfish. Plants, such as acorns, geophytes, and small seeds of annual plants, likely played a major role in the diets of individuals at *Yakmuy ‘Ooyákma-tka*. This is consistent with ethnographic and archaeological data indicating Ohlone diets were rich in these plant resources (Margolin 1978; Milliken 2009).

We ran a non-parametric Mann-Whitney U test to see if there were sex differences (n = 16) in diet and a Kruskal-Wallis test to evaluate any dietary patterns by age among adult individuals only (n = 17) from bone collagen and bone bioapatite. Figure 2 plots δ^{13}C and δ^{15}N values for the sexed burials. Sex differences were not statistically significant for collagen δ^{13}C and δ^{15}N or bioapatite δ^{13}C ($p > 0.05$). Figure 3 plots δ^{13}C and δ^{15}N values for the adult burials with age at death information. For age, we also found no statistically significant differences among adults 20-29, 30-39, and 40+ years ($p > 0.05$). While there were no significant dietary differences by sex and age, the sample size is small and unlikely to be representative of the entire population.

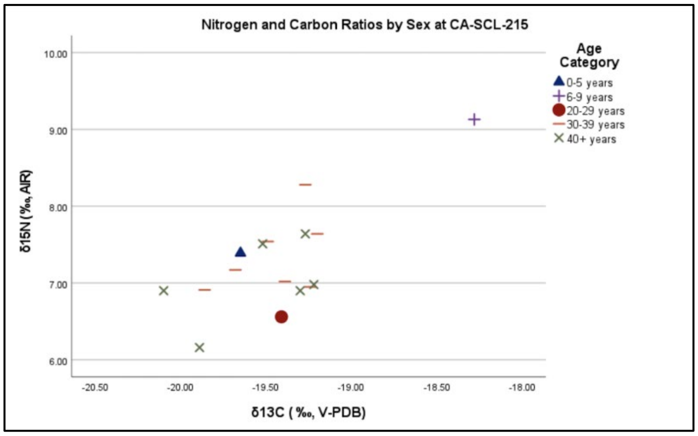

Figure 2. Biological sex group comparison of δ^{13}C and δ^{15}N at CA-SCL-215.

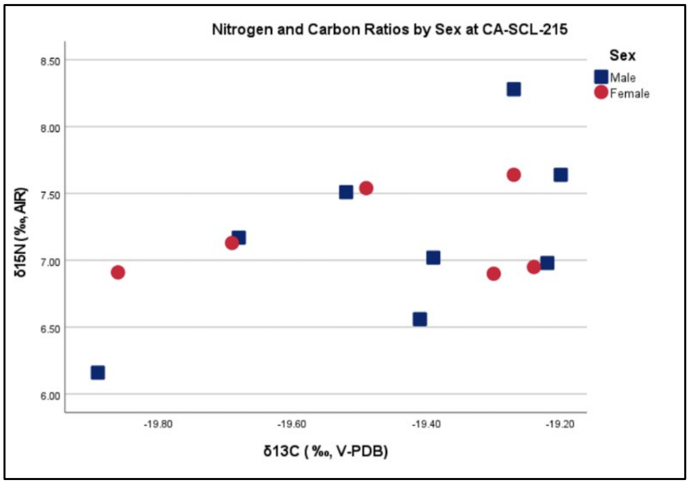

Figure 3. Age group comparison for δ^{13}C and δ^{15}N at CA-SCL-215.

