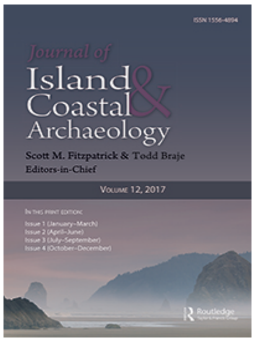

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Report

Modeling Breastfeeding and Weaning Practices (BWP) on the Coast of Northern Chile's Atacama Desert During the Formative Period

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ABSTRACT

Stable isotope analysis of bone collagen is frequently employed as a means of studying the breastfeeding and weaning practices (BWP) of archaeological populations. Such studies are strengthened greatly through the application of statistical models that permit precise and model-bound estimates of weaning age, duration, trophic enrichment, and the isotopic characterization of supplementary foods. Here we present the result of a stable isotope ($\delta^{15}N$) and Bayesian computational modeling study of bone collagen from human subadults from two coastal cemetery sites located near the mouth of the River Loa in the Atacama Desert. Recent bioarchaeological and paleodemographic research on remains from these marine hunter-gatherer sites, which are contemporary with the Formative Period (1500 BC–AD 400), has found evidence for notably elevated rates of female fertility. Ultimately, we argue that the modeled BWP parameters, which indicate the early introduction of supplementary foods, support an argument

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of high fertility as gleaned from the bioarchaeological evidence, and that these results provide novel insights into the child-rearing practices of the coastal populations of the Atacama. Indeed, these populations would have seemed to have developed a set of BWP that carefully balanced the biological and economic production/reproduction of the community.

Keywords archaeometry, bone, economy and subsistence, mortuary remains, Southern Andes

INTRODUCTION/BACKGROUND

Breastfeeding and weaning are fundamental to the mammalian, primate, and human life course, and have profound impacts at both the individual and societal level (Humphrey 2010; Sellen 2007; Stuart-Macadam and Dettwyler 1995). Anthropological studies of both modern and ancient societies have found huge global variation in breastfeeding practices and the timing and process of weaning (Stuart-Macadam and Dettwyler 1995; Tsutaya and Yoneda 2015). The study of breastfeeding and weaning practices (BWP) is important in the field of anthropology not only because of the high degree of inter-cultural variation in, for example, weaning time (Sellen 2001), but also because BWP can be a reliable proxy for female fertility. Although the exact mechanism is debated, the linkage between BWP and female fertility is well established in medical and public health literature, with more rapid supplementation and weaning permitting/promoting greater individual fertility and the potential for more rapid population growth (Bongaarts and Potter 1983; Campbell and Wood 1988; Howie and McNeilly 1982; McNeilly 1997; Wood 1994).

The Formative Period (1500 BC–AD 400) in Chile was a period in which a profound shift in subsistence strategies engendered acute social transformations. In much of northern Chile's Atacama Desert (Figure 1), the Formative Period saw the emergence of a suite of novel phenomena, including sedentism, agriculture, camelid pastoralism, surplus production fostering far-flung exchange networks, and burgeoning cultural and ceremonial complexity (Gallardo 2009; Lumbreras 2006; Núñez et al. 2006; Pimentel 2013). During this period, the marine hunter-gatherers of the coast increased their production of marine goods, began burying their dead in tumulus cemeteries, and exponentially increased their exchange with the agriculturalists and pastoralists of the interior oases (Ballester and Clarot 2014). While these coastal populations are not considered Formative in culture-historical terms (they did not live in villages nor practice agriculture/pastoralism), they are of Formative date, and their new economic and social forms gave rise to stable and surplus producing economies that fostered increasing population size and nucleation, brought about a reduction of residential mobility, saw an elaboration of mortuary practices in collective cemeteries, and fostered the development of region-wide systems of social interaction (Agüero et al. 2006; Agüero and Uribe 2011; Ayala 2001; Lumbreras 2006; Núñez 1971; Pestle et al. 2015a; Uribe 2009).

Rather little is known, from archaeological data, about the role(s) of women in the economic and social life of hunter-gatherer coastal communities of this era. Skeletal analysis of earlier (Archaic) coastal populations found stark sex-related differences in patterns of activity-related pathologies, differences attributed to male participation in fishing and marine hunting and female participation in marine gathering and child-rearing (Quevedo Kawasaki 2000). Sixteenth–nineteenth century ethnographic sources from the Atacama coast provide ample evidence of the differences in gender roles in an admittedly much later era, with fishing and long-distance

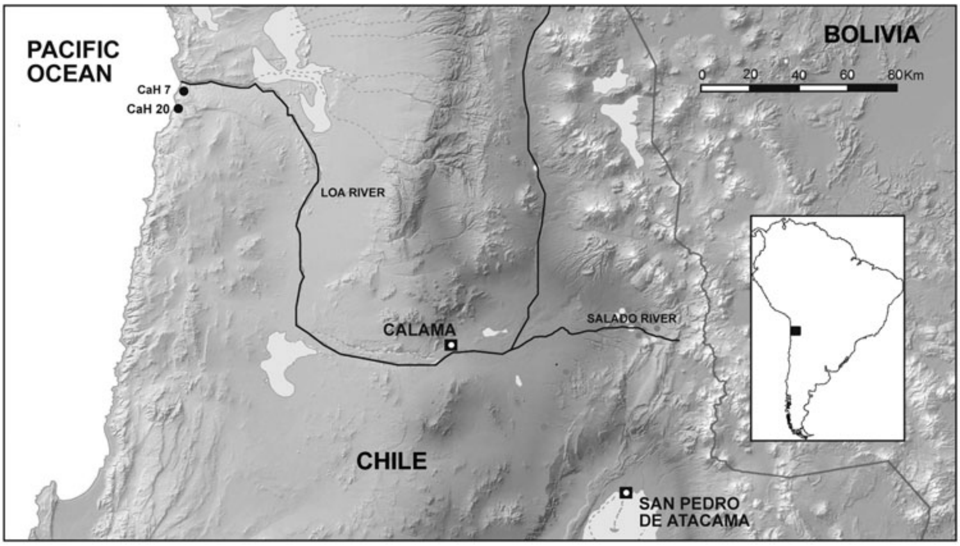

Figure 1. *Map of northern Chile with locations mentioned in text noted.*

travel/exchange being a male activity, whereas gathering (of marine mollusks and water), domestic activities, and child-rearing were the sole domain of females (Ballester et al. 2010; D'Orbigny ([1835–1847] 1945; Feuillée 1714; Pretty [1599] 1904). The centrality of female activities in the economic and social reproduction of their (admittedly temporally later) communities is evident from these accounts.

As already mentioned, a key element of the drastic socio-cultural changes of the Formative Period in northern Chile was the rapid growth of local populations. Indeed, bioarchaeological research on remains from a series of coastal sites contemporaneous with the Formative Period has found substantial evidence for elevated rates of female fertility. Clarot and Moraga (2016) calculated three indices of fertility: the D_{30+}/D_{5+} index (Buikstra et al. 1986; Konigsberg et al. 1989), the D_{5-14+}/D_{20+} index (Bocquet 1979; Bocquet-Appel and Masset 1982), and the crude birth rate (Weiss 1973, 1975; Weiss and Wobst 1973) for these coastal Atacama populations, which were then compared with three ethnographically well-studied hunter-gatherer populations (!Kung, Agta and Ache). In the case of all three indicators, and as seen in Table 1, the coastal populations of the Atacama Desert possessed much higher levels of fertility than those observed in any of the comparative populations (Clarot and Moraga 2016). All things being equal, we would expect this observed high fertility to be linked to an early average weaning time, a correlation seen in other archaeological examples of expanding populations (Tsutaya et al. 2015).

To test this hypothesis, we employed cross-sectional (i.e., not longitudinal)

Table 1. **Comparison of fertility indices among coastal Chilean and ethnographically documented hunter-gatherer populations.**

	D_{30+}/D_{5+}	D_{5-14}/D_{20+}	b
Chilean Atacama	0.33	1	0.24
Ache	0.63	0.26	0.21
Agta	0.77	0.05	0.13
!Kung	0.97	0.11	0.13

isotopic analysis of bone collagen and Bayesian computational modeling to investigate BWP in two cemetery populations from sites located near the mouth of the Loa River, the only river in the region that reaches the Pacific Ocean (Figure 1). Ultimately, the results of this study at least partially support an argument of high fertility as gleaned from the bioarchaeological evidence, suggest the development of a novel strategy balancing biological and economic necessities, and provide novel insights into the child-rearing practices (in particular the types of supplementary foods used during weaning) of the coastal populations of the Atacama.

ISOTOPE ANALYSIS AS A METHOD OF RECONSTRUCTING WEANING AGE

Biogeochemical methods, in particular stable isotope analysis, have become commonplace for the reconstruction of both paleodiet and ancient BWP (Fuller et al. 2006; Humphrey 2014; Lee-Thorp 2008; Pestle et al. 2014; Tsutaya and Yoneda 2015). As with other broader isotopic studies of paleodiet, the central premise of such analysis is that the consumption (and cessation of consumption) of a particular foodstuff, in this case breastmilk, will impart certain identifiable chemical characteristics in the biomolecular composition of consumer bone. While such analysis is predicated on certain assumptions (i.e., sufficient preservation of bone biomolecules, that breastmilk differs significantly from other available foods), "if a certain elemental signal systematically differs among breast milk, weaning foods, and the adult diet, BWPs can also be reconstructed" (Tsutaya and Yoneda 2015:3).

As Tsutaya and Yoneda (2015:4) note in their recent and extensive review of biogeochemical approaches to the reconstruction of BWP, "Nitrogen is the most frequently used element in the isotopic reconstruction of BWP," due to the clear trophic enrichment factor engendered by infant consumption of maternal breast milk.This trophic enrichment effect makes breastfeeding infants appear, chemically, as if they are carnivores, consuming their mother. This is not to suggest that data gleaned from $\delta^{13}C_{collagen}$ analysis is not useful for examining, in particular, the types of supplementary foods provided during weaning, but cross-sectional analysis of the $\delta^{15}N_{collagen}$ values of the subadult portion of ancient skeletal populations has become routine (Tsutaya and Yoneda 2015:7), with some 40 studies since the original work of Fogel and colleagues (1989).

While such analysis has become commonplace, until rather recently, its execution has not been as rigorous as it might otherwise have been. The data obtained from a simple visual inspection or mathematical comparison of a series of known age subadult and "maternal" $\delta^{15}N$ values does not take into account: 1) variability in the enrichment factor from mother to infant tissue (which varies from <1‰ to nearly 5‰); 2) differences in the signatures of the weaning foods; or 3) differences in collagen remodeling rates for individuals of different ages (which, in varying from nearly 150% per year during infancy to just over 10% per year by age 20, make it difficult to ascertain what dietary stage in each subadult individual's life the recorded isotopic signatures represent) (Tsutaya and Yoneda 2013). Thus, while the $\delta^{15}N$ values of subadult collagen, as well as those from adult females of the same populations, provide essential information for beginning to determine average weaning age, the use of computational models, which account for such confounding effects as enumerated above, is necessary for obtaining reliable probabilistic estimates of weaning age. Such models also allow for comparison of weaning age data between sites of any age or location because they take into account variation in supplemental foods and trophic enrichment factors between individuals and populations. This new emphasis on model-based analysis mirrors a discipline-wide tendency towards the use of such Bayesian computational models (Fernandes et al. 2014; Moore and Semmens 2008).

MATERIALS AND METHODS

The present study comprises 22 subadult individuals with ages-at-death between perinatal age and 10 years old as well as six adult females, used here as a proxy for a maternal isotopic signature. All analyzed individuals were excavated from two cemetery sites (CH7 and CH20) of Formative Period age and located near the mouth of the River Loa in the coastal Atacama Desert (Figure 1). Site configuration and artifact types for both sites are consistent with a Formative Period date, as are the available radiocarbon dates, which are presented in Table 2.

Subadult age for skeletal materials from both sites was assessed using indices of long bone growth (Hoppa 1992; Scheuer et al. 1980), dental formation and eruption (Moorrees et al. 1963; Smith 1991), and the state of epiphyseal appearance and fusion (Schwartz 1995). Adult age was determined by reference to the state of the pubic symphysis (Brooks and Suchey 1990), the auricular surface (Buckberry and Chamberlin 2002; Lovejoy et al. 1985), and the state of closure of the cranial sutures (Buikstra and Ubelaker 1994; Meindl and Lovejoy 1985). Funerary and demographic data on these samples are provided in Table 3.

As previous research (Tsutaya et al. 2015; Tsutaya and Yoneda 2015) have shown that the isotopic composition of bone collagen (and, in particular, $\delta^{15}N_{co}$) is the most reliable measure of human BWP, only that portion of bone was extracted and analyzed in the present study. Bone collagen from both subadults and adult female samples were extracted, purified, and analyzed using the following well-established methods, and all samples were extracted and analyzed in the same facilities, thereby obviating concerns of inter-laboratory variation (Pestle et al. 2014).

Collagen extraction was performed in the Archaeological Stable Isotope Lab at the University of Miami. Collagen extraction followed a modified version of that established by Longin (1971) and previously detailed elsewhere (Pestle 2010). Weighed 0.5 g aliquots of coarsely ground (0.5–1.0 mm) cortical bone were placed in 50 ml centrifuge tubes, to which was added 30 ml of 0.2 M HCl. The tubes were capped and placed in a constantly spinning rotator for 24 hours, at which time the degree of demineralization was assessed. Samples requiring another 24 hours to demineralize had their acid refreshed at this time. After demineralization, samples were rinsed to neutral and treated with 30 ml of 0.0625 M NaOH for a period 20 hours. After this removal of humics, samples were again rinsed to neutral, and then gelatinized for 24 hours at 90°C in 10^{-3} M HCl. The resulting gelatin was then filtered using 40μm sterile single-use Millipore Steriflip® vacuum filters, allowed to condense at 85°C, frozen, and then freeze-dried. Collagen yield data were collected after extraction and freeze-drying to assess the state of sample preservation.

Isotopic analysis of collagen extracts was performed in the Marine Geology and Geophysics' Stable Isotope Laboratory at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. Collagen samples were analyzed using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20–20 isotope ratio mass spectrometer (IRMS). This process produces data on both sample elemental composition (carbon and nitrogen weight yields, from which atomic C:N can be computed) as well as the isotopic measures of $\delta^{13}C_{co}$ and $\delta^{15}N_{co}$. Typical precision of in-house organic standards (acetanilide and glycine) was ±0.07‰ for $\delta^{13}C$ and ±0.11‰ for $\delta^{15}N$.

In order to remediate the effects of confounding factors such as differences in subadult collagen remodeling rate, differences in producer-consumer (mother-child) enrichment, and variation in supplementary food, the results of these isotopic analyses were used as inputs for the WARN v1.2 (Weaning Age Reconstruction with Nitrogen isotope analysis) model of Tsutaya and Yoneda (2013). WARN (in the form of a freely available package in R (Team 2014)) employs Approximate Bayesian Computational (ABC) modeling and sequential Monte Carlo (SMC) sampling of user-specified age and $\delta^{15}N$ value for all analyzed subadult samples (the consumer signal) and

Table 2. **Radiocarbon dates for sites CH7 and CH20. Given the high level of marine food consumption at these sites, sample HV-557, a fragment of human bone, was calibrated using both SHCal13 and Marine13 to account for marine reservoir effect.**

Site	Lab code	Material	Source	Radiocarbon age (BP)	2 sigma range (SHCal13)	2 sigma range (Marine13)
CH7	IVIC-788	Basketry/plant fiber	Tamers 1973; Núñez 1976	2030 ± 80	cal BC 200–cal AD 210	n/a
CH7	Beta 360552	Textile	FONDECYT 111072	1450 ± 30	cal AD 430–770 (0.990), cal AD 820–830 (0.01)	n/a
CH20	HV-557	Bone	Geyh 1967; Spahni 1967	1735 ± 100	cal AD 120–580	cal AD 440–880

the mean (±standard deviation) of adult female δ^{15}N (the maternal/producer signal). Outputs of the WARN simulation includes maximum density estimators and posterior probabilities for: weaning beginning age (t_1, the age at which food other than mother's milk is first added to the child's diet), weaning ending age (t_2, when breast milk is no longer provided), as well as the δ^{15}N value ($\delta^{15}N_{wnfood}$) of weaning foods and *E*, the enrichment between mother and child. For the purposes of the present study, we employed the author-recommended settings for WARN (Tsutaya and Yoneda 2013:8), excluded one 13-year-old subadult (CH-7, B-8) from the analysis (as WARN does not include individuals of over 10 years of age in its calculations), and employed a particle size of 10,000.

RESULTS

All but one individual (CH20, T79) had sufficient collagen yields for isotopic analysis (Table 3), with a mean collagen yield of 16.6 ± 5 wt%, reflecting the excellent collagen preservation typical of skeletal materials from the hyperarid Atacama Desert. As seen in Table 3, chemical data (wt% C, wt% N, and atomic C:N ratios) for the 22 subadult and six adult samples possessing significant collagen indicate overall excellent collagen preservation (Ambrose 1990; DeNiro 1985; DeNiro and Weiner 1988; Schoeninger et al. 1989; van Klinken 1999). Isotopic data ($\delta^{13}C_{co}$ and $\delta^{15}N_{co}$) for both subadult and adult female samples are also presented in Table 3, although we only consider $\delta^{15}N_{co}$ henceforth. Visual inspection (Figure 2) of these data indicated that the $\delta^{15}N_{co}$ signatures of individuals between two and three years of age approached the range of adult female $\delta^{15}N_{co}$ values (26.0 ± 0.9‰) indicating that weaning would appear to have been completed by the third year of life.

Use of WARN, as outlined above, allowed a far more rigorous and probabilistic estimation of both weaning ages and the isotopic characteristics of the foods involved in weaning (Table 4). Using the author-recommended settings, WARN estimated t_1 MDE at 0.2 years (credible interval 0.0–1.9 years), and t_2 MDE at 2.5 years (credible interval 1.5–3.1 years) as shown in Figure 3. Furthermore, in terms of supplementary foods, WARN estimated a producer-consumer enrichment factor (*E*) for mother to infant tissue of 3.3‰ (credible interval 2.7–4.0‰), and a $\delta^{15}N_{wnfood}$ of 25.7‰ (credible interval 25.0–26.4‰). This final value suggests the use of foodstuffs highly enriched in ^{15}N in the weaning process.

Table 3. **Contextual, demographic, chemical, and collagen isotopic data for subadult and adult female bone samples from sites CH7 and CH20.**

Lab number	Site	Burial number	Age (years)	Collagen yield (wt%)	wt% C	wt% N	Atomic C:N	$\delta^{13}C_{co}$ (‰)	$\delta^{15}N_{co}$ (‰)
				Subadults					
K-19	CH20	D-2	0	20.1	41.0	14.6	3.3	− 13.4	26.0
K-20	CH20	C-6	0.75	19.7	42.4	15.1	3.3	− 12.2	28.9
K-21	CH20	T79	2.5	2.2	33.5	9.4	4.2	− 14.5	29.5
K-22	CH7	B-10	7	21.0	41.5	15.1	3.2	− 12.5	26.7
K-23	CH7	A-4	1.5	10.4	40.3	14.6	3.2	− 12.8	27.2
K-24	CH7	B-3	0.75	9.2	41.6	14.7	3.3	− 12.6	29.9
K-25	CH7	B-7	2.5	17.4	42.9	15.2	3.3	− 13.1	27.1
K-26	CH20	E-4	7.5	19.9	44.0	15.8	3.3	− 13.1	26.6
K-27	CH7	B-6	0	13.9	41.9	15.2	3.2	− 13.2	29.3
K-28	CH20	E-5	0	14.2	37.2	13.3	3.3	− 13.8	27.6
K-29	CH7	B-7	2.5	14.8	40.1	14.6	3.2	− 12.9	28.0
K-30	CH7	C-9	0.75	17.4	42.6	15.6	3.2	− 13.0	30.3
K-31	CH7	C-12	1.5	18.0	40.5	14.8	3.2	− 13.1	30.3
K-32	CH7	B-8	13	20.7	40.9	15.0	3.2	− 15.3	23.3
K-33	CH20	D-3	5.5	21.8	41.4	14.9	3.2	− 12.5	27.1
K-34	CH20	F-2	6	17.4	40.2	14.2	3.3	− 13.1	23.4
K-35	CH7	B-4	1.5	18.9	41.2	14.9	3.2	− 12.5	28.3
K-36	CH20	H-6	0.17	18.0	41.1	14.8	3.2	− 12.7	28.2
K-37	CH7	C-1	3.5	22.3	42.6	15.6	3.2	− 13.0	26.0
K-38	CH20	B-3	6.5	12.9	38.1	13.7	3.3	− 14.6	25.4
K-39	CH7	C-11	0.08	19.6	41.7	15.0	3.3	− 12.9	30.5
K-40	CH7	C-8	5.5	16.9	40.1	14.8	3.2	− 12.2	25.5
K-41	CH7	B-12	3.5	15.5	41.2	15.1	3.2	− 13.2	25.4
				Adult females					
J-6	CH7	B-24	18–35	15.1	40.3	15.4	3.0	− 14.2	25.8
I-113	CH7	C-2	18–35	20.2	43.2	15.5	3.2	− 12.5	26.6
I-115	CH7	D-3	35–50	20.7	40.6	14.8	3.2	− 12.3	26.7
J-7	CH7	F-1	18–35	20.9	42.7	15.8	3.2	− 12.8	27.0
J-16	CH20	L-1	18–35	19.2	41.6	15.3	3.2	− 13.5	24.8
J-19	CH20	H-03	>50	17.9	43.7	15.8	3.2	− 13.6	25.0

DISCUSSION AND CONCLUSIONS

In comparison with other archaeologically and ethnographically studied populations, the BWP practices observed in the sample from the sites at the mouth of the Loa River are noteworthy in several respects.

Tsutaya and Yoneda (2013:S2) present WARN analyses of 39 archaeological populations, which averaged 1.1 ± 0.8 years

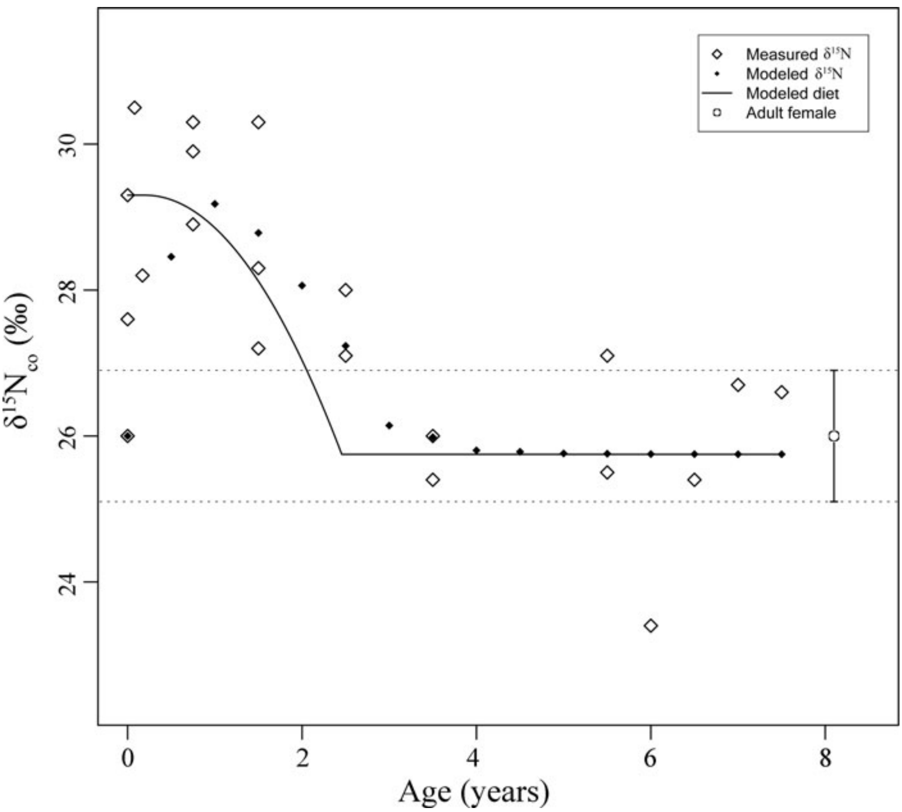

Figure 2. *Plot of Caleta Huelén subadult $\delta^{15}N$ values (by age) as compared with adult female (maternal) $\delta^{15}N$ signature.*

for t_1 and 2.9 ± 1.3 years for t_2. As compared with these previously published data, the estimated t_1 value of these Atacama marine hunter-gatherers (0.2 years) stands out, equaling the lowest t_1 value modeled for these 39 comparative examples, while the estimated t_2 of 2.5 years is near the middle of the observed archaeological range

Table 4. **WARN generated maximum density estimators and credible intervals for initiation of weaning (t_1), completion of weaning (t_2), producer-consumer enrichment (E), and nitrogen isotope value of weaning food ($\delta^{15}N_{wn}$).**

	MDE		Range		
Parameter	**Estimator**	**Probability**	**Upper**	**Lower**	**Probability**
t_1	0.2	0.08	0	1.9	0.96
t_2	2.5	0.09	1.5	3.1	0.96
E (‰)	3.3	0.12	2.7	4	0.96
$\delta^{15}N_{wn}$ (‰)	25.7	0.1	25	26.4	0.96

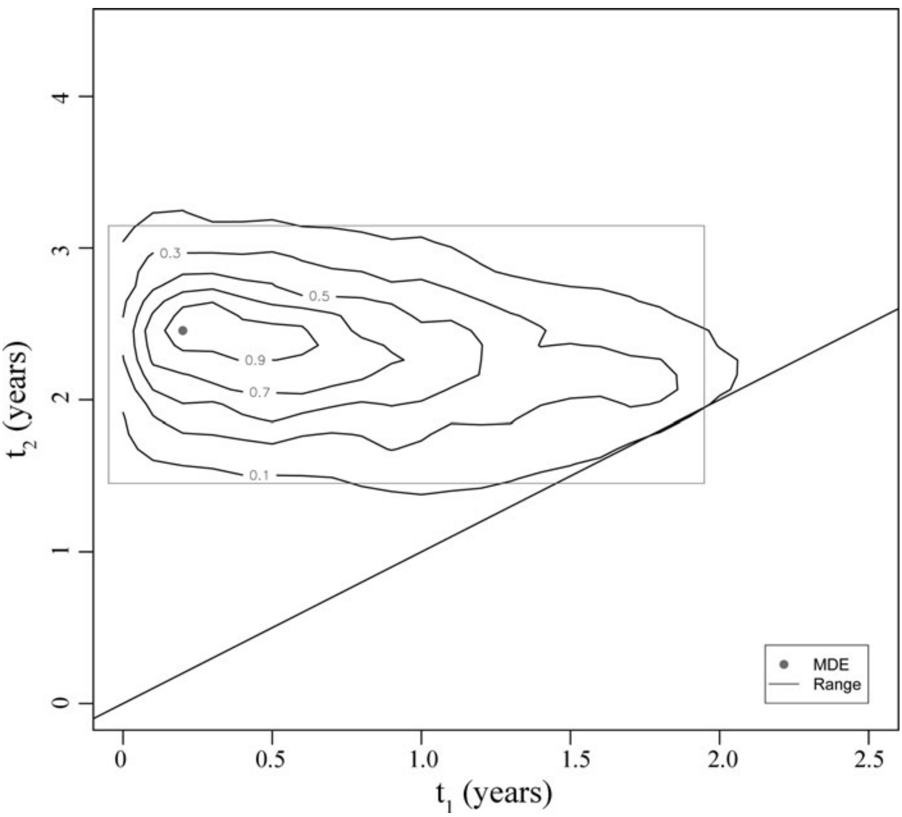

Figure 3. *Probability distribution of modeled t1 and t2 ages for Caleta Huelén subadults. Box represents 95% credible interval.*

(ranking 16th out of 39). The estimated values for the individuals from the sites at the mouth of the Loa River are also at the early end of the range established in a series of 113 ethnographically studied non-industrial populations (Sellen 2001), which found an average t_1 of 0.5 ± 0.5 years and average t_2 of 2.4 ± 0.8 years. Again, it is the t_1 estimate of these Chilean marine hunter-gatherers that stands out as precocious, with the t_2 value falling close to the midpoint of the observed modern range. Combined, this means that the duration of the weaning process for the Loa River mouth population (2.3 years) is half a year longer than the average seen for the comparative populations (1.8 ± 1.2 years), ranking 26th of those 39. Children's diets were supplemented early at the Atacama sites, but they continued to receive at least some breast milk for a prolonged period thereafter.

These data on weaning timing can be seen as at least partially supporting our hypothesis of a linkage between observed high fertility and early weaning age among the ancient inhabitants of these coastal sites. As early supplementation and weaning is linked to increased fertility (Howie and McNeilly 1982; McNeilly 1997; Wood 1994), an early introduction of supplementary foods may have permitted higher levels of fertility and a shorter birth interval while still facilitating infant/child health and reducing infant mortality (another key in the growth of populations) (Sellen 2001).

A combination of the early introduction of supplementary foods with continued (if reduced) breastfeeding also may have represented a concerted economic strategy that permitted nursing mothers to return to the labor force rapidly while still promoting infant health. As noted above, there is limited archaeological evidence (Quevedo Kawasaki 2000), and a wealth of ethnographic testimony (Ballester et al. 2010; D'Orbigny ([1835–1847] 1945; Feuillée 1714; Pretty [1599] 1904), regarding the repeated and prolonged involvement of the women of the Atacama coast in gathering, domestic, and child-rearing activities. Indeed, ethnohistoric/artistic evidence of (possibly) nursing mothers involved in fishing activities on the Chilean/Bolivian coast was documented by Auguste Borget in 1850 (Figure 4). The isotopic data presented here may then be taken as evidence of an economic and reproductive strategy intended to balance the biological and economic production/reproduction of the community. While continuing to care for their children, and to procure food and water for their families, the women of the Atacama Coast also made use of a weaning strategy that facilitated rapid population growth.

The types of foods used to supplement breast milk are also intriguing in the present case, and may have something to do with the apparent success (high fertility and burgeoning populations) of the reproductive strategy evidenced here. While the estimated producer-consumer enrichment observed for individuals from the sites at the mouth of the Loa River (3.3‰) is within one standard deviation of the values observed for Tsutaya and Yoneda's (2013:S2) 39 comparative populations (2.3 ± 1.1‰), this study's observed $\delta^{15}N_{wnfood}$, 25.7‰, is astronomical as compared to the 39 population average for $\delta^{15}N_{wnfood}$, which stands at 10.4 ± 2.6‰. The next highest $\delta^{15}N_{wnfood}$ value among Tsutaya and Yoneda's 39 comparative populations was 18.4‰, from Kellis, Egypt (Dupras 1999; Dupras et al. 2001; Tsutaya and Yoneda 2013), a value that is still more than 7‰ lower than that observed for the sites at the mouth of the Loa River

The extremely high $\delta^{15}N_{wnfood}$ value seen at these sites is a clear testament to use of high trophic level, more than likely marine, proteins as a supplementary food during weaning. Similarly high values are characteristic of adult individuals of the Formative Period Atacama coast, who uniformly relied on ^{15}N enriched marine fish or marine mammals for dietary protein (Pestle et al. 2015a, 2015b). Indeed, the $\delta^{13}C_{co}$ values of the post-weaning age (>2.5 years) subadults (−13.0 ± 0.6‰) are also indistinguishable from those of their adult female counterparts (−13.1 ± 0.7‰), pointing again to a diet dominated by marine protein. Early ethnographers reported instances of infants on Northern Chile's Pacific coast consuming raw fish during the weaning period (e.g., Feuillée 1714), which lends credence to the idea that the supplementary and/or weaning foods in the sites at the mouth of the Loa River, in contrast to many other archaeological and modern populations, included high fat and high protein (and possibly uncooked) fish (Clarot 2015). It is interesting to note that, in some regards, the protein and energy content of such foods may be more in line with the needs of weanlings than the grains/vegetable products provided in many modern/industrialized societies.

Data from additional individual sites from the review of Tsutaya and Yoneda (2013) make for particularly interesting points of comparison. Conchopata, Peru, is the only South American comparative site from the dataset (Finucane et al. 2006). At Conchopata, weaning began later (t_1 = 0.8 years MDE) than we have determined for coastal Chile, but was then terminated much more rapidly (t_2 = 1.5 years MDE). Producer-consumer enrichment at Conchopata was similar to that seen at the mouth of the Loa River (3.9‰), but the weaning foods used had much lower $\delta^{15}N$ values (10.2‰). These disparate values would seem to represent not only a different range of available/preferred weaning foods but also a different approach to BWP and reproductive strategy more

Figure 4. *Drawing, ca. 1850, by August Borget showing coastal family engaged in fishing. Note possible breastfeeding mother and child in vessel at center.*

broadly. Further research into the demographic characteristics of the Conchopata sample, among others documented in Tsutaya and Yoneda (2013), would make for interesting comparisons of different BWPs and their correlates in terms of fertility and population growth.

CONCLUSIONS

The application of Bayesian computational modeling is instrumental in biogeochemically reconstructing the breastfeeding and weaning practices (BWP) of archaeological populations because of its capacity to account for a whole series of factors that are overlooked in more traditional isotopic reconstructions thereof. The modeling of isotopic data from the marine hunter gatherer cemetery sites at the mouth of the Loa River suggest a very early beginning to a somewhat prolonged weaning process, as well as the use of high trophic level, likely marine, supplementary foods. The early weaning age suggests an interesting accommodation of high fertility, the need for women's labor in key economic activities (gathering and possibly fishing), and efforts at maintaining infant/child health through continued breastfeeding. This study also found intriguing evidence of the use of a weaning food (fish) not often considered as part of the modern child-rearing practice. Combined, these would seem to represent a novel adaptation to coastal life during northern Chile's Formative Period.

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