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## RESEARCH ARTICLE

# Sex-biased parental investment and female wealth accumulation in ancient California

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## Abstract

**Objectives:** The mortuary record at Middle Period site *Kalawwasa Rummeytak* (CA-SCL-134) (2600-1225 cal BP) in California's southern Santa Clara Valley shows pronounced wealth inequality; *Olivella* shell bead wealth, as well as other grave goods, are concentrated in the burials of several older adult females. The concentration of wealth among women, along with regional strontium isotopic evidence of male-biased residential shifts in early adulthood, suggests a matrilineal kinship system that practiced matrilocal post-marital residence patterns. We suggest local resource enhancement effects incentivized keeping women in their natal communities and investing more in female offspring.

**Materials and Methods:** With the consent of, and in collaboration with, the Muwekma Ohlone Tribe of the San Francisco Bay Area, this paper employs isotopic analysis ( $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$ ,  $^{86}\text{Sr}/^{87}\text{Sr}$ ) to examine duration of exclusive breastfeeding, weaning age (complete cessation of breastmilk consumption), early childhood diet, and lifetime residential mobility of individuals interred at *Kalawwasa Rummeytak* to test the assumption that the site inhabitants favored matrilocality and that female offspring received greater levels of investment in groups with female wealth/status attainment. First molars, third molars, and bone was sampled from 22 individuals.

**Results:** The average weaning age for females at *Kalawwasa Rummeytak* is  $36.3 \pm 9.7$  (1 SD), or just over 3 years. The average weaning age for males is  $31.2 \pm 7.9$  months (1 SD), or about 2.6 years. Infants at the site were provisioned with supplemental foods dominated by  $\text{C}_3$  plants and terrestrial herbivores, as well as anadromous fish. After weaning, individuals consumed a diet dominated by acorns,  $\text{C}_3$  plants, and terrestrial herbivores, with periodic inclusion of anadromous fish. 30% of the sampled population of females exhibit local first molar  $^{87}\text{Sr}/^{86}\text{Sr}$  values, suggesting that *Kalawwasa Rummeytak* is their natal community. None of the males interred at the site are locals.

**Discussion:** Despite the small sample size often unavoidable in archaeological contexts, we find possible female-biased parental investment strategies. Cessation of breastfeeding (weaning) was, on average, 5 months earlier for males compared to females. There are no differences between females and males in the consumption of supplemental or post-weaning foods. Strontium data suggest a flexible postmarital

residence system that favored matrilocality. This may have incentivized greater investment in female offspring.

#### KEYWORDS

parental investment, inequality, breastfeeding and weaning, hunter-gatherers

## 1 | INTRODUCTION

Human social organization is shaped by our novel life history trajectory. Humans experience an exceptionally long lifespan that extends beyond our reproductive years, an extended period of juvenile growth and development that results in family units with multiple juvenile dependents, cooperation in food production, sharing between related and unrelated individuals, and a multi-generational flow of resources and support of reproductive individuals by post-reproductive individuals (Hawkes et al., 1998; Kaplan et al., 2009). Among forager societies studied ethnographically, this nearly always results in a sexual division of labor and cooperative food sharing that reduces the risk of shortfalls and compensates for the reduction of female foraging efficiency associated with infant care (Hawkes et al., 1998; Kaplan, 1997; Kaplan et al., 2000).

Forager social organization typically takes the form of communities of inter-related three-generation nuclear families (Kaplan et al., 2009). In small communities comprised of kin, exogamous marriage has the dual advantage of increasing genetic diversity and establishing reciprocal social networks with neighboring groups (Fox, 1967). Many California ethnographic cultures practiced exogamy at the community level, so the arrival of adulthood and marriage for males or females was marked by a departure from their natal community (Heizer, 1978; Kroeber, 1925; Wallace, 1978).

Post-marital residence patterns among foraging populations vary. Patrilocality entails the settlement of a wife with her husband's kin group, and occurs in patrilineal societies where descent is reckoned through the male line. A matrilocal post-marital residence pattern is defined by a couple's co-residence with the wife's kin group, and is less common cross-culturally than patrilocality (Fox, 1967). Matrilocality can be a permanent arrangement, as is most common among matrilineal societies, or a temporary arrangement lasting until the weaning of a first child or the payment of a bride-price through goods or labor by the husband to his wife's family (e.g., Wood & Marlowe, 2011). The couple may thereafter reside with the husband's family in a patrilineal system, or establish a new household in the case of a neolocal post-marital residence system. Neolocal post-marital residence could also be practiced immediately after a union, and is often associated with bilateral kinship patterns (Fox, 1967). While societies may have stated preferences for marriage patterns, in practice, most societies have some degree of flexibility in how individuals enact such rules (e.g., Chagnon, 1988; Jakoubek & Budilová, 2006). This is especially true in small-scale societies where marriage options for an individual may be limited.

Post-marital residence patterns, and the underlying lineage patterns with which they are associated, have important consequences

for subsistence practices, wealth accumulation, and the safety of kin groups. Local resource enhancement effects (LRE) will favor the sex responsible for the majority of contributions to the subsistence economy remaining in their natal community, because cooperative behavior among kin associated with complex foraging behavior and intimate knowledge of the local environment will provide superior foraging returns compared to newly arrived outsiders exploiting the same environment (Lawson Handley & Perrin, 2007; LeGallard et al., 2006; Perrin & Goudet, 2001). In precontact California, where women's foraging efforts contributed substantially to the subsistence economy, matrilocality may have been an optimal strategy in some ecological zones during the Early and Middle Holocene.

Previous work utilizing strontium (Sr) isotope ratios in tooth and bone from the San Francisco Bay Area has identified values consistent with preference for matrilocal post-marital residence, wherein males migrate away from their natal communities to join their wife's community (Eerkens et al., 2014; Jorgenson, 2012). Sr isotope ratios sampled across tissues formed at different ages indicate males experienced a residential shift at an age consistent with ethnographic data on the age of marriage. For example, Eerkens et al. (2014) demonstrate a modal pattern of matrilocality at the nearby contemporaneous South Bay site *Yuki Kutsuimi Šaatoš Inūxw* (CA-SCL-287; also see Leventhal et al., 2010). Because post-marital residence practices and associated lineage patterns present a coordination problem, it is likely that other sites in this area during the Middle Period (2150-930 BP) shared the practice. This study employs strontium analysis to assess postmarital residence patterns at *Kalawwasa Rummeytak* and test this assumption.

### 1.1 | Kinship and parental investment

Kinship systems and their associated sex-dispersal patterns at marriage have implications for parental investment strategies. Parents may be expected to invest more in offspring remaining in their natal communities who will continue to contribute to the household economy and whose mating efforts will yield the benefits of inclusive fitness.

Anthropologists have long focused on lactation as a quantifiable form of parental investment, which pits maternal costs against offspring benefits (Trivers, 1974). Lactation is a post-gestational physiological investment in offspring. Breastmilk production represents a metabolically costly mobilization of maternal resources, which incurs caloric deficits of approximately 500 to 700 kilocalories per day (Goldberg et al., 1991; Lunn, 1994). Breastfeeding also presents high opportunity costs to women, and can significantly curtail women's

productivity (Borgerhoff Mulder, 1992; Hawkes et al., 1997; Hurtado et al., 1992; Kaplan et al., 2000). However, breastmilk provides essential, non-pathogenic nutrition to infants; it contains essential macronutrients (carbohydrates, lipids, protein), micronutrients (vitamins and minerals), immune factors, and growth hormones necessary for healthy infant development and survival (Dewey et al., 1999; Ellison, 2001; Lönnerdal, 2000).

Unlike our closest primate relatives, human children remain nutritionally dependent on parental or alloparental provisioning of developmentally appropriate foods well past weaning, until nutritional independence is reached in adolescence (Hawkes et al., 1998; Hrdy, 1999; Sellen, 2006; Smiseth et al., 2012). Non-lactational parental provisioning in children may be considered to begin with the introduction of complementary foods while the infant is still breastfeeding (Hrdy, 1999; Sellen, 2006). Complementary foods, or weaning foods, are described clinically as any foods suitable as a supplement to breastmilk, when breastmilk alone is unable to satisfy an infant's nutritional needs (Dewey, 2013; Sellen, 2006). Infants' nutritional needs begin to outstrip their mother's lactational output and the micronutrient content of breastmilk (primarily iron and zinc) beginning around 6 months of age (Dewey, 2013; Kramer & Kakuma, 2002). Withholding of household foods past around 6 months of age is associated with stunting and failure to meet physical and cognitive developmental milestones (Akre, 1990; Dewey, 2003; Dewey, 2013). Exclusive breastfeeding past 6 months of age can therefore represent reduced levels of parental investment in offspring, while prolonged breastfeeding with supplementation of household foods starting around 6 months and extending well into toddlerhood represents greater levels of parental investment.

The current study focuses on measuring duration of exclusive breastfeeding (i.e., how long an individual consumed breastmilk before the introduction of supplementary foods) and age at cessation of breastmilk consumption (i.e., completion of the weaning process.) We consider an individual weaned when they have fully transitioned to consuming household foods.

## 1.2 | Kinship and wealth distribution

Cross-cultural and ethnographic evidence from California suggests a greater likelihood of wealth accumulation among women in matrilineal, matrilocal groups. Wealth was likely passed matrilineally in this kinship system, and women are in the community longer and have more time to accumulate wealth and prestige. *Olivella* shell beads interred in burials are used in this study, and in scholarship throughout the region, as a proxy for wealth or status that provided increased access to resources.

Studies by Milliken and Bennyhoff (1993), Milliken et al. (2007), and Bettinger (2015) have used *Olivella* bead counts in burials to examine changes in wealth and inequality over time in California. The cultural significance of shell beads did not remain static over time: importance as status markers likely preceded the more directly economic role beads played ethnographically (Bettinger, 2015; Burns, 2019; King, 1990).

Although evidence suggests beads did not function as money before 930 BP (Burns, 2019), their distribution throughout Western North America follows major trade patterns after 5500 BP, and bead concentration in Central California burials is closely linked to access and control of trade by 1530 BP (Bennyhoff & Hughes, 1987; Burns, 2019). For sites contemporary to *Kalawwasa Rummeytak*, *Olivella* beads correlate strongly with other markers of high-status burials (Luby, 1992). Since most beads required similar inputs of shell and labor, even *Olivella* bead types that were not culturally important as markers of prestige or stores of wealth likely represent a similar stored value, so simple bead counts may be reasonable for comparing value across time (cf. Barbier, 2019).

Regionally, bead wealth inequality peaks in Middle Period Phase 2 (1530–1365 BP), but remains unusually high, even by the elevated standards typical of burial wealth distributions (Bettinger, 2015; Fochesato et al., 2019; Groza et al., 2011; Milliken & Bennyhoff, 1993). Decreasing inequality and higher mean bead wealth may be related to development of more egalitarian access to trade, but is probably also a product of declining polity size that reduced the opportunity to extract surplus (Bettinger, 2015; Milanovic et al., 2011). Across Central California, males have more burial wealth on average than females for all time periods, and the degree of inequality within each sex follows the same pattern as overall inequality (Burns, 2018).

Recent scholarship in inequality in forager societies has come to avoid using burial wealth because it tends to result in estimates that are incommensurate with other archaeological signals (Prentiss et al., 2018). One reason is that individuals buried without any grave goods tend to skew measures of inequality upward in a manner that is not seen with residence size or household refuse (Peterson & Drennan, 2018). More generally, burials must necessarily reflect individual inequality, while most other measures aim to reconstruct household inequality (Smith et al., 2014). Even at the individual level, the origin of funerary objects may be a mixture of individual, household, and group contributions, thus representing prestige as much as lifetime wealth accumulation (Peterson & Drennan, 2018). Burial data are also fraught for comparisons across cultures or time because differences in culturally defined wealth division within households may be conflated with inequality between households. However, since the division of wealth and prestige within households is as important as overall inequality in understanding kinship and parental investment, we argue that burial wealth data represent a reliable proxy for inequality for sites such as *Kalawwasa Rummeytak*.

## 2 | SITE BACKGROUND

CA-SCL-134, named by the Muwekma Ohlone tribal leadership and language committee *Kalawwasa Rummeytak* meaning the [Calabazas] Squash Creek Site, is a large Middle Period cemetery/habitation site located in what is now the City of Santa Clara. The site is located on a broad alluvial flood plain in the coast littoral zone approximately 125 meters west of Calabazas Creek and 6 miles southeast of the San Francisco Bay shore. The site was first noted by archaeologists in the



**FIGURE 1** Map of Kalawwasa Rummeytak/CA-SCL-134

1960s and has been subject to excavation by academic researchers and as part of cultural resource management projects since then (Archaeological Resource Management, 1994; Edwards & King, 1974; Farnsworth et al., 2010).

The archaeobotanical assemblage is dominated by goosefoot (*Cheopodium* spp.), acorn, geophytes (unidentified to taxa), *Asteraceae*, and *Poaceae*. Tobacco (*Nicotiana*), clover (*Trifolium*), rush (*Juncus*), and sedge (*Carex*) were found in lower numbers (Farnsworth et al., 2010). Zooarchaeological materials suggest exploitation of terrestrial mammals, including deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), and rabbits (*Sylvilagus* spp. and *Lepus californicus*). Marine and brackish water invertebrates are represented by *Cerithidea californica*, *Mytilus edulis* and *M. californianus*, *Ostrea lurida*, and *Haliotis* (Farnsworth et al., 2010). The archaeobotanical and faunal remains suggest residents of Kalawwasa Rummeytak primarily consumed  $C_3$  plants, and supplemented their diet with terrestrial herbivores and shellfish (Figure 1).

Muwekma Ohlone tribal members and San Jose State University conducted burial recovery excavations in 2001 and recovered 31 individuals interred in 24 burials (Morley, 2001). Twelve additional burials were recovered during excavations in 2009 and 2010 (Farnsworth et al., 2010).

Osteoarthritis, dental caries, and cribra orbitalia are common among the burials interred at Kalawwasa Rummeytak, identified in

both the 2001 and 2010 excavations (Farnsworth et al., 2010; Morley, 2001). Two individuals exhibit signs of sharp-force perimortem trauma, and a third shows evidence of healed blunt-force trauma (Farnsworth et al., 2010). Five older adult individuals, four of whom are female and the other of indeterminate sex, were interred with large quantities of *Olivella* shell beads (Farnsworth et al., 2010; Morley, 2001).

*Olivella* bead wealth distribution in burials at Kalawwasa Rummeytak (Table 1) is similar, but slightly lower than the overall level of bead wealth inequality for the Middle Period in Central California. Inequality in wealth can be summarized with the Gini coefficient, and the nature of underlying inequality visually represented by the associated Lorenz Curve (McGuire, 1983; Peterson & Drennan, 2018). Gini values range from zero at perfect equality, to approximately one, when all wealth is held by a single individual. The Lorenz curve plots cumulative share of wealth with increasing percentile of the wealth distribution. Estimating the Gini coefficient of inequality based on the recovered burials as a sample of the population produces a value of 0.96 (0.93–0.99 at  $1\sigma$  confidence) at Kalawwasa Rummeytak. The Gini value for Middle Period sites in Central California is 0.97 (0.94–0.98 at  $2\sigma$  confidence) based on a large sample of excavated sites (Milliken, 2018; Bettinger, 2015; Milliken & Bennyhoff, 1993).



**TABLE 1** *Kalawwasa Rummeytak* burials and grave associations.

Burial	Sex	Age at death	Grave assoc.	<i>Olivella</i> #	Cal BP	Exclusive breastfeeding (months)	Weaning (months)
<b>3</b>	F	20–22		0		4	26
<b>4</b>	F	30		0		8	42
<b>6</b>	M	18–20		0		12	45
<b>7A</b>	F	35–40		0		6	24
<b>7B</b>	M	25–32		0	2583	7	22
<b>7C</b>	I	6		0		12	30
<b>8A</b>	F	10–14		0		12	42
<b>8B</b>	M	40–45		0		6	24
<b>9</b>	F	12–15		0		8	36
<b>11</b>	F	45	“Lots of <i>Olivella</i> beads”	?		-	-
<b>12</b>	M	16–18		0	2313	18	42
<b>13</b>	F	40–44	<i>Olivella</i> and <i>Haliotis</i>	1226	1450	-	51
<b>14</b>	I	Adult	<i>Olivella</i> and <i>Haliotis</i>	8			
<b>15A</b>	M	50–60		0	1226	9	30
<b>16A</b>	F	38–45	<i>Olivella</i>	603		4	27
<b>18</b>	M	35		0		8	33
<b>20</b>	M	50–55		0		6	27
<b>21</b>	M	40	3 <i>Haliotis</i> pedants	0		6	26
<b>23</b>	F	>45	<i>Olivella</i>	148	2583	-	42
<b>WSA1</b>	F	>60		0			
<b>WSA2</b>	I	4–5		0		11	31
<b>WSA3</b>	M	>60	Groundstone frag	0	2585	-	-
<b>WSA4</b>	I	Adult		0			
<b>WSA5</b>	I	40–45	<i>Olivella</i> beads, groundstone fragment	174			
<b>WSA6</b>	M	15–17		0	2484	11	32
<b>WSA7</b>	I	3–4		0	2518	12	-
<b>WSA8</b>	I	6–10	<i>Olivella</i> beads	1		8	41
<b>WSA9</b>	I	2.5–3.5		0			
<b>WSA10</b>	M	35–40		0			
<b>WSA11</b>	M	35–45		0			
<b>WSA12</b>	M	30–35		0			
<b>WSA13</b>	M	16–17	<i>Haliotis</i> bead, groundstone fragment	0			

Note: Bolded burial numbers are individuals sampled for isotopic analysis in the current study. Exclusive breastfeeding and weaning ages are listed in months. Calibrated dates are median date from Bchron with Intcal 20 (Haslett & Parnell, 2008).

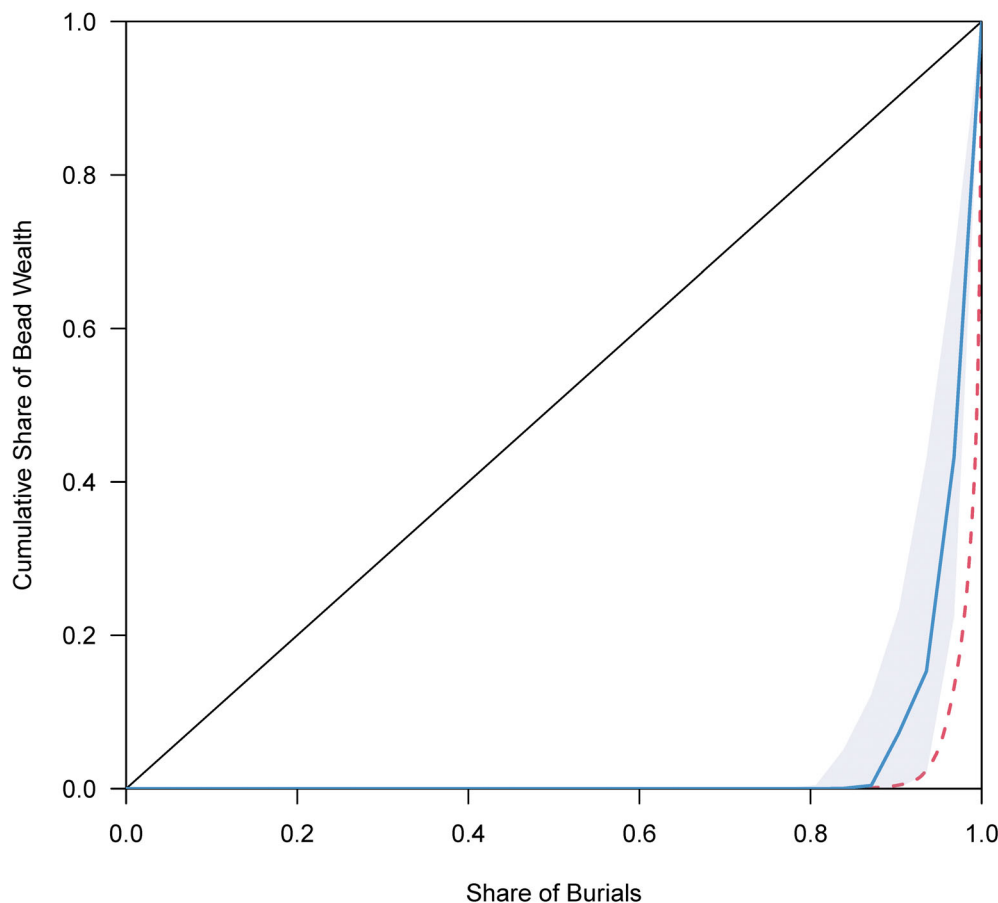
Figure 2 compares the bead wealth Lorenz curve for *Kalawwasa Rummeytak* and other Middle Period burials.

*Kalawwasa Rummeytak* looks less similar to other Middle Period sites when the distribution of *Olivella* bead wealth by sex is examined. For the Middle Period as a whole, burials identified as female slightly more frequently include beads (25.5%) than do male burials (22.3%), but not nearly as frequently as the 40% of female burials at *Kalawwasa Rummeytak*. Middle Period males were buried with more beads ( $\bar{x} = 200.4$ ) than females ( $\bar{x} = 58.6$ ).<sup>1</sup> At *Kalawwasa Rummeytak*, female burials were recovered with an average bead count over 220, while no *Olivella* beads were found with male burials. Due to the difficulty

in accounting for adult burials with indeterminate sex, it is not possible to exactly quantify the difference in burial wealth share, but in contrast to the Middle Period as a whole, where male burials held a larger share of total burial wealth, at *Kalawwasa Rummeytak*, bead wealth was concentrated in female burials. There is insufficient data on Middle Period bead wealth distribution in the Santa Clara Valley at other sites known or hypothesized to be matrilocal; it is probable that data from other, patrilocal, areas of Central California are obscuring regional trends in the Santa Clara Valley.

Regional Sr isotope data and female-biased wealth inequality suggest *Kalawwasa Rummeytak* may have been matrilocal. We expect to

## Lorenz Curve



**FIGURE 2** Empirical Lorenz curve for burial bead wealth at *Kalawwasa Rummeytak* (solid blue, with  $1\sigma$  bootstrapped confidence interval shaded) and other Central California Middle Period burials (dashed red). The diagonal line represents perfect equality (Gini = 0).

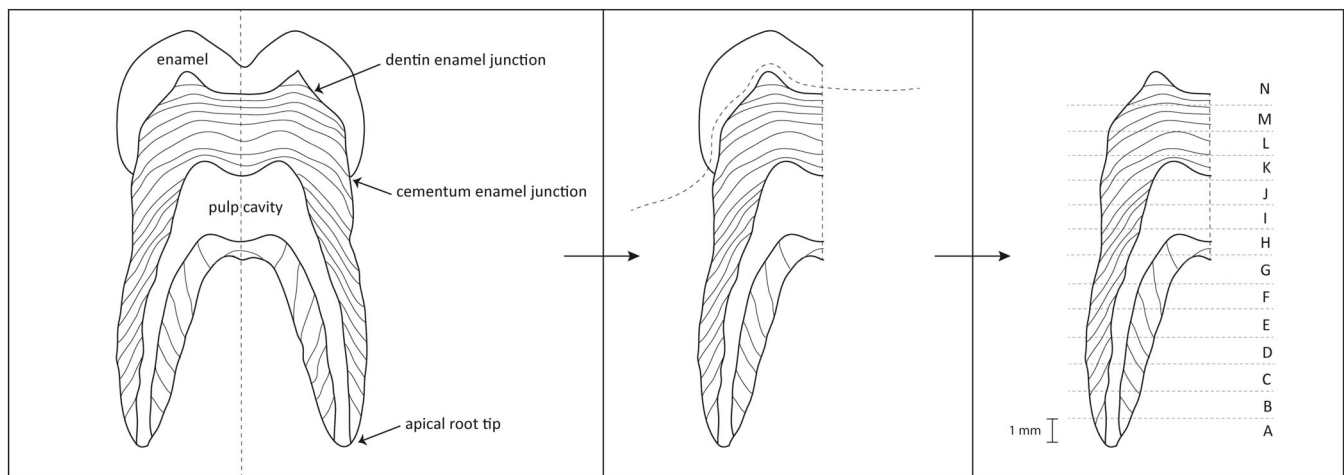
see greater levels of parental investment, as measured by weaning age, in female offspring because they are more likely to remain in their natal community in higher proportions and are a source of important labor and local knowledge. The corollary of this is that parents should invest less in male offspring, who are more likely to disperse from their natal communities.

### 3 | ISOTOPIC ANALYSIS

Human biological tissues record isotopic evidence of the food and water sources consumed by individuals. Foods vary in their stable isotope composition, including the ratio of  $^{13}\text{C}$  to  $^{12}\text{C}$  and  $^{15}\text{N}$  to  $^{14}\text{N}$ . These elements, and their stable isotope ratios, are metabolized, often undergoing internal fractionation, and incorporated into tissues. Collagen—the primary organic component of bodily tissues—is synthesized primarily from dietary protein, and therefore reflects the stable isotope ratios of individuals' protein consumption (Ambrose & Norr, 1993; Schoeninger, 1985; Schwarcz, 2000; Tieszen & Fagre, 1993).

Bone is approximately 27% collagen, and is remodeled throughout an individual's life. Depending on the skeletal element, tissue turnover occurs every 5–20 years (Hedges et al., 2007; Manolagas, 2000; White & Folkens, 2005). Stable isotope measures derived from bone

collagen are indicative of dietary protein consumed during the individual's last decades of life (Eerkens & Bartelink, 2013; Schwarcz & Schoeninger, 1991). Unlike bone, permanent teeth do not experience tissue turnover and replacement, though secondary dentin growth may occur in the pulp cavity during adulthood in response to trauma or biomechanical forces (Hillson, 1986; White & Folkens, 2005). The interior portion of the root and much of the crown is comprised of dentin, which is approximately 20% collagen. Dentin accrues incrementally, forming from the dentin-enamel junction (DEJ) in the crown to the apical root tip, with growth layers—similar to tree rings or sediment strata—accumulating at a predictable rate during tooth ontogeny (Hillson, 1986; Hillson, 1996) (Figure 3). Permanent first molars, as opposed to deciduous teeth, begin development at birth, erupt at around six years of age, and complete root development at age eight to eleven (Alqahtani et al., 2010; Gustafson & Koch, 1974; Hillson, 1986; Hillson, 1996). Cutting small serial samples of first molars permits isotopic analysis of diet during small-time intervals of an individual's childhood. Because the angle of dentinal growth layers slowly changes from roughly horizontal in the crown to over  $45^\circ$  in the lower portions of the root (Hillson, 1996) our horizontal slices from the root overlap slightly in their temporal range and result in time averaging (Figure 3). This time averaging is on the order of months, as opposed time averaging over years resulting from bone collagen data.



**FIGURE 3** Diagram of molar anatomy depicting age-related landmarks (dentin enamel junction (DEJ) and cementum enamel junction (CEJ)), cross-section of the tooth, removal of the enamel, and serial micro-sections taken from the apical root tip to the DEJ.

Nitrogen isotope ratios, expressed as  $\delta^{15}\text{N}$ , display a trophic-level effect, wherein the collagen of a consumer will be enriched 2%–4% over the source of dietary protein (Schoeninger, 1985; Schwarcz & Schoeninger, 1991). This effect is preserved in the isotopes of serial samples in first molars. Thus, dentin from coronal sections, corresponding to breastfeeding infants, generally exhibit  $\delta^{15}\text{N}$  variation at one trophic level above collagen from adult bone (Beaumont et al., 2012; Eerkens et al., 2011; Fuller et al., 2003; Fuller, Fuller, et al., 2006; Fuller, Molleson, et al., 2006). An infant exclusively consuming breastmilk will exhibit maintenance of this elevated nitrogen enrichment across multiple coronal samples. When a child is introduced to supplementary foods and transitions to greater quantities of household resources relative to breastmilk,  $\delta^{15}\text{N}$  predictably drops, as measured in dentinal collagen (Eerkens et al., 2011; Fuller et al., 2003). A child is considered fully weaning when  $\delta^{15}\text{N}$  matches that of the average adult values at the site/ecological zone. Post-weaning  $\delta^{15}\text{N}$  indicates the approximate trophic level of dietary protein for an individual. In terrestrial environments, low  $\delta^{15}\text{N}$  (6‰–8‰) indicates consumption of primarily plant-based proteins, while higher levels indicate incorporation of increased levels of animal-derived proteins (Figure 4).

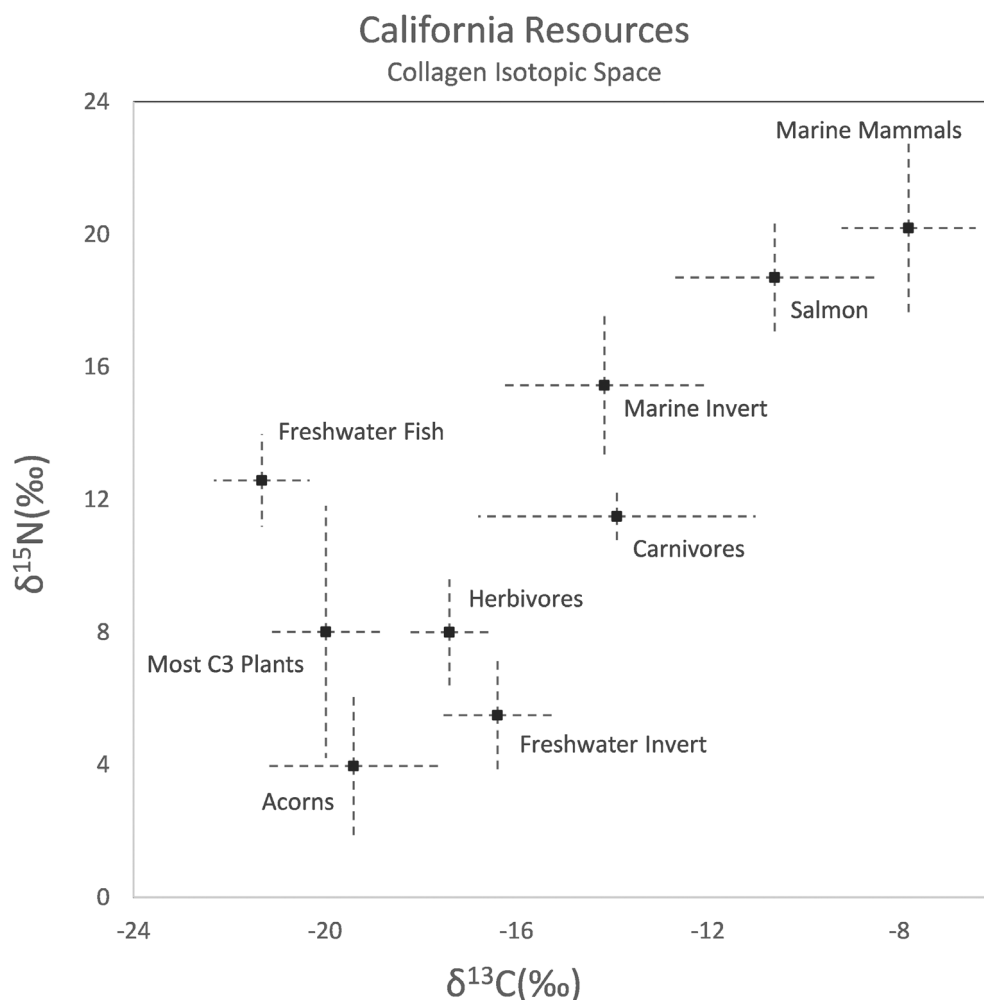
Stable carbon isotopes show a correlation with the source of dietary protein, rather than trophic scale. In Central California, stable carbon isotopes track marine versus terrestrial sources to the total protein budget (Figure 3). In coastal settings, this permits the detection of shellfish, fish, and marine mammal consumption. In interior regions, it more closely reflects consumption of anadromous fish such as salmon and sturgeon (Chisholm et al., 1982; Eerkens et al., 2011; Eerkens & Bartelink, 2013; Fuller, Fuller, et al., 2006; Fuller, Molleson, et al., 2006; Schoeninger & DeNiro, 1984). Freshwater fish and shellfish exhibit strong differences in stable carbon enrichment, and can be differentiated from anadromous and marine protein sources (Bartelink, 2006). Stable carbon isotope ratios may also be used as an indicator of the dietary importance of  $\text{C}_3$  versus  $\text{C}_4$  plants, which allows archaeologists to assess the use of  $\text{C}_4$  plants such as maize,

sorghum, and millet in human diets, or as fodder for animals consumed by humans (Schoeninger, 2009). However, in Central California,  $\text{C}_4$  plants may be ruled-out as a source of protein. Plants utilizing the  $\text{C}_4$  photosynthetic pathway are uncommon in California's Mediterranean climate, and were not a significant contributor to the subsistence economy of foragers in the region (Bartelink et al., 2020).

In contrast to dietary stable isotopes that occur in concentrations determined by fractionation events during metabolic activity and provide evidence of their incorporation into the diet, geographic isotopes result from physical fractionation and are incorporated into tissues based on their concentration in local surface and ground water (Budd et al., 2000; Capo et al., 1998; Ericson, 1985; Faure, 1986). This provides evidence of the geographic location of individuals during tissue formation throughout their lives. This study focuses on strontium isotope ratios ( $^{86}\text{Sr}/^{87}\text{Sr}$ ), which occur when a geological formation rich in radioactive rubidium ( $^{87}\text{Rb}$ ) decays into its daughter isotope  $^{87}\text{Sr}$ , which will, therefore, be found in greater abundance only in geological formations that were once rich in its radioactive parent (Bentley, 2006; Ericson, 1985; Price et al., 2002). Strontium isotopes are incorporated into bone and tooth apatite in proportion to their concentration in locally available water. These variations across the landscape are well documented in California where numerous studies have leveraged strontium isotopes to document individuals' movement throughout their lives and reconstruct associated kinship patterns (Eerkens et al., 2014; Eerkens, Carlson, et al., 2016; Eerkens, Harold, et al., 2016; Ericson, 1985; Harold et al., 2016; Jorgenson, 2012; Jorgenson et al., 2009).

Sampling strontium ratios in tooth and bone apatite permits the reconstruction of an individual's movement during the window of formation of the sampled tissue. The most common approach, and the one taken in the current study, is to sample enamel apatite from individuals' permanent first molars to identify residence in the first several years of life, from third molars to identify residence in early adolescence, and from bone in adults to identify residence in the last 10 years of adulthood (Eerkens et al., 2014; Eerkens, Carlson, et al., 2016; Eerkens, Harold, et al., 2016; Harold et al., 2016; Jorgenson, 2012; Jorgenson et al., 2009).





**FIGURE 4** Plot of economically important food resources of Central California in collagen isotopic space.  $\delta^{13}\text{C}$  values are on the x-axis and  $\delta^{15}\text{N}$  values are on the y-axis. Error bars indicate  $\pm 1$  SD, the combined source + discrimination SD calculated as  $\sqrt{(\sigma^2_{\text{source}} + \sigma^2_{\text{discr}})}$ , under the assumption of independence. Isotopic values based on Bartelink (2006).

Individuals' movement across the landscape, especially in a relatively sedentary population, reflects residence patterns indicative of kinship-related practices. In patrilocal groups, a majority of males remain in their natal community and strontium values across first and third molars and bones should remain in the local range for the site. Females marrying into a patrilocal group are expected to exhibit non-local first and third molar strontium signatures, and adult bone within the local strontium range. In matrilineal groups, a majority of females remains in their natal group, and their strontium values are expected to fall in the local range across first and third molars and bone. First and third molar strontium measures in males marrying into a matrilineal group are expected to be non-local to the site, with adult bone strontium signatures in the local range. Among groups practicing flexible or neolocal postmarital residence patterns, strontium signatures would not vary predictably based on sex.

## 4 | METHODS

### 4.1 | Sampling

Well-preserved first molars, third molars, and bone, were sampled from 22 *Kalawwasa Rummeytak* burials housed in museum collections at San

Jose State (Table 1) for carbon and nitrogen analysis, and 18 individuals were sampled for strontium analysis (Table 3). This work was conducted with permission from, and in collaboration with, the Muwekma Ohlone Tribe of the San Francisco Bay. The Native American Heritage Commission of California has identified this tribe as the Most Likely Descendants (MLDs) of individuals from *Kalawwasa Rummeytak*.

### 4.2 | Stable carbon and nitrogen isotope analysis

Extracted first molars were photographed prior to beginning destructive analysis. Any calculus adhering to the teeth was removed and saved for future analysis. Molars were subsequently sonicated in deionized water ( $\text{dH}_2\text{O}$ ) for 5–10 min and then cut in half with a slow-speed diamond saw to focus isotopic analyses on one crown-root sequence. Enamel and cementum, as well as any secondary dentin growth in the pulp cavity, was removed with a Freedom drill equipped with a diamond grit bit. Teeth were demineralized in 0.5 molar HCl at  $5^\circ\text{C}$ . The HCl was replaced every 1–2 days for approximately 5–14 days until the tooth no longer reacted with the solution and was soft and spongy. Following demineralization, the tooth was rinsed with  $\text{dH}_2\text{O}$ , and max-length, DEJ, and CEJ were again measured to

**TABLE 2** Post-weaning  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  values for sampled individuals at *Kalawwasa Rummeytak*

Burial	Sex	Age at death	Isotopic values							
			Post-weaning		6 years		9 years		Mean ( $\sigma$ )	
			$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
3	F	20–22	8.7	–19.2	8.7	–19.0	6.7	–19.7	7.8 (0.91)	–19.2 (0.50)
4	F	30	8.0	–20.1	8.0	–20.1	8.6	–19.9	8.0 (0.36)	–20.0 (0.13)
6	M	18–20	7.9	–19.2	7.9	–18.9	7.6	–19.6	8.1 (0.42)	–19.1 (0.27)
7A	F	35–40	9.4	–19.7	8.7	–19.6	7.7	–19.3	8.8 (0.48)	–19.2 (0.60)
7B	M	25–32	9.2	–19.5	8.9	–19.3	8.8	–19.2	8.8 (0.25)	–19.1 (0.27)
7C	I	6	10.0	–19.1	8.5	–18.1	-	-	10.1 (0.99)	–18.4 (0.38)
8A	F	10–14	7.8	–18.7	8.1	–18.5	7.3	–19.3	7.5 (0.51)	–19.0 (0.48)
8B	M	40–45	7.9	–20.0	6.0	–19.9	5.8	–19.8	6.5 (0.85)	–19.7 (0.32)
9	F	12–15	7.2	–19.5	5.8	–19.5	-	-	6.8 (0.81)	–19.3 (0.20)
11	F	45	-	-	9.6	–19.5	7.5	–19.9	9.1 (0.86)	–19.4 (0.41)
12	M	16–18	9.6	–19.1	9.2	–19.8	8.7	–19.7	8.9 (0.41)	–19.7 (0.28)
13	F	40–44	8.5	–19.5	8.0	–19.9	8.6	–20.1	8.3 (0.29)	–19.9 (0.24)
15A	M	50–60	7.3	–19.9	8.3	–19.5	8.9	–19.4	8.0 (0.52)	–19.6 (0.12)
16A	F	38–45	7.9	–18.9	7.6	–19.7	5.5	–20.1	7.8 (0.89)	–19.3 (0.46)
18	M	35	8.4	–19.6	7.8	–19.7	5.4	–20.0	7.5 (0.97)	–19.8 (0.12)
20	M	50–55	7.6	–20.0	6.7	–20.3	7.4	–20.4	7.2 (0.31)	–20.2 (0.32)
21	M	40	8.3	–20.3	8.6	–19.7	7.8	–20.0	8.3 (0.47)	–20.0 (0.16)
23	F	>45	7.8	–19.7	8.1	–19.9	-	-	7.9 (0.19)	–19.7 (0.12)
WSA2	I	4–5	9.7	–18.4	-	-	-	-	-	-
WSA3	M	>60	-	-	9.8	–18.2	10.8	–18.5	9.7 (0.45)	–18.1 (0.24)
WSA6	M	15–17	7.7	–19.3	8.3	–18.6	-	-	7.9 (0.26)	–18.9 (0.28)
WSA7	I	3–4	-	-	-	-	-	-	-	-
WSA8	I	6–10	-	-	-	-	-	-	-	-

account for any volume loss associated with demineralization. Despite absence of enamel at this stage, the CEJ remains as a clear visible landmark due to distinct color differences between dentin that was formerly covered by enamel and formerly covered by root cementum, and an obvious cervix, or contraction, as the crown transitions to the root (lending the landmark its common name—the *cervico*-enamel junction). Teeth were then cut with a surgical steel blade into 10–20 thin parallel sections approximately 1–2 mm thick, perpendicular to the central axis of the root, controlling for age-related landmarks [dentino-enamel junction (DEJ), cervico-enamel junctions (CEJ), and apical root tip] that permit the age estimates for each serial section (see Figure 3). The serial samples were placed in separate glass vials and treated with 0.125M NaOH at 20°C for 24 h to remove humic contaminants. Samples were then rinsed with  $\text{dH}_2\text{O}$ , immersed in a  $\text{pH} \approx 3$  HCl solution and placed in an oven at 80°C for 24–48 h to solubilize the collagen. Solubilized samples were centrifuged, with the liquid fraction removed and frozen. The cortical component of bone samples was isolated and cleaned, and subject to the same chemical processing as teeth described above.

The frozen solubilized collagen from tooth serial samples and bone was then freeze dried using a VirTis 50-SRC-5 Freeze Dryer

housed at the UC Davis Food Science and Technology Pilot Plant. One milligram of lyophilized collagen from each tooth section and bone sample was weighed out on a high precision balance, pressed into tin capsules, and analyzed for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  on a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20–20 light isotope ratio mass spectrometer (IRMS) at the UC Davis Stable Isotope Facility (SIF). Long-term analysis of standards indicates instrument precision of 0.2‰ and 0.3‰ for  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$ , respectively.

### 4.3 | Analysis

To assign median age estimates to each serial sample, samples' locations, as measured during sectioning, were compared to the stage of first molar dental development and associated temporal markers and growth rates as defined by the London Atlas (Alqahtani et al., 2010; Czermak et al., 2020; see also Hillson, 1996). Duration of exclusive breastfeeding is estimated by identifying the point (and associated age assignment) at which nitrogen enrichment initiates a drop from its apex at 2‰–4‰ in  $\delta^{15}\text{N}$  above adult values corresponding to the onset of supplemental food introduction. Age at complete cessation

**TABLE 3** Strontium values for adolescent and adult individuals with sex determinations at *Kalawwasa Rummeytak*.

Burial	Sex	Age at Death	M1 Sr	M3 Sr	Bone Sr
3	F	20–22	0.7081	0.7080	0.7076
4	F	<b>30</b>	<b>0.7076</b>	<b>0.7078</b>	<b>0.7075</b>
5	M	50	0.7082	0.7079	0.7075
6	M	18–20	0.7080	0.7080	0.7075
7A	F	35–40	0.7079	0.7078	0.7076
7B	M	25–32	0.7078		0.7075
8A	F	10–14	0.7081		0.7075
8B	M	40–45	0.7079		0.7076
9	F	12–15	0.7068	0.7068	0.7075
11	F	<b>45</b>	<b>0.7075</b>	<b>0.7072</b>	<b>0.7076</b>
12	M	16–18	0.7078	0.7078	0.7076
13	F	40–44	0.7078	0.7079	0.7075
15A	M	50–60	0.7083	0.7081	0.7076
16A	F	38–45	0.7080		0.7077
18	M	35	0.7077	0.7079	0.7075
20	M	50–55	0.7077	0.7080	0.7075
21	M	40	0.7079	0.7079	0.7076
23	F	<b>&gt;45</b>	<b>0.7075</b>	<b>0.7076</b>	<b>0.7075</b>

Note: Individuals who lived as adults in their natal community are in bold.

of breastmilk consumption (weaning) occurs at the point when  $\delta^{15}\text{N}$  drops to the average adult values at the site/ecological zone.

Post-weaning  $\delta^{15}\text{N}$  indicates the approximate trophic level of dietary protein for an individual. In terrestrial environments, low  $\delta^{15}\text{N}$  (6‰–8‰) indicates consumption of primarily plant-based proteins, while higher levels indicate incorporation of increased levels of animal-derived proteins (Figure 4). Carbon enrichment indicates the degree to which dietary protein is derived from marine versus terrestrial environments. Post-weaning dietary shifts may be tied to biological age using the same method described above.

#### 4.4 | Strontium isotopic analysis

First molars, third molars (when available), and bone were sampled from 18 adolescent and adult individuals with high confidence sex determination (Table 3). Powdered bone and enamel (~0.05 g each) were treated with 2 mL of 15% hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), sonicated for 5 min, and soaked for 24 h to remove organic material. Samples were then rinsed in distilled water, dried down, treated with 2 mL of 0.1 N acetic acid, and soaked for 24 h to remove secondary non-biogenic carbonates. Samples were then rinsed twice with distilled water, dried down and dissolved with 4 mL of 2.5 N hydrochloric acid (HCl). All samples were dissolved completely with no residual solids remaining by placing them on a hotplate for 24 h in HCl solution. Samples were then dried down to evaporate HCl. Samples were subsequently brought up in 800  $\mu\text{L}$  of 8 N nitric acid ( $\text{HNO}_3$ ) and centrifuged. The supernatant was loaded

onto teflon columns containing Eichrom<sup>®</sup> Sr Spec resin. Rubidium (Rb), barium (Ba), lead (Pb), and most other elements were eluted in 2 mL 3 N  $\text{HNO}_3$ . Sr was collected in 2.8 mL of 0.5 N  $\text{HNO}_3$ , dried down and reloaded onto the columns a second time (in 8 N  $\text{HNO}_3$ ) to ensure complete purification of Sr from Rb. All acids employed were distilled to ensure purity and titrated to ensure the correct concentrations.

Strontium isotope ratios were determined by Nu Plasma HR MC-ICP-MS at the University of California, Davis Interdisciplinary Center for Plasma Mass Spectrometry. Sample solutions were introduced through a DSN 100 desolvating nebulizer and isotope analyses were mass-fractionation corrected internally to the 'true'  $^{86}\text{Sr}/^{87}\text{Sr}$  ratio of 0.1194.  $^{85}\text{Rb}$  and ions with mass 84 (including  $^{84}\text{Kr}$  and  $^{84}\text{Sr}$ ) were monitored to correct for  $^{87}\text{Rb}$  interfering with  $^{87}\text{Sr}$  and  $^{86}\text{Kr}$  with  $^{86}\text{Sr}$ , respectively.  $^{85}\text{Rb}$  was only present at a few mV or less due to the double-pass of Sr through the columns.  $^{84}\text{Kr}$ , and by extension  $^{86}\text{Kr}$ , interference on  $^{86}\text{Sr}$  was corrected by iterations using the assumption that  $^{84}\text{Sr}/^{86}\text{Sr} = 0.00675476$ .

## 5 | RESULTS

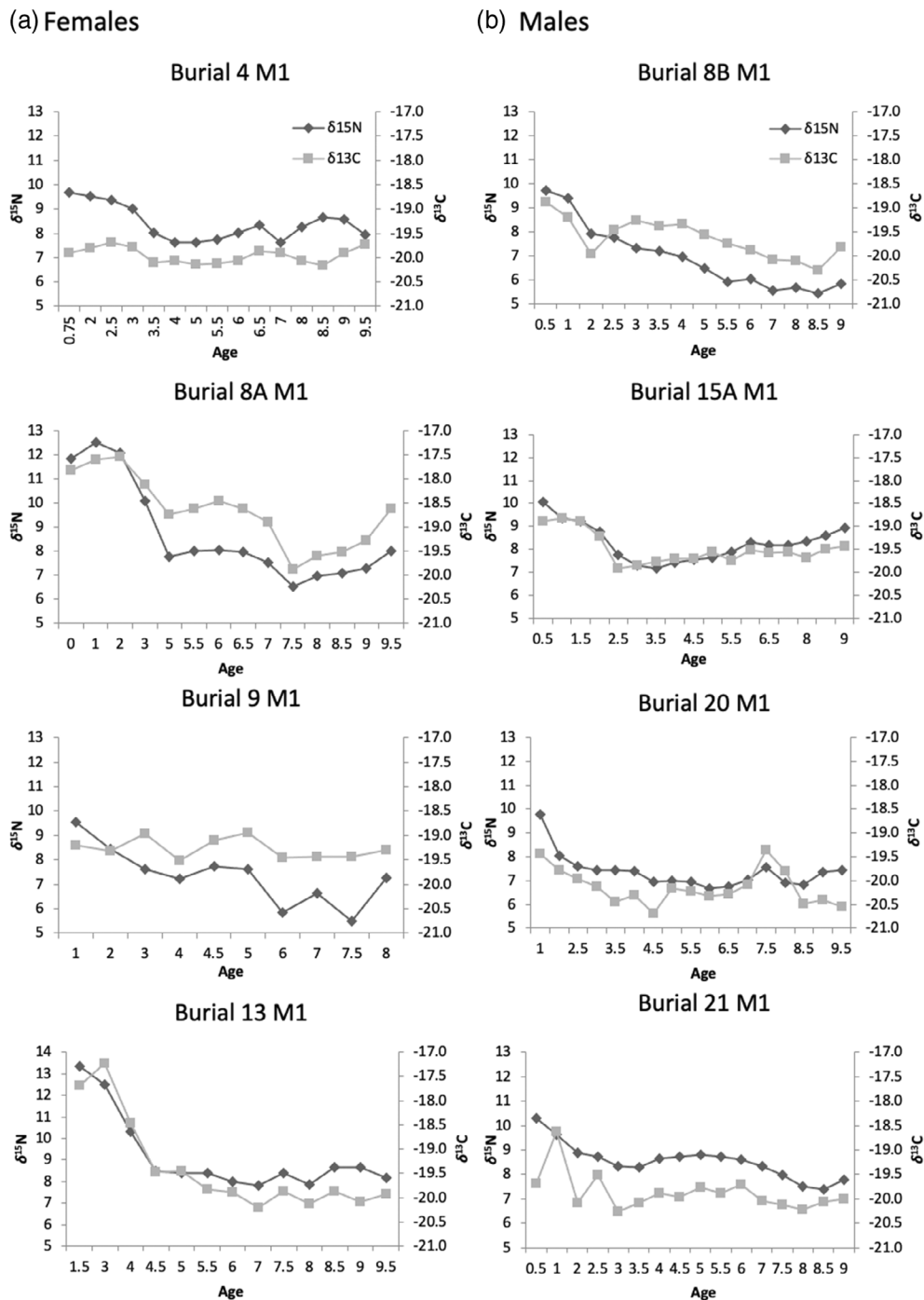
### 5.1 | Breastfeeding and weaning

Seventeen of the 31 individuals recovered as part of a 2001 excavation led by the previous Muwekma Ohlone Tribe's Cultural Resource Management arm Ohlone Families Consulting Services and 5 of 13 excavated by the William Self and Associates excavation were sampled for the current study (Table 1). Duration of breastfeeding and weaning was inconclusive for two individuals (Burials 11 and WSA3). Two individuals (Burials 13 and 23) had no discernable transition from exclusive breastfeeding to supplementation of breastmilk, although they exhibited clear weaning signals. Both these individuals are older adults, with a degree of occlusal tooth wear that obliterated the coronal portion of the tooth that formed during first 12–18 months of their life.

The average duration of exclusive breastfeeding at *Kalawwasa Rummeytak* is 8.8 months  $\pm$  3.5 (1 SD). Infants at the site were provisioned with supplemental foods dominated by  $\text{C}_3$  plants and terrestrial herbivores. As indicated by higher  $\delta^{13}\text{C}$  values, a few individuals (Burials 7A, 8A, 16A) were also provisioned with  $^{13}\text{C}$  and  $^{15}\text{N}$ -enriched fish during the weaning process in addition to  $\text{C}_3$  plants and terrestrial herbivores. This variable inclusion of these fish in the Santa Clara Valley is consistent with previous findings in the region that suggest periodic access to the resource is associated with years of good and bad runs (Greenwald, Eerkens, et al., 2016), and fish as a weaning food has also been previously documented in Central California, where evidence suggests dried fish is pulverized and mixed with acorn mush (Greenwald, DeGeorgey, et al., 2016). The average weaning age is 33.7 months, or 2.8 years,  $\pm$  8.4 mos (1 SD). First molar serial sample charts for a subsample of eight individuals from CA-SCL-134 are presented below in Figure 5.

Among females, the average duration of exclusive breastfeeding is 7 months  $\pm$  3.0 (1 SD). Males were exclusively breastfed 9.2 months

**FIGURE 5** First molar serial-sample charts for *Kalawwasa Rummeytak* burials 4, 8A, 8B, 9, 13, 15A, 20, and 21.



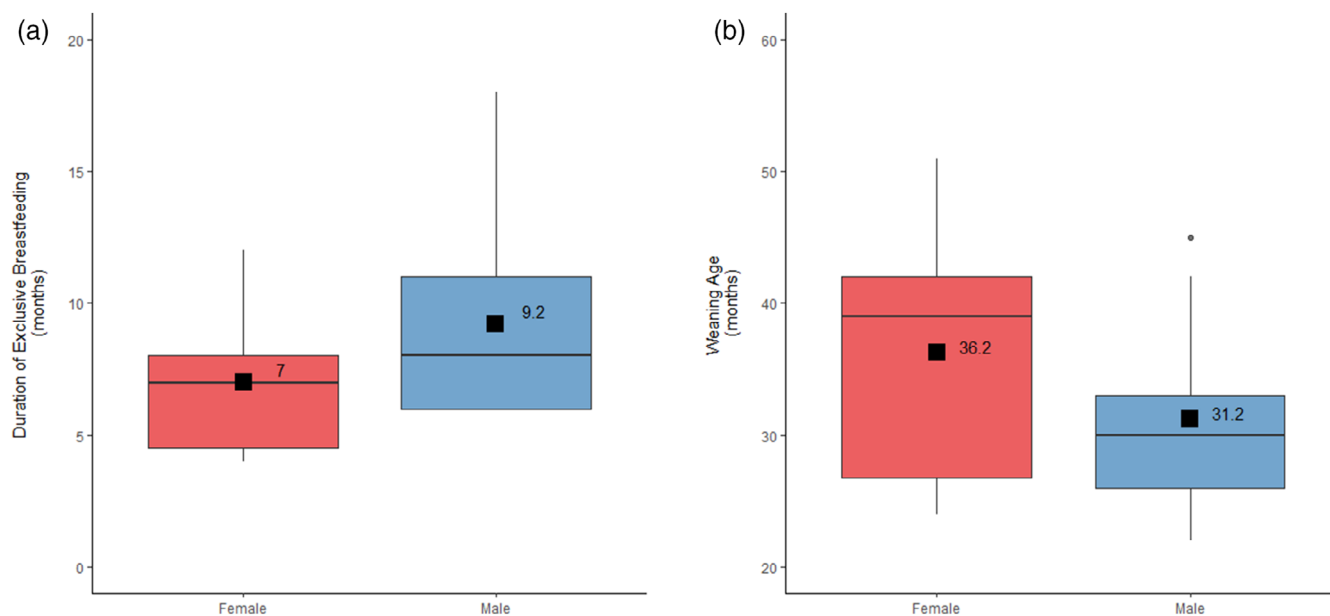
$\pm 4$  (1 SD) (Figure 6a). This trend is reversed for average weaning age. The average weaning age for females at *Kalawwasa Rummeytak* is  $36.3 \text{ months} \pm 9.7$  (1 SD), or just over 3 years. The average weaning age for males is  $31.2 \pm 7.9$  months (1 SD), or about 2.6 years (Figure 6b). Small sample size precludes statistical significance.

## 5.2 | Childhood diet

$\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  isotopic values for individuals at several points in time, including immediately after the completion of the weaning process,

and at around ages 6 and 9 years, are presented in Table 2 and Figure 7. The post-weaning average and standard deviation for first molar serial samples is also presented. Weaning age and post-weaning isotopic values could not be determined for Burial 11. In some cases, isotopic signatures were unavailable for the specified age categories used due to tooth wear, tooth damage (i.e., broken roots), low collagen yield in a particular serial sample, or instrument failure.

After weaning, the sampled individuals interred at *Kalawwasa Rummeytak* consumed a diet dominated by acorns,  $\text{C}_3$  plants, and terrestrial herbivores. Several individuals, including Burials 7C, 8A, 16A, WSA2, and WSA3 appear to have consumed  $^{13}\text{C}$  and  $^{15}\text{N}$ -enriched fish



**FIGURE 6** Average duration of exclusive breastfeeding (a) and average weaning age (b) for females and males at *Kalawwasa Rummeytak*.

(e.g., marine or anadromous fish) in early childhood. By ages 6–9, however, the  $^{13}\text{C}$  and  $^{15}\text{N}$  enrichment associated with consumption of anadromous fish is no longer apparent among all but WSA3 (Table 2).

In general, *Kalawwasa Rummeytak* residents experience a net reduction in  $^{15}\text{N}$  enrichment throughout childhood. Some individuals exhibit considerable fluctuations in  $\delta^{15}\text{N}$ , driven primarily by increased inclusion of terrestrial game in the diet, indicative of periodic dietary variation (Table 2).

Despite evidence of a strongly female-biased distribution of grave goods and notable variation in weaning age between females and males at *Kalawwasa Rummeytak*, sex-based differences in childhood diet are small. Immediately after weaning, males and females at *Kalawwasa Rummeytak* exhibit similar average  $\delta^{15}\text{N}$  values. Females, on average, have marginally greater  $\delta^{13}\text{C}$  values than males. This trend is primarily driven by the elevated  $\delta^{13}\text{C}$  values noted post-weaning in Burials 8A and 16A associated with a short period of  $^{13}\text{C}$  and  $^{15}\text{N}$ -enriched fish consumption in these females' early lives. Comparisons between females and males at 6 and 9 years of age show children of both sexes are consuming, on average, nearly identical diets, which does not indicate sex-biased post-weaning investment by parents.

### 5.3 | Residence patterns

Strontium isotope ratios were recorded on all 18 sampled adolescents and adults with reliable sex determinations. Bone samples produced an average  $^{87}\text{Sr}/^{86}\text{Sr}$  of  $0.7075 \pm 0.000097$  (Table 3, Figure 8), consistently between 0.7074 and 0.7076 (95% CI). This narrow range defines the local signature for *Kalawwasa Rummeytak*, depicted in Figure 8 as a horizontal band with dashed lines.

Three females (burials 4, 11, and 23), or 30% of the female sampled population, exhibit local first molar  $^{87}\text{Sr}/^{86}\text{Sr}$  values, suggesting that *Kalawwasa Rummeytak* is their natal community (Table 3,

Figure 7). All other individuals appear to have been born and spent their childhoods elsewhere and migrated to the site in early adulthood. None of the males interred at *Kalawwasa Rummeytak* are locals.

Most individuals, irrespective of sex, exhibit non-local third molar  $^{87}\text{Sr}/^{86}\text{Sr}$  values, including two of the three women who spent both early childhood and adulthood in their natal community. This suggests that both males and females spent early adolescence outside the local  $^{87}\text{Sr}/^{86}\text{Sr}$  range of *Kalawwasa Rummeytak*.

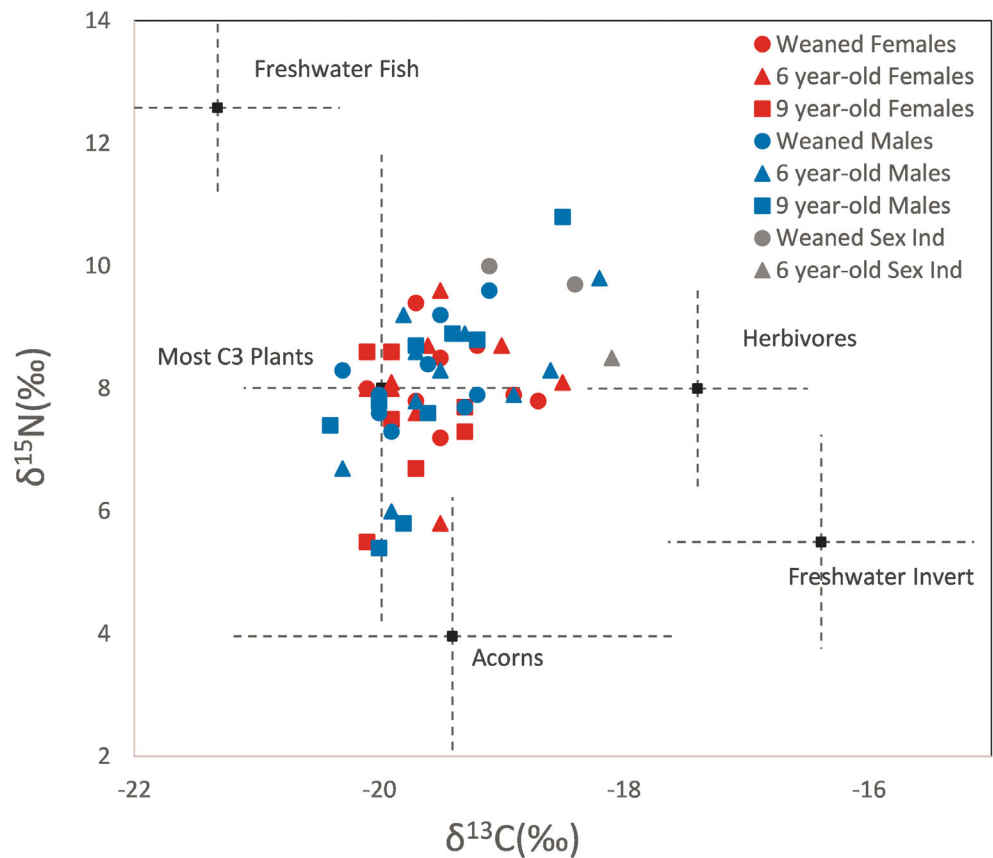
## 6 | DISCUSSION

Females interred at *Kalawwasa Rummeytak* are, on average, breastfed longer than males interred at the site. This younger average weaning age among males may suggest reduced maternal investment, as compared to females. Due to small samples sizes, however, these results are not significant. This pattern is also noted at nearby Middle Period matrilocal site *Yuki Kutsumi Šaatoš Inūxw*, where average weaning age for females is  $40.5 \pm 3.5$  months and  $32.6 \pm 5.9$  months for males (Greenwald, 2017).