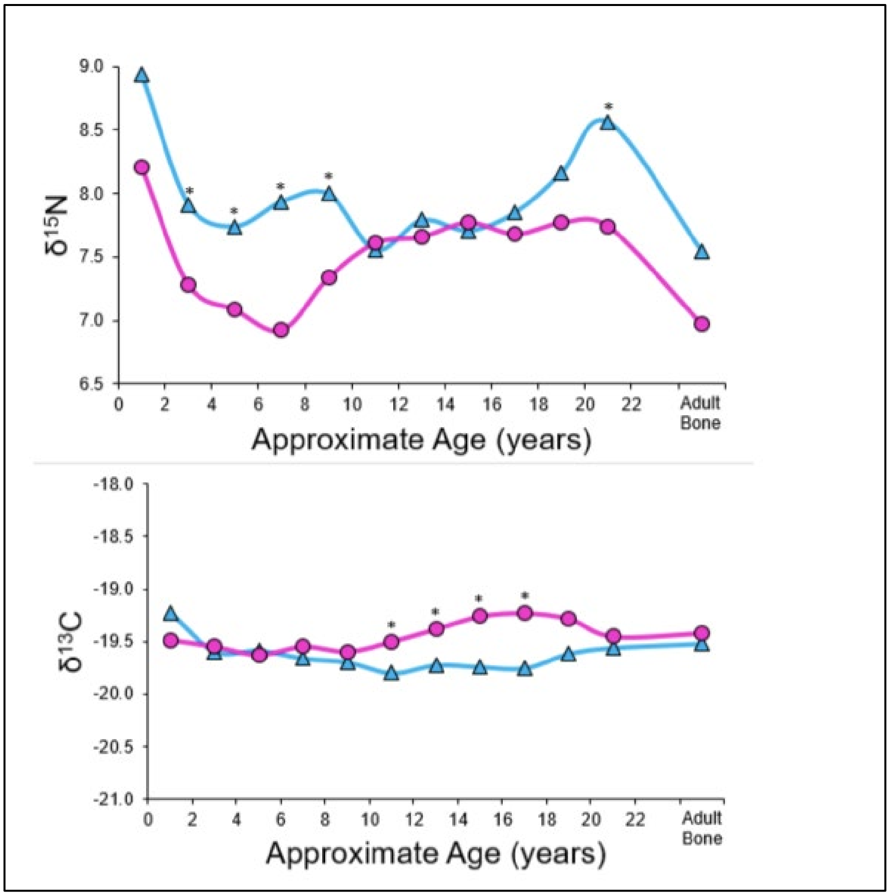

Figure 4. Reconstructed sex-biased dietary life histories for males versus females at Yakmuy 'Ooyákma-tka. P-values less than 0.05 are indicated with a ∗ symbol.

Isotopic values from the serial dentin samples at this site indicate interesting life-history patterns within this ancestral Ohlone population. Figure 4 represents the typical pattern of isotopic life history for males and females at CA-SCL-215. Univariate *t*-tests (2-tailed, unequal variance) were used to compare δ^{13}C and δ^{15}N values for different age increments sampled (Eerkens et al. 2022). The results suggest fluctuations in both male and female δ^{15}N values, most notably females, while δ^{13}C values were relatively consistent across the growth and development period. Statistical comparisons by sex revealed significant differences between ages 11-17 for δ^{13}C, and between ages 2-8 and age 21 years for δ^{15}N ($p < 0.05$).

Figure 5 plots the life history isotope data for a female (Burial 1A) and male (Burial 20) individual. The plots highlight the weaning process, weaning completion, and diet extending into adulthood. The results parallel those of Figure 4. Elevated δ^{15}N values can be seen in the earliest forming dentin of the first molar for both individuals. This is consistent with the timing of when a breastfeeding signature would be expected, since δ^{15}N values peak in the earliest forming tissues (i.e., samples taken from the crown; Eerkens et al. 2022). Infants who are breastfeeding will look isotopically one trophic level above their mother (Beaumont et al. 2013, 2015; Craig-Atkins et al. 2018; Eerkens and Bartelink 2013; Eerkens et al. 2011).

Upon weaning, which is estimated to have occurred between the ages of 2.5 and 3.5 among the Muwekma, the δ^{15}N values tend to drop to the local minimum. Following the weaning process, low δ^{15}N

