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Alan M. Leventhal
San Jose State University, alan.leventhal@sjsu.edu

Karen S. Gardner

Rosemary Cambra

Eric J. Bartelink

Antoinette Martinez

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**MOTHERS AND INFANTS IN THE PREHISTORIC SANTA CLARA VALLEY:
WHAT STABLE ISOTOPES TELL US ABOUT ANCESTRAL OHLONE WEANING PRACTICES**

KAREN S. GARDNER

DEPARTMENT OF ANTHROPOLOGY, CALIFORNIA STATE UNIVERSITY, CHICO

ALAN LEVENTHAL

COLLEGE OF SOCIAL SCIENCES, SAN JOSE STATE UNIVERSITY

ROSEMARY CAMBRA
MUWEKMA OHLONE TRIBE

ERIC J. BARTELINK

DEPARTMENT OF ANTHROPOLOGY, CALIFORNIA STATE UNIVERSITY, CHICO

ANTOINETTE MARTINEZ

DEPARTMENT OF ANTHROPOLOGY, CALIFORNIA STATE UNIVERSITY, CHICO

Breast-feeding and weaning are a part of childhood in all human populations, but the exact timing of these milestones varies between groups. As infants incorporate the nutrients from breast milk into their growing bones, chemical evidence is captured in the form of higher stable nitrogen ($\delta^{15}N$) isotope values. This study interprets $\delta^{15}N$ values in the bone collagen of children ($n = 24$) buried at the Yukisma Mound (CA-SCL-38), in Santa Clara County, California. Radiocarbon dates for this site span 2200-250 B.P., but primarily fall during the Late period (740-230 B.P.). In the one probable mother-infant pair available for study, a 2.9 per mil enrichment of $\delta^{15}N$ values was observed, consistent with the expected trophic level enrichment of breast-feeding infants. $\delta^{15}N$ values of children under seven years old suggest the introduction of weaning foods between 1.5 and 2 years of age, and cessation of breast-feeding by 3 to 3.5 years of age. These results differ from the practices reported in the ethnohistoric literature.

This paper includes photos of human remains, taken during excavation at CA-SCL-38 by Ohlone Family Consulting Services, the CRM arm of the Muwekma Ohlone Tribe (which also served as the Most Likely Descendant tribal group for this project). The images were provided to the authors by the tribe, and specific permission was granted to include them in this publication.

The choices made by mothers in caring for their infants are personal and vary based upon local cultural norms as well as the health and preferences of both mother and infant. Ethnographic studies show that children in traditional, natural-fertility populations are typically breast-fed for the first one to four years of life, with an average duration of two-and-a-half years (Kennedy 2005:123, 129). In 1989, a new method was pioneered, enabling the visualization of this important life process in archaeological contexts (Fogel et al. 1989). Analysis of stable nitrogen isotopes in human bone has since been used to understand breast-feeding and weaning practices among archaeological populations from places including ancient Egypt and Nubia (e.g., Dupras et al. 2001; White and Schwarcz 1994), Medieval England (e.g., Fuller et al. 2003; Richards et al. 2002), South Africa (e.g., Clayton et al. 2006), North America (e.g., Fogel et al. 1989; Herring et al. 1998; Katzenberg et al. 1996; Schurr 1998; Schurr and Powell 2005; Tuross and Fogel 1994), and Central America (e.g., Williams et al. 2005; Wright and Schwarcz 1998). The present study is the first to use stable isotopes in bone collagen to understand weaning practices in prehistoric California. Specifically, our study focuses on the ancestral Ohlone who were interred in the Yukisma Mound (SCL-38) and who inhabited the Santa Clara Valley of central California approximately 2,200 to 250 years ago.

BACKGROUND

Weaning Practices: Perspectives

Weaning is a process, beginning with the introduction of soft foods and ending when breast-feeding stops (Fuller et al. 2006). For the purposes of this study, “weaning age” refers to the age at cessation of breast-feeding. As primates, humans are atypical in their weaning practices. Weaning generally occurs much earlier in humans than in any of the great apes, even though humans have longer juvenile periods and longer average life expectancies (Rowe 1996). Chimpanzee infants are weaned between four and five years of age; orangutan infants are weaned as late as age eight (Kennedy 2005; Rowe 1996). Humans in traditional, natural-fertility populations, in contrast, wean at an average of two-and-a-half years, although there is a large range of variation (Howell 2000; Kennedy 2005; Yale University 2011).