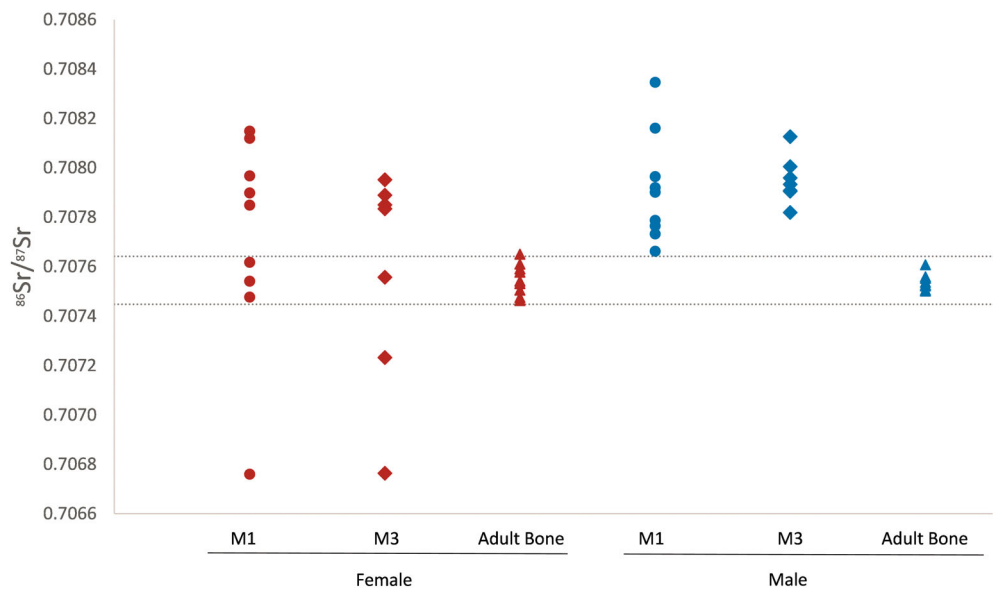
The pattern of extended exclusive breastfeeding among males to an average of 9 months, combined with shorted overall duration of breastfeeding, might also be suggestive of reduced investment in males. An infant's nutritional needs begin to outstrip both their mother's breastmilk nutritional content and production at 5–7 months of age. This means that mothers and alloparents must not only provide an infant with breastmilk, but also developmentally appropriate supplemental foods, to ensure healthy growth and development. Strassman has noted the presence of exclusive breastfeeding beyond 6 months in female infants among the patrilineal Dogon as a form of reduced investment; girls are denied household foods and experience growth stunting as infants due to delayed introduction of supplemental foods. Males at *Kalawwasa Rummeytak* could have experienced an



**FIGURE 7** Children's isotopic signatures plotted in collagen isotopic space at three points during development (at weaning, or complete cessation of breastmilk consumption, 6 years old, and 9 years old).



**FIGURE 8** Strontium ratios for males and females at *Kalawwasa Rummeytak*. The local strontium signature is depicted as a horizontal band.



analogous bias, with mothers delaying introduction of developmentally appropriate household foods. However, we note there is a paucity of additional ethnographic and archaeological data to support this conclusion; further investigation of this dynamic in archaeological and ethnographic populations is warranted.

Sex-bias in childhood diet is nonexistent, and stable isotope indicators of diet across individuals' childhoods suggest minimal dietary fluctuation across a broad area within the site's ecological

zone. Irrespective of sex, individuals interred at the site had access to a similar suite of food resources in childhood.

Strontium data suggest a mixed postmarital residence pattern that favors adult females remaining in their natal community. A third of adult females sampled for strontium analysis lived in their natal community as adults and were interred there, while none of the adult males interred at *Kalawwasa Rummeytak* were born or lived there in childhood or early adolescence.

Of the three females (burials 4, 11, and 23) who remained in their natal community, two yielded reliable data to estimate age at complete cessation of breastmilk (weaning) (burial 4 and 23). These individuals were both weaned at approximately 42 months, or 3.5 years of age, in contrast with the immigrant female average of  $34.3 \pm 10.7$  months (no significance). When locals' weaning age (42 months) is compared to all immigrants irrespective of sex ( $32.5 \pm 9.2$  months), the difference is significant ( $p = 0.001$ ,  $t$ -test, two-tailed heteroscedastic). Two of the three females who lived in and were interred in their natal community at *Kalawwasa Rummeytak* (burials 11 and 23) were buried with *Olivella* shell bead wealth. Two immigrant females, and one older adult individual of indeterminate sex were also buried with appreciable bead wealth (>10 beads). No males were interred with shell bead wealth.

In general, women at *Kalawwasa Rummeytak* appear to have obtained higher status and wealth during their lifetimes than the men interred at the site, and were more likely to have remained in their natal community. Wealth, in the form of thousands of *Olivella* shell beads and *Haliotis* ornaments, is disproportionately interred with older women at the site (Farnsworth et al., 2010; Morley, 2001). Post-marital residence pattern was flexible but skewed toward matrilocality. Local resource enhancement effects may have incentivized keeping women in their natal communities and investing more in female offspring. This is supported by the older weaning ages for females at *Kalawwasa Rummeytak*, as compared to males at the site.

In modern populations that have undergone the demographic transition and have ready access to infant formula for use in lieu of breastmilk, wealth is negatively correlated with duration of breastfeeding (Santana et al., 2018). However, ethnographic evidence suggests that in some traditional societies, wealth or status was leveraged to support increased maternal investment in the form of delayed weaning (e.g., Quinlan et al., 2003). Although isotopic reconstruction of breastfeeding duration for archeological populations has become common, examination of the correlation with wealth or status has seen little examination. In many cases, discrete archaeological cemetery populations limit the potential for cross-status analysis, with burial populations explicitly recognized as elite (e.g., Gregoire, 2019) or poor (e.g., Väre et al., 2022). In other studies, differences in status may be present, but are strongly correlated with other variables under analysis, including mobility, changing subsistence practices, demography, or cultural chronology (e.g., Pfeiffer et al., 2017; Scharlotta et al., 2018; Schurr, 2018). Because of uncertainty regarding the inheritance of status, markers of individual burial status do not necessarily imply that parents enjoyed the same status. Henderson et al. (2022) consider the correlation between bone pendent status markers and childhood diet, but do not explore the possibility a correlation with weaning age data presented in the same paper. The evidence presented here supports a tie between intergenerational status and prolonged breastfeeding within confined circumstances. Where applicable, future studies should probe the correlation between status and breastfeeding duration among foragers and other small-scale societies.

## 7 | CONCLUSION

This study examined postmarital residence pattern as a proxy for kinship systems and the duration of exclusive breastfeeding, age of weaning (complete cessation of breastfeeding), and early childhood diet as proxies for parental investment strategies at the Middle Period site, *Kalawwasa Rummeytak* (CA-SCL-134). Given the disproportionate accumulation of wealth among females, measured in quantity of *Olivella* shell beads interred in burials, we assumed that the site residents shared a regionally documented matrilineal kinship system, and corresponding matrilocal post-marital residence pattern, with surrounding sites from the same time period. Strontium evidence suggests a flexible postmarital residence pattern, albeit one that favored females remaining in their natal communities. All adult males were immigrants to the site, while a third of females remained in their natal community. Our hypothesis that matrilocality would favor female-biased investment in offspring was supported by evidence of older weaning ages among women at the site as compared to men.

Evidence from this site, as well as previously published work in the region, add to growing evidence that groups in what is now the San Francisco Bay Area likely practiced some degree of matrilocal postmarital residence patterns in the Middle and Late Holocene. Early in time, the trade-offs between local resource enhancement effects favoring matrilocality, and density-dependent competitive advantage favoring patrilocal, seem to have often fallen on the side of retaining women in their natal communities. This appears to switch after the Middle Period with the advent of the Medieval Climatic Anomaly (1100–700 BP), when resource shortage may have triggered higher rates of violent inter-group conflict (Allen et al., 2016), which likely favored maintaining males in their natal community in order to provide defense.

Our results highlight the diversity and adaptive flexibility of human kinship systems in response to local ecology, and the impacts these strategies have on women's roles in society, and on parents' reproductive and parental-investment decision-making. Archaeological evidence from this site suggests that groups that place a high value on the economic contributions of women invest more in girls and provide women viable avenues for the accumulation of wealth and prestige throughout their lives. This provides valuable insight, as our society struggles to address gender inequality and disparities in pay.

### AUTHOR CONTRIBUTIONS

**Alexandra M. Greenwald:** Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (supporting); investigation (lead); methodology (lead); writing – original draft (lead). **Gregory R. Burns:** Formal analysis (supporting); software (supporting); visualization (supporting); writing – review and editing (equal). **Jelmer W. Eerkens:** Funding acquisition (equal); methodology (equal); resources (equal); supervision (equal); writing – review and editing (equal). **Eric J. Bartelink:** Funding acquisition (equal); methodology (equal); writing – review and editing (equal). **Alan Leventhal:** Resources (equal); writing – review and editing (equal). **Monica V. Arellano:** Writing – review and editing (supporting).

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## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available as a supplement.

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## ENDNOTE

<sup>1</sup> Milliken and Bennyhoff (1993) prefer to exclude the extreme outlier case of Burial 25 at CA-ALA-413, a male with 28,287 beads, when generating comparative statistics. Excluding this case yields a mean value for Middle Period Males of 81.9 beads per burial.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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