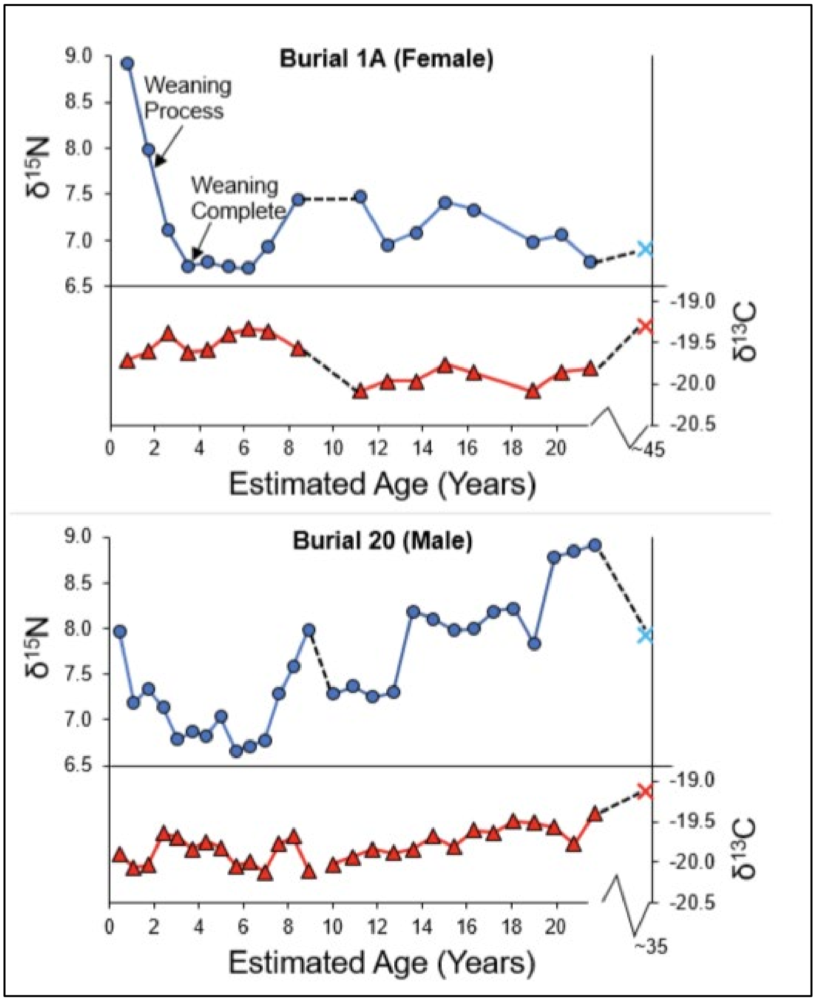

Figure 5. Example dietary life histories for two individuals from Yakmuy 'Ooyákma-tka (Eerkens et al. 2022). Age-controlled δ^{15}N values are plotted along the left y-axis). δ^{15}N values are plotted along the right y-axis.

values (< 7.0‰) are seen in both individuals until about age six. These values then increase in the later portion of this first decade of life. Eerkens et al. (2022) provide a summary of the data, noting a further increase of these δ^{15}N values during the second decade or teenage years. This increase is most prominent in the male example which reaches values even above the pre-weaning levels in the late teenage years and early 20s. The δ^{15}N values then drop in later adulthood based on the bone collagen data (Eerkens et al. 2022). The δ^{13}C values show little variation (< 1.0‰) for both individuals. The variance in both δ^{15}N and δ^{15}N can be seen in more detail below, broken down into 3 decades of life for the whole sample pool.

First, in the initial decade of life, the peak in δ^{15}N values noted above is consistent with an individual whose dietary protein is predominantly sourced from breastmilk shortly after birth. Following this, values drop approximately 1.4‰ and remain low throughout that first decade. Within this sequence, male δ^{15}N values tend to be significantly elevated compared to females with approximately 0.6-1.0‰ differentiating them. To compare further, male δ^{13}C values overlap with females with slight fluctuations, such as a slightly higher δ^{13}C in males within earliest forming dentin, suggesting that young boys typically consumed greater proportions of higher trophic level resources, such as meat, while young girls tended to consume more plant-based foods throughout this time (Eerkens et al. 2022).

Similar patterns have been documented at other sites in the area, such as CA-CCO-548 (Eerkens and Bartelink 2013). Eerkens et al. (2022) suggested that the male-female δ^{15}N offset in childhood, as based on the first molar serial sequence, may reflect enculturation practices within the site. Young boys may have been in training to become effective hunters, and as a result would have spent more time with adult male relatives, where they consumed greater amounts of meat (Eerkens et al. 2022). On the other hand, young girls were in the process of learning to become effective gatherers, and likely spent much of their time with adult female relatives, consuming food while gathering. Many of these gathered foods may have included small seeds from annual plants including grasses, acorns, and root foods (Eerkens et al. 2022). This could have led to the slight sex-based differences in isotopic values in their dentinal tissues.

For individuals who survived through the second decade of life at this site, the opposite trend can be seen in the third molar serial sequences (Eerkens et al. 2022). During this decade of life, δ^{15}N values converge for males and females. This indicates that both biological sexes shared a similar trophic position throughout the second decade of life. The higher δ^{15}N values in females, as seen in Figure 4, suggest they had greater access to meat during their second decade compared to their first. The converging sex-based values may reflect greater intra-household sharing of foods, possibly between newly established or married couples (Eerkens et al. 2022). This equaling out of trophic levels could be the result of protein obtained from "spouses, the community at large, or through their own hunting activities" (Eerkens et al. 2022). This is a meaningful change for females who are beginning to enter their reproductive and breastfeeding years.

On the other hand, δ^{13}C values begin to diverge between male and females around years 10 and 18 in life. Once again, the female diet shows an increase, this time by 0.2-0.5‰. At the same time, male δ^{13}C values are more parallel to earlier childhood years. Diverging δ^{13}C values may be indicative of maintained sex-biased diets during late adolescence (Eerkens et al. 2022). Higher δ^{13}C values are consistent with greater amounts of marine-derived foods in the diets of late adolescent and young adult females. As a result of the lower absolute δ^{15}N values, which are below 8‰, their diets would have included greater amounts of "low trophic-level marine foods, such as shellfish or small fishes" (Eerkens et al. 2022). Another possibility is that females were consuming elevated amounts of plants, such as pine nuts, which are typically elevated by 1-3‰ in δ^{13}C relative to acorns due to conditions of water stress (Picon et al. 1996; Van de Water et al. 2002).

Moving on to the third decade, the bone collagen data are representative of a diet with lower δ^{15}N values, suggesting that both males and females had a dip in trophic position beyond 22 years, especially in those over 40 years of age. This trend in older individuals at *Yakmuy 'Ooyákma-tka* would have occurred following the completion of raising a family. Hunting returns may have decreased among elderly males. Notably, female bone collagen δ^{13}C values also see a decrease. This suggests that the high δ^{13}C foods females consumed in their second decade saw a decrease in quantity in the following years.

The trends discussed above, which relate to Figure 4, can also be seen in Figure 5. Most notably, both individuals show a diet that emphasizes C_3 resources, likely vegetal foods. The time in which the weaning process took place is also of note. As stated previously, Fogel (1989) examined weaning practice patterns in agricultural and non-agricultural societies and found that weaning may have taken place earlier in agricultural societies. This study also found an increase in an infant's trophic level based on elevated δ^{15}N values (+2.4‰ on average) following birth up to around three months. This is followed by a decrease in δ^{15}N once the mother's milk was supplemented with complementary foods, providing a record of the weaning process (Fogel 1989). As reflected in Figure 5, the weaning process is not complete until around 2-4 years of age at *Yakmuy ʻOoyákma-tka*, much longer than the three months. This is more in line with weaning practices that took place at the Yukisma site (CA-SCL-38), which showed weaning commencing between 1.5 and 2 years of age (Gardner et al. 2011:1, 2018). The results of this study also show a "cessation of breast-feeding by 3 to 3.5 years of age" (Gardner et al. 2011:1, 2018).

CONCLUSION

The purpose of this study is to give a deeper understanding of the dietary changes and variation by age and sex within the ancestral Ohlone site of *Yakmuy ʻOoyákma-tka* ("Place of the East Ridge Site"). The results show that the diets of individuals from the site displayed significant variation during growth and development and by sex during this period, even though no differences were identified between adults (Eerkens et al. 2022). Such variation correlates with biological sex in a variety of ways, with more elevated δ^{15}N values in males compared to females (especially between 1 and 9 years of age), indicating greater meat consumption among males. Differences in gender roles and the age at which children assume them may account for these patterns. Beyond this, females show a notable increase in δ^{15}N that is parallel to that of males in the second decade of life. This pattern reverses once more in adulthood.

Further analysis of *Yakmuy ʻOoyákma-tka* and surrounding sites would be beneficial to expand understanding of ancestral Muwekma Ohlone dietary patterns from infancy into adulthood. Some plausible research paths moving forward are inter-site comparisons on weaning age, building on the work of Greenwald et al. (2016). Beyond this, additional research into the outliers in this data set and other data from neighboring sites should be examined in the case that any culturally relevant materials are found in their burial. For example, Burial 11 has a portion of abalone shell associated with the burial, which in other sites has been used to denote differences in social status or occupation. A regional dietary comparison of individuals buried with abalone and other burial goods could be used to investigate potential differences in social status, occupation, or other factors. Lastly, another research path is the continued analysis of trophic level variation both throughout the Holocene as a whole and throughout the Central California Delta and Bay Area. As has been seen in past studies, residential location within the Bay Area leads to considerable variation within diet and therefore there is still much to understand about ancestral Ohlone diet as is reflected in the archaeological record.

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