While breast-feeding provides a child with valuable immune support and protects a child from water- and food-borne pathogens, the nutrition supplied by breast milk alone is not enough to meet the extraordinary energetic needs of a growing human brain (Kennedy 2005). By the time a child is seven years old, the brain has reached its full size by weight. Estimated caloric value and protein content of breast milk would only supply about half of the nutritional needs of a three-year-old child, and only about a third of the needs of a four-year-old child (Kennedy 2005:132). Additional sources of protein and energy are required by age two to three years, which is exactly when most traditional, natural-fertility populations wean their children.

The !Kung breast-feed their children for more than four years on average (Howell 2000), whereas Fijian islander populations breast-feed for only 12 months (Yale University 2011). Native North American groups show weaning ages between two and four years of age (e.g., Delaware and Inuit groups at 36-48 months, Ojibwa at 24-36 months, Iroquois at 24-30 months, Yokut at 24 months; Yale University 2011). Accounts of French explorers in the late eighteenth century state that the Costanoan (Ohlone) weaned their children between 18 and 20 months (Rollin 1959:115, cited in Levy 1978:490). This study will test the weaning age of the ancestral Ohlone buried at the Yukisma Mound.

Site: The Yukisma Mound (CA-SCL-38)

The Yukisma Mound is a mortuary mound site located approximately 6 mi. southeast of the present shoreline of the San Francisco Bay. The site is located between the Coyote Creek and Lower Penetencia Creek drainages, near several other important archaeological sites in Santa Clara and Alameda counties (Figure 1). In recent decades, the site has been subsumed by modern-day Milpitas and is now within the grounds of the Elmwood Correctional Facility.

In response to an expansion project of the prison, SCL-38 was excavated in 1993 and 1994. This work was completed by the Ohlone Families Consulting Services, the CRM arm of the Muwekma Ohlone Tribe (Leventhal et al. 1993). Approximately 248 individuals and 32,000 beads and artifacts were recovered (Bellifemine 1997; Jurmain 2000; Morley 1997). At the request of the tribe, rib samples were retained from 202 burials for future special studies, a subset of which comprises this study sample. In 1996, the burials were reinterred near their original location.

Stable Isotope Analysis and Weaning Studies

Stable isotope analysis reveals nuances of dietary patterns. Bone is constantly remodeled during life, and built from the components obtained through foods consumed. Two elements are of particular interest in dietary studies, nitrogen and carbon (Schwarcz and Schoeninger 1991).

Nitrogen is a vital component of all amino acids, which are the building blocks of proteins. Amino acids from protein in the diet are routed by the body to build new proteins, such as those in bone collagen. Nitrogen, as an element, is defined by having seven protons in the nucleus. Most nitrogen has seven neutrons in the nucleus, but a very small portion of nitrogen atoms (0.4 percent) contain eight



Figure 1. Map of selected archaeological sites in the San Francisco Bay Area (created by Kevin Dalton, used with permission).

neutrons. The atoms with eight neutrons are slightly heavier, form stronger bonds, and react more slowly than atoms with seven neutrons (Fry 2006).

Proportions of heavy to light isotopes in a sample are reported by comparing the observed ratio to that in a known standard, and then multiplying the result by 1,000. The result is written as a delta value (δ), and reported in per mil (‰). In the following example, R represents the ratio of the heavier isotope to the lighter isotope (e.g., $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$):

$$\delta = [(R_{\text{Sample}} / R_{\text{Standard}}) - 1] * 1000$$

The heavier isotope of nitrogen is more likely to be left behind in the body of a consumer, resulting in enriched proportions of ^{15}N in each trophic level of an ecosystem. Plants have very low delta nitrogen-15 ($\delta^{15}\text{N}$) values. The $\delta^{15}\text{N}$ values in the tissues of an herbivore (e.g., rabbit, deer) are enriched by about 2-3 per mil (DeNiro and Epstein 1981). The tissues of humans who consume herbivore meat

Table 1. CA-SCL-38 burial population and individuals included in study.

SEX	AGE GROUP	DISCRETE BURIALS ^a	INCLUDED IN ISOTOPE STUDY (GARDNER 2012)
Males	Adult	100	57
Females	Adult	63	38
Undetermined	Adult	43	7
	Subadult	42 ^b	24
	Infants (I): birth-2 years		8
	Young Children (S1): 3-5 years		5
	Older Children (S2): 6-10 years		9
	Adolescents (S3): 11-15 years		2
Total		248	126

^a Discrete burial count is a maximum estimation, based on all individuals mentioned in Bellifemine (1997), Morley (1997), and Jurmain (2000).

^b Rib samples were retained for only 24 subadults, all of whom are included in this study.

will be enriched by an additional 2-3 per mil in their bone collagen $\delta^{15}\text{N}$. Marine ecosystems have more trophic levels than terrestrial ecosystems, and therefore even higher $\delta^{15}\text{N}$ values are found in consumers of marine foods (Schoeninger and DeNiro 1984).

The $\delta^{15}\text{N}$ values of breast milk correspond to those of the mother. The tissues of a newborn infant have similar $\delta^{15}\text{N}$ values to those of their mothers, but with breast-feeding the $\delta^{15}\text{N}$ values of the infant's bone collagen become progressively enriched, due to the trophic level effect, until the values plateau at 2-3 per mil greater than those of the mother (Fogel et al. 1989; Fuller et al. 2006). With the introduction of weaning foods, the $\delta^{15}\text{N}$ values of an infant's tissues begin to decline, approaching the levels seen in the general population following cessation of breast-feeding.

Carbon also has two stable isotopes which are useful in dietary analysis. Carbon-12 (^{12}C) is the more common form, and contains six protons and six neutrons. Carbon-13 (^{13}C) has one additional neutron and is slightly heavier. Heavy isotopes of carbon do not accumulate significantly from one trophic level to the next. However, $\delta^{13}\text{C}$ values are very useful in discerning between terrestrial and marine food sources (Ambrose et al. 1997; Chisholm et al. 1983; DeNiro and Epstein 1978; Keegan and DeNiro 1988; Richards and Hedges 1999; Walker and DeNiro 1986).

Terrestrial plants obtain carbon from atmospheric CO_2 , which contains very little ^{13}C . Important dietary plants in prehistoric California had $\delta^{13}\text{C}$ values ranging between -22.45 per mil (scrub oak, *Quercus dumosa*) and -26.5 per mil (holly-leaved cherry, *Prunus ilicifolia*) (Bartelink 2006:Table 5.1, values adjusted to represent preindustrial equivalents). No terrestrial plants with significantly less negative $\delta^{13}\text{C}$ values (e.g., C_4 plants) were available in early Californian ecosystems. Marine organisms obtain their carbon primarily from dissolved inorganic carbon in ocean water, which has a base level of ^{13}C that is 7.0 per mil higher than that available in air (Katzenberg 2008). Consumers of marine foods will therefore have higher $\delta^{13}\text{C}$ values than consumers of terrestrial foods. Because consumption of marine foods results in higher delta values of both ^{13}C and ^{15}N , the correlation of elevated values is a useful means of differentiating between elevated $\delta^{15}\text{N}$ values due to marine consumption and elevated $\delta^{15}\text{N}$ due to other dietary practices, such as breast-feeding.

MATERIALS AND METHODS

Of the subadults recovered at SCL-38, rib samples were retained for 24 individuals, all of whom are included in this study (see Table 1). Age estimations are based on the work of Jurmain (2000) and Morley (1997), as well as new estimations of dental age, completed in 2010 with the help of Dr. Leon Pappanastos. The *estimated age* for each individual is a range, which is likely to accurately include the actual age of the individual (see Table 2). The *probable age*, used for graphic presentation of results, is based primarily upon the precise estimations of Morley (1997). Where age estimations differed between

Table 2. Results of stable isotope analysis of bone collagen for subadults and selected adults from CA-SCL-38.

BURIAL #	AGE CODE	ESTIMATED AGE ^A (YEARS)	PROBABLE AGE ^B (YEARS)	ASSOCIATED BURIALS	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
127	I	0.5-1.5	1.5		-18.52	10.25
220	I	0.5-1.0	0.75	219	-17.90	10.27
186	I	0.75-1.0	1.0		-17.90	11.97
235	I	0.5-1.5	1.5	235a	-20.19	8.32
119	I	1.0-2.5	1.5	120	-19.25	11.62
128	I	1.0-2.0	1.5		-19.76	8.92
156	I	1.0-2.0	1.5	155	-17.60	12.77
136	S1	2.0-3.0	2.5		-20.09	10.61
137	S1	3.0-4.0	3.5	159	-19.27	7.98
177	S1	2.5-3.5	3.5		-19.25	10.72
115	S1	3.8-5.0	4.5		-19.38	6.96
169	S1	3.5-5.5	4.5		-17.84	10.37
159	S1	4.0-5.0	4.5	137	-19.31	8.04
44	S2	4.5-6.0	6.0		-19.45	6.14
195	S2	5.0-7.0	6.0		-19.19	8.34
214	S2	4.0-6.0	6.0		-20.28	6.37
217	S2	5.5-6.5	6.1		-18.85	6.97
222	S2	6.0-7.0	6.5		-17.29	9.79
203	S2	7.0-10.0	8.5		-19.48	5.79
108	S2	8.5-9.5	9.0		-19.86	6.79
135	S2	8.0-11.0	10.0		-19.21	8.22
3	S2	8.0-10.0	9.5		-18.84	6.37
23	S3	9.5-12.0	11.0		-19.32	6.53
194a	S3	10.0-13.0	12.0		-18.81	8.77
120	Adult	18.0-20.0	19.0	119	-19.34	8.75
219	Adult	25.0-30.0	27.0	220	-19.31	7.45
Mean $\delta^{15}\text{N}$ value for females of child-bearing age (16-49 yrs)						7.68

^a Estimated Age from Morley (1997) and Jurmain (2000). Where sources differed, Jurmain's estimate is used.

^b Probable Age from Morley (1997), modified where inconsistent with Jurmain (2000). Calculation for burials 128, 137, 177, 159, 44, 214, 222, 3, and 23 also includes dental age estimation (Dr. Leon Pappanastos, personal communication 2010).

these sources, data from Jurmain (2000) and Pappanastos (2010, personal communication) were favored. The retained ribs from subadults at SCL-38 represent eight infants under three years old, five children between three and five years old, nine children between six and 10 years old, and two adolescents between 11 and 15 years old.

The stable isotope data used in support of the present study were obtained from a larger study of dietary patterns within the SCL-38 population (Gardner 2012). As part of that study, stable isotope analysis was completed for 57 adult males, 38 adult females, and seven adults of indeterminate sex, in addition to the 24 subadults, for a total of 126 individuals (see Table 1).

All bone samples were prepared for analysis by Karen Gardner in the Stable Isotope Preparation Laboratory (SIPL) at California State University, Chico, following standard protocols (Ambrose 1993; Beasley 2008; Schwarcz and Schoeninger 1991). Purified collagen was analyzed by the Stable Isotope Facility (SIF) in the Department of Plant Sciences at UC Davis. Values for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were obtained using a PDZ Europa ANCA-GSL elemental analyzer, which was interfaced to a PDX Europa 20-20 isotope ratio mass spectrometer (reported precision ± 0.2 per mil for $\delta^{13}\text{C}$ and ± 0.3 per mil for $\delta^{15}\text{N}$).



Figure 2. Excavation photograph of individuals B119 and B120, a probable mother-child pair. (Image courtesy of Ohlone Families Consulting Services and the Muwekma Ohlone Tribal Council, used with permission).

RESULTS

Establishing $\delta^{15}\text{N}$ Enrichment of Breast-feeding Infants from SCL-38

The first goal of this study is to establish that there is a $\delta^{15}\text{N}$ enrichment between mothers and infants at SCL-38. To do this, we compared the $\delta^{15}\text{N}$ values of bone collagen from infants and young children who were interred in double burials with those of the associated individual. Of the six subadults under the age of five years in double burials, only one (Burial 119, age ~18 months) was interred with an adult female (Burial 120, age ~19 years) (Figure 2). The infant was placed upon a large, inverted mortar, positioned on top of the thorax of the adult female. The association suggests that this is likely to be a mother-child pair. Comparing the $\delta^{15}\text{N}$ values between the female and infant, a difference of 2.9 per mil is seen (Table 2). The expected enrichment between a mother and her breast-fed infant is between 2.0 and

3.0 per mil (Fuller et al. 2006; Katzenberg et al. 1996). Radiocarbon dating on the female places the pair between 650 and 580 calibrated years B.P. (Late period 1B).

Another infant in this study (Burial 220, age ~18 months) was buried with an adult male (Burial 220, age ~27 years) (Figure 3). Although a male-child pair, their co-burial suggests a relationship; thus, it is possible that this adult male, the infant, and the infant's mother may have had access to similar foods. When the isotopic results are compared, the infant's $\delta^{15}\text{N}$ values are enriched by 2.9 per mil, the same as the first pair.

Four other children were interred in double burials. Burial 137 (age ~3.5 years) and Burial 159 (age ~4.5 years) were interred together and have the same $\delta^{15}\text{N}$ values (8.0 per mil). Both are also very similar to the mean value of 7.7 per mil for women of child-bearing age (16 to 49 years). As these children's values do not appear to be enriched relative to adult females, it is likely that they had already been weaned. The other two children in this study who were part of double burials (Burial 156 and Burial 235) were interred with an individual who was not available for analysis, so a comparison of values was not possible.

Results of Stable Isotope Analysis for Subadults at SCL-38

A plot of the $\delta^{15}\text{N}$ values from all individuals in the sample group reveals some dietary variation between individuals (see Figure 4). Values for eight faunal samples from the site are also included in this graphic (shown as yellow stars). Trophic level enrichment of $\delta^{15}\text{N}$ values is evident when comparing the human results to those of the faunal remains found at the same site. Humans generally have higher $\delta^{15}\text{N}$ values than those found in the faunal remains. The coyote has a $\delta^{15}\text{N}$ value very consistent with humans, and likely consumed a similar range of food resources. Enriched $\delta^{15}\text{N}$ values are clear in both young children (shown as green diamonds) and some young males (shown as red squares). The challenge at this point is to distinguish enriched $\delta^{15}\text{N}$ values due to the consumption of marine foods from enriched $\delta^{15}\text{N}$ values from consumption of breast milk.

Earlier we established that both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values levels will be higher in individuals who consume marine resources. Figure 5 illustrates the variation in diet seen in this population. Individuals who consumed more marine foods have higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, and are closer to the top right quadrant of this plot; those who included more terrestrial resources in their diets have lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values and are closer to the bottom left. For the population as a whole, the carbon and nitrogen values covary along the line of best fit. If individuals are choosing foods from the local menu of terrestrial and marine resources, the $\delta^{13}\text{C}$ value of each individual should be a reasonable proxy for predicting their $\delta^{15}\text{N}$ value, and should fall close to this line.

A linear regression was run to normalize the effect of marine consumption on nitrogen values. Using isotopic values from only the adults from SCL-38, the linear regression predicts $\delta^{15}\text{N}$ values, based on observed $\delta^{13}\text{C}$ values ($n = 102$; $r = 0.752$ [adults]; $r^2 = 0.565$; $F = 127.193$; $p < .001$). If four adult outliers are removed from the calculation, the correlation improves ($n = 98$; $r = 0.879$; $r^2 = 0.772$; $F = 325.678$; $p < .001$), suggesting that over 77 percent of variability in $\delta^{15}\text{N}$ values can be explained by $\delta^{13}\text{C}$ values for adults within this population.

Standard residuals were calculated for each individual based on the first regression ($n = 102$), which indicate how far the observed $\delta^{15}\text{N}$ value varied from the predicted value (Figure 6). Each standard deviation of variance has a value of 1.0, so we can be 95 percent confident that individuals with residual values between -2.0 and 2.0 are consuming food items consistent with the local menu of terrestrial and marine foods. Residual values outside this range suggest a different food source or menu selection than most adults in the local population. The results of this analysis clearly show elevated $\delta^{15}\text{N}$ values in young children that cannot explained by consumption of a marine diet, suggesting that breast-feeding is the cause.



Figure 3. Excavation photograph of individuals B219 and B220, an adult male and associated infant. (Image courtesy of Ohlone Families Consulting Services and the Muwekma Ohlone Tribal Council, used with permission).

Figure 7 includes only the residual values of children less than seven years of age. The addition of a trend line illustrates a pattern of gradual enrichment of $\delta^{15}\text{N}$ values up to age two-and-a-half, then a decline to values consistent with the diet of the adult population by age three-and-a-half to four years.

DISCUSSION

Feeding studies in modern populations indicate that infants who are completely weaned show $\delta^{15}\text{N}$ values similar to those of their mothers within approximately three to five months (Fuller et al. 2006; Katzenberg et al. 1996:188). By applying a conservative estimate of a six-month delay in changes to bone collagen $\delta^{15}\text{N}$ levels in infants, it appears that the children in the Yukisma study were breast-fed from birth, introduced to weaning foods at one-and-a-half to two years of age, and were completely weaned between three and three-and-a-half years of age.

These results are not unusual when compared to other North American populations (Yale University 2011), but differ from the historical records of infant care among the Costanoan (Ohlone) people, as documented by French explorers in 1786 (Rollin 1959, cited in Levy 1978). Those records indicated complete weaning by the age of 18-20 months. The discrepancy may reflect differences in local traditions, suggest change in infant care at the onset of the historic period, or may simply be a result of incomplete understanding of cultural practices by early Europeans.

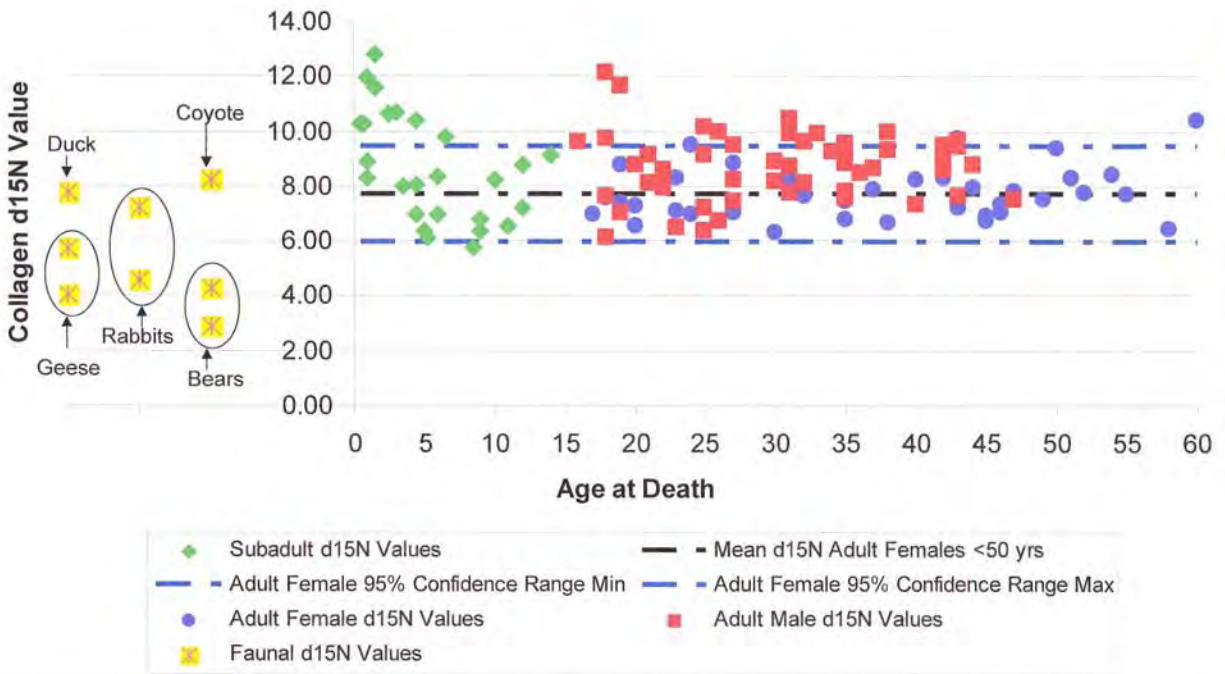


Figure 4. Stable $\delta^{15}\text{N}$ values (in per mil) for humans and fauna from CA-SCL-38, relative to expected range of variation for females of childbearing age (women aged 16-49, $n = 32$; $\delta^{15}\text{N}_{\text{Mean}} = 7.7$ per mil; $S.D. = 0.9$ per mil; 95 percent confidence range (2σ) = 5.9 per mil to 9.4 per mil). Trophic enrichment is evident between faunal values and human values.

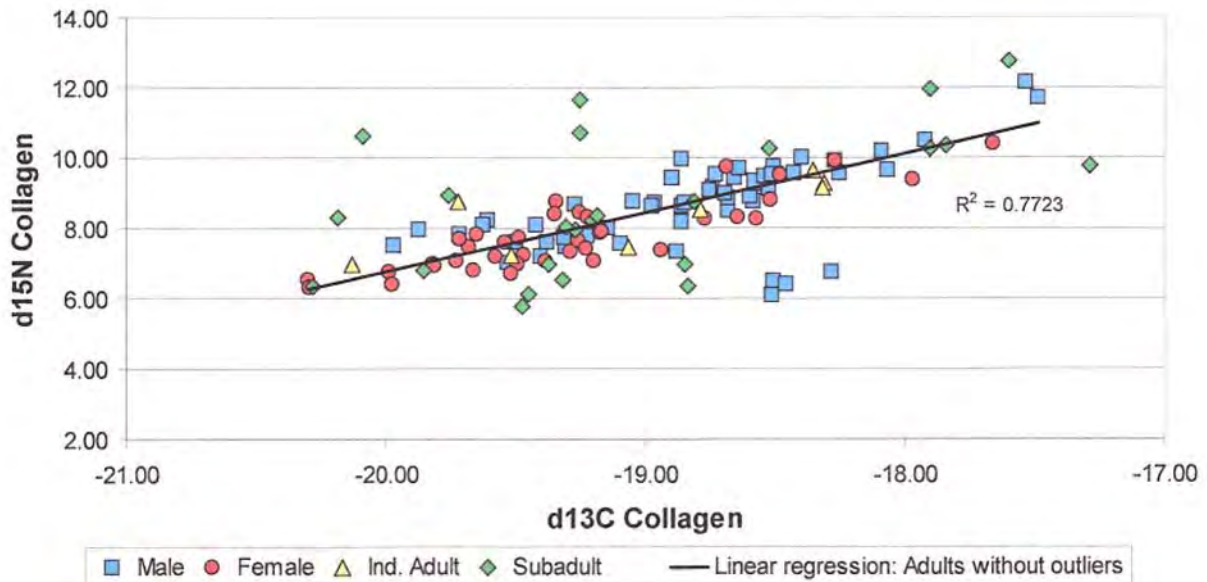


Figure 5. Results of stable isotope analysis of bone collagen for individuals from CA-SCL-38 ($n = 126$). Consumption of marine foods results in higher $\delta^{15}\text{N}$ values and higher (less negative) $\delta^{13}\text{C}$ values. However, enriched $\delta^{15}\text{N}$ values may also be due to the trophic effect of breast-feeding.

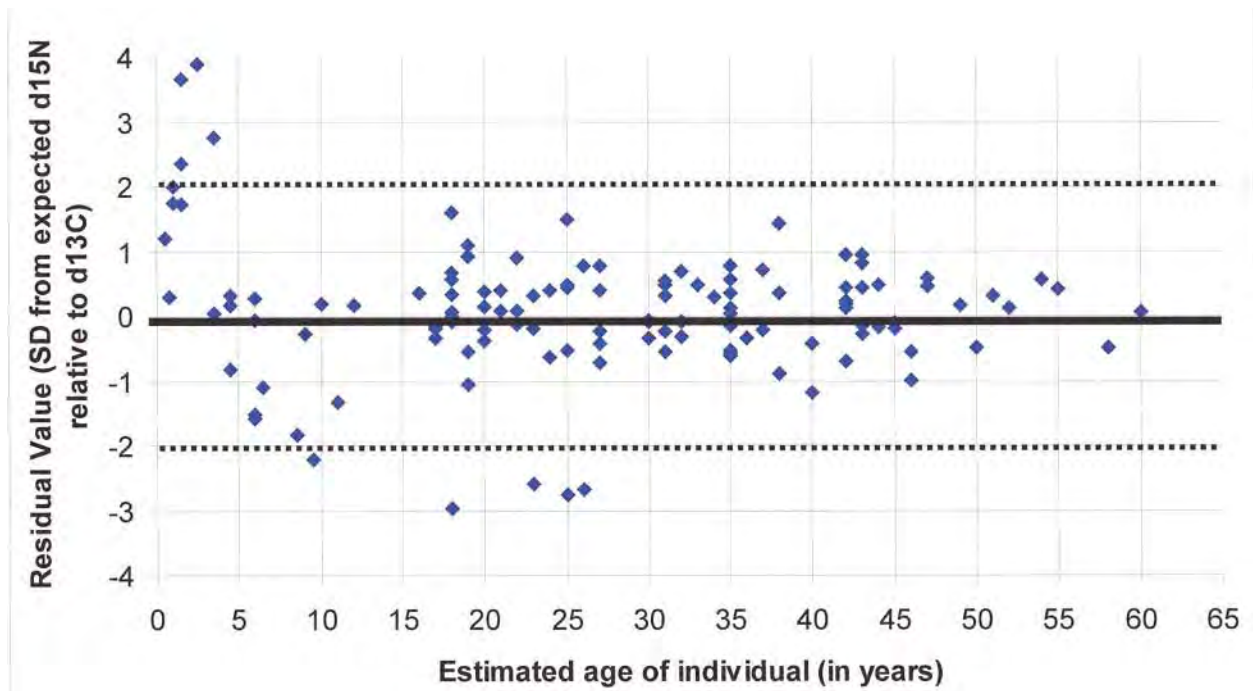


Figure 6. Plot of standardized residuals for $\delta^{15}\text{N}$ values of all individuals from CA-SCL-38 (based on a linear regression predicting $\delta^{15}\text{N}$ values based on $\delta^{13}\text{C}$ values of adults from this population; $n = 102$; $r = 0.752$; $r^2 = 0.565$; $F = 127.193$; $p < 0.001$). A standardized residual value of 0 indicates that the $\delta^{15}\text{N}$ value is as expected, based on the $\delta^{13}\text{C}$ value. Each standard deviation from the mean = ± 1 residual value. Where residual values are more than ± 2 standard deviations from the mean, the $\delta^{15}\text{N}$ values are not well explained by the $\delta^{13}\text{C}$ values within this population, suggesting that this individual is not eating from the same menu as the local adult population.

CONCLUSIONS

The Yukisma Mound (SCL-38) project is unique in its sizeable burial population, the documentation of age, sex, and unique characteristics of individuals prior to reburial, the research opportunities afforded by the tribal decision to retain ribs for future studies, and the collaboration between tribal agencies, archaeologists, and academic researchers throughout the project. The isotope results of this study of breast-feeding and weaning were produced as part of a larger dietary study (Gardner 2012). By focusing on the results of the 24 subadults in this population and comparing them to the dietary patterns of adults, it was possible to expand the interpretations possible from these same data.

Trophic level enrichment of 2.9 per mil was seen in the $\delta^{15}\text{N}$ values of infants relative to values in associated adults. A linear regression allowed for distinction between the influence of marine foods on isotopic values and that of other resources, such as breast milk. An examination of the residual values of the 18 children less than seven years of age suggests progressive enrichment in $\delta^{15}\text{N}$ values with the onset of breast-feeding, a peak of enrichment and then decline of $\delta^{15}\text{N}$ values with the introduction of weaning foods, and return to $\delta^{15}\text{N}$ values within population norms following the cessation of breast-feeding. Allowing a six-month delay for remodeling of tissues, this pattern suggests that infants were weaned by three to three-and-a-half years of age, significantly later than is suggested in the only known historic reference (Levy 1978).

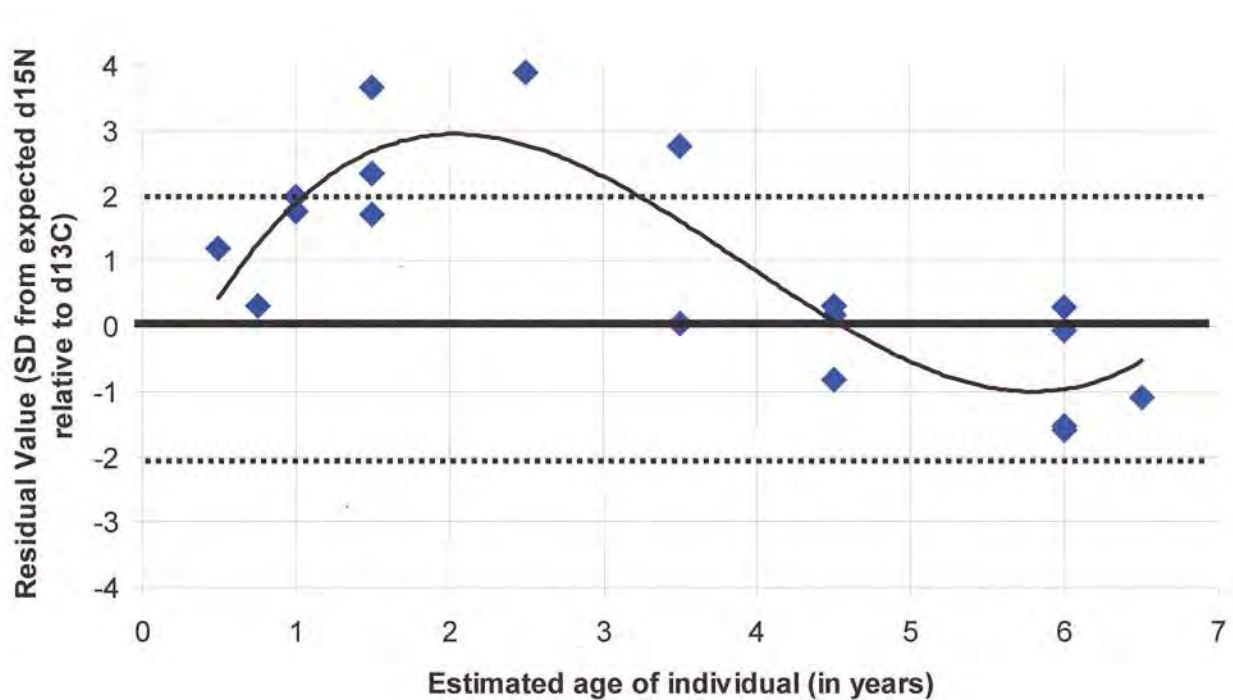


Figure 7. Plot of standardized residuals for predicted $\delta^{15}\text{N}$ values, based on $\delta^{13}\text{C}$ values, for subadults under the age of seven years from CA-SCL-38. A trend line (polynomial, third order) highlights the pattern of progressive enrichment with breast-feeding, followed by decline to adult population norms with weaning.

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