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Isotopic evidence on human bone for declining maize consumption during the little ice age in central western Argentina

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ABSTRACT

This paper explores variation in maize consumption among human societies in arid environments of central-western Argentina over the last 2500 years. Increasingly positive human $\delta^{13}C$ signatures suggest a high intake of C_4 resources (maize) until *ca.* A.D. 1400. After this time, the importance of maize in the diet drops and never reaches pre-Hispanic consumption rates, despite the known importance of maize to Inka and other late-prehistoric societies in the region. This decline appears to be related to colder temperatures during the Little Ice Age from the beginning of the 15th to the mid19th centuries.

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1. Introduction

The development of farming and the relationship between food producers and hunter-gatherers is a central issue in anthropological research and one that continues to receive substantial theoretical and empirical attention (e.g., Gepts et al., 2012; Kennett and Winterhalder, 2006; Piperno, 2006; Staller et al., 2006). Why domesticates were incorporated and how they became significant through time is central to understanding human dietary strategies, settlement patterns, and changes in social organization. In this regard, the relationship between human organization, resource exploitation, and environment are central (Bettinger et al., 2007; Halstead and O'Shea, 1989; Richerson et al., 2001; Smith, 2001; Winterhalder and Goland, 1997). The recent availability of fine grained paleoclimatic and dietary data from late Holocene central western Argentina make it an ideal region in which to explore these issues.

The central-western area of Argentina, between 30° and 40° S, is considered the pre-Hispanic southern limit of maize agriculture in the Americas (Fig. 1). The present paper is focused in the northern

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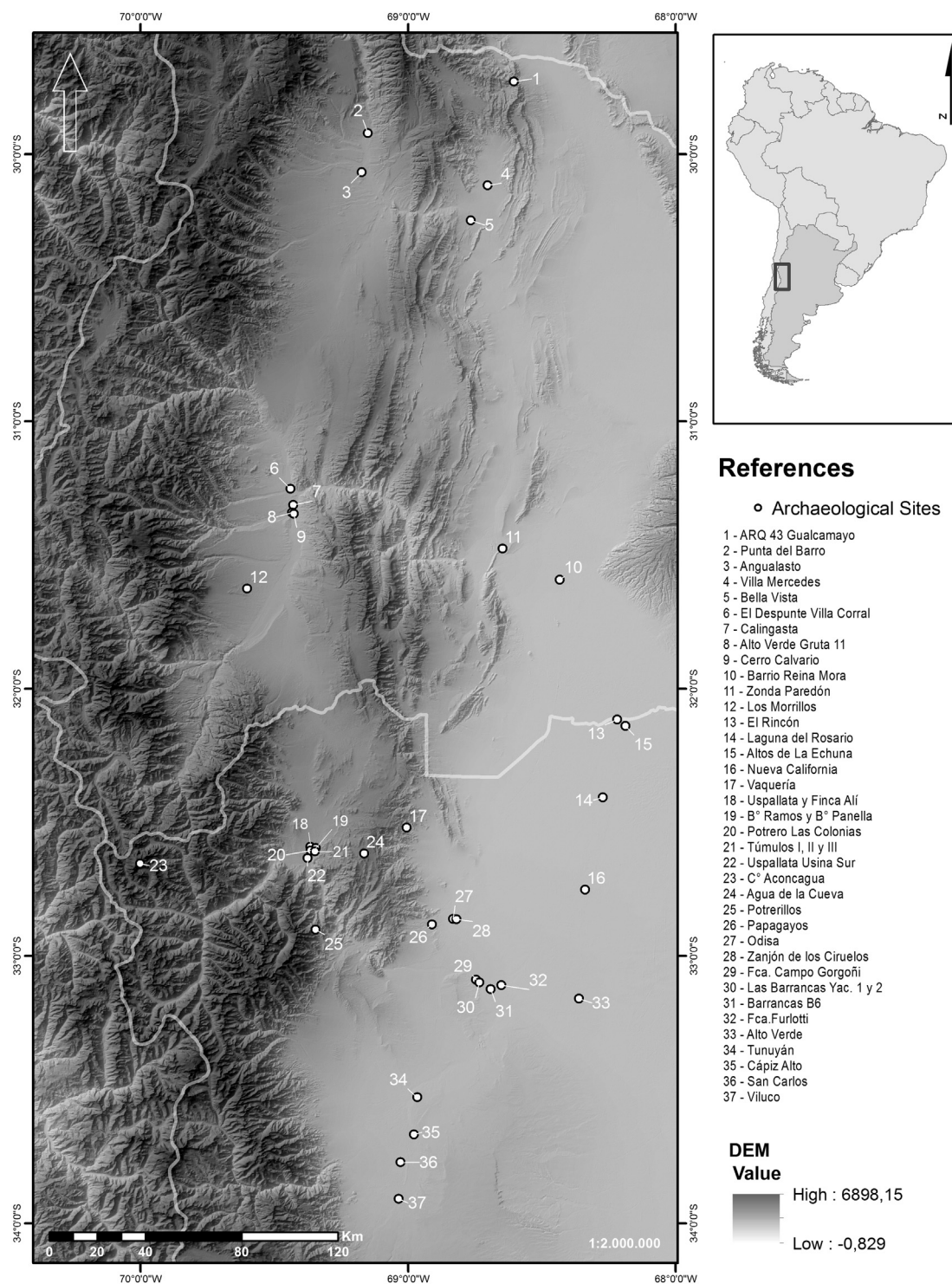
Fig. 1. Digital elevation model of the study region and sites from which human isotope samples were taken.

sector of the area, between 30° and 33° S (Fig. 1). This area has typically been considered a periphery of the northwest Argentine culture area (*noroeste argentino*, or NOA; Bárcena, 2001; Lagiglia, 1977; Schobinger, 1975), which saw the development of several complex, Andean civilizations prior to Spanish contact, most famously the Inca. The presence of cultivars such as maize, squash, bean, quinoa (Bárcena, 2001; Gambier, 1977, 2000; Gil et al., 2006a)

and ceramic technology have been interpreted as evidence of farming and sedentary settlement in the region (Bárcena, 2001; Gambier, 2000; Lagiglia, 2001), and in some cases have been associated with pastoralism as well (Bárcena, 2001; Gambier, 2001; Gasco et al., 2011). Researchers have identified the presence of pit houses, domesticated camelids (llama, *Llama glama*), and corn in the intermountain valleys and interpret these as evidence of a shift

to agriculture and reduced residential mobility as well (Cortegoso, 2006; Gambier, 1988).

Maize is the most ubiquitous domesticate and dates to as early as *ca.* 2000 years ago (Gambier, 1977, 2000; Gil, 2003; Ots et al., 2011). There are few direct radiocarbon dates on theses domesticates, however. The overall chronology remains coarse grained and is usually assigned to cultural-historical periods based on the presence of time-sensitive artifacts or an association between maize macrofossils and other, directly-dated materials. It has also generally been assumed that maize was a significant resource when added to the central western human diet 2000 years ago, and that it rapidly became a staple.

Of course, domesticates do not necessarily become staples in every circumstance (e.g., Coltrain and Leavitt, 2002; Gremillón, 1996; Tylor et al., 2013). Recently, a more limited role for maize has been proposed for pre-Hispanic human occupations in central western Argentina based on isotopic information from human bone samples between 30° and 36° S (Gil et al., 2009, 2010, 2011a). These papers focus on spatial variation and broad temporal differences in human stable isotope data. Based on the results, Gil et al. (2009, 2010, 2011a) suggest that maize was significant in human diets in the area between 30° and 33° S mostly during the last 1000 years, the area presented in this paper. Recent archaeobotanical studies regarding the significance of maize during historic times (after 1600 AD) have also found the record of maize consumption wanting, and some researchers reject any significant role for maize agriculture after contact (Chiavazza and Mafferra, 2007; Mafferra, 2010; but see García, 2011; Chiavazza and Mafferra, 2011). This is despite its known importance to the Inka, who were present in the area when the Spanish arrived. Finally, support for increased sedentism has also come into question, with evidence varying across space or occurring very late in time (Cortegoso, 2006; Gil et al., 2011b; Ugan et al., 2012).

Clearly the significance of maize in late Holocene human diets remains in debate (Chiavazza and Mafferra, 2007, 2011; García, 2011; Gil et al., 2011a; Mafferra, 2010), and temporal and spatial variance in the underlying botanical and isotopic data (Gil et al., 2006a, 2011a; Mafferra, 2010; Otz et al., 2011) suggests that the region was a dynamic one from the late Holocene through Spanish contact. Yet to this point, this variation and its underlying causes have been explored only at coarse scales and with limited attention to underlying causes. Here we begin to address changes in human stable isotope data through time by looking at temporal trends in collagen ^{13}C and ^{15}N and hydroxyapatite ^{13}C.

Using the largest discrete set of individuals ($n = 131$) with temporal data, we show that human ^{13}C values begin to gradually increase from approximately 600 B.C. to A.D. 800. Values then fluctuate at this higher level for 650 years before declining again circa A.D. 1450. Initial increases in the reliance on C$_4$ resources match well the timing of introduction of maize to the region. We show that subsequent declines in human ^{13}C signals coincide with increasingly cold temperatures as seen in both local and regional paleoclimatic records (the Little Ice Age), and consider why temperature, not drought, should be the key factor limiting maize agriculture in this region. Finally, we conclude by discussing the importance of these findings in terms of the ongoing debates about the late prehistoric and early historic periods.

2. Geography and climate of central-western Argentina

Central-Western Argentina is an area of contrasting geography located in the southern sector of South America between approximately 30° and 40° S but in the present paper focused between 30° and 33° S (Fig. 1). To the west lies a region of mountainous topography that includes the Andean cordillera and numerous longitudinal montane valleys. To the east lies a vast, lowland area known as the Oriental Plains, and in between is an area of lower foothills or Piedemonte.

The Andean ecosystem extends throughout the cordillera and is characterized by a relatively wetter environment, strongly conditioned by altitude. Winter precipitation, controlled by the Pacific anticyclone, is the dominant moisture source, and rainfall ranges from 300 mm to 800 mm per year from low to high elevations (Abraham et al., 2009; Capitanelli, 1972). Altoandina vegetation communities develop above 2500 masl and they consist of grass and brush steppe of low-lying bunch grasses, cacti, and brushy shrubs adapted to dry, cold, and windy conditions. Between 2500 and 1000 masl, vegetation shifts to brush steppe dominated by more xeric grasses and bushes typical of the Patagonian or, in the northern part of the region, Puna vegetation community (Abraham et al., 2009; Luebert and Pliscoff, 2006; Roig et al., 2000). Most of the Andean environment is highly productive with regards to larger mammals (mostly *Lama guanicoe*), but less productive in terms of seeds, roots, fruits, and other edible plant resources.

Moisture in the piedmont and oriental plains is controlled by the Atlantic anticyclone. Precipitation is summer dominant and ranges from 250 to 500 mm per year, again increasing with elevation. The primary vegetation community in this area is Monte desert (Abraham et al., 2009; Roig et al., 2000). The distribution of Monte vegetation is determined by interactions between regional physiography and atmospheric circulation in the 25°–45° south latitude sectors of South America (Labraga and Villaba, 2009). It is found throughout the eastern plains and in lower-elevation intermontane valleys below roughly 1000 masl (Fig. 1). The productivity of edible plants is higher than in the Andes, but faunal productivity decreases at the same time, especially in terms of big game. Mean annual temperature is lower in the foothills and longitudinal valleys like Uspallata (11 °C) than in the lowlands (16 °C), with daytime maximums often exceeding 40 °C in summer months.

3. Human strategies and maize

Maize productivity is highly variable as a consequence of inter- and intra-annual variation in key climatic parameters such as temperature and precipitation (Claessens et al., 2012; de la Casa y Ovando, 2006; Demerit, 1991; Maddonni, 2012; Thompson, 1975). High-frequency climate and weather variations would have induced the evolution of methods for traditional exploitation of plant foods difficult, and Holocene weather extremes significantly affected agricultural production (Fagan, 2000; Lamb, 1977).

Although maize is found across several tropical and subtropical regions of the Americas, it requires special thermal and hydrological conditions for cultivation (Demerit, 1991; Maddonni, 2012). Temperature and moisture extremes can have particularly negative effects. Low temperatures during the seedling-emergence period, crop damage by late and early frosts, and heat stress during the critical flowering period can all reduce or eliminate yields. Low soil water content in the soil profile at sowing and low water balance during the flowering period can have similar effects.

Demerit (1991) proposes the use of the corn heat unit or growing degree days (GDD) as a tool to explore this temperature constriction. His scheme assumes that a plant matures by a daily accumulation of heat units. For prehispanic maize cultivation, Demerit (1991) proposed the 2000 GDD isoline as a broad estimate of agricultural potential. From this perspective, changes in temperature can affect the geographic limit and the productivity of corn by reducing the number of GDD's accumulated per day and by reducing the actual length of the growing season. Either or both can lead to reduced yields or failed growing seasons.

In the extremely arid regions of western Argentina, with total annual rainfall around 200–300 mm, maize agriculture would have been limited to areas with irrigation or sites with supplementary water provided by natural streams or channels (Gambier, 2000; Mayntzhusen, 1968). Water management structures had been recorded in parts of Argentina for the last 2000 years (Damiani and García, 2011), but are not abundant in the central-western part of the country. Most are limited to the mountain and piedmont region in San Juan province (Damiani and García, 2011; Gambier, 2000), where they are associated with the Angualasto and Calingasta tardio cultures (AD 1200 to AD 1460; Michieli, 2012b). In contrast, spring, seeps, and small perennial or ephemeral streams occur intermittently throughout the region, though nowhere at great density outside of the upper Andes. Most are directly or indirectly fed by Andean snowpack or groundwater and provide more consistent water than summer rainfall. Since crops could only be planted in naturally or manually irrigated areas, inter-annual variations in yields along the eastern slopes of the arid central Andes would have been regulated as much or more by temperature changes than variability in precipitation.

4. Stable isotopes and human diet

While a range of isotopes can be used to study diet, carbon and nitrogen isotopes are by far the most common. Carbon is a key component of all fats and carbohydrates and together with nitrogen forms a primary component of proteins as well. In addition to its important role in the structure of organic molecules, it also comprises a large part of the inorganic phase of structural tissues such as bone, shell, and teeth. Where these carbons are derived from dietary sources, as occurs in vertebrates (Schwarcz, 2006), variation in their stable isotopes can be used for dietary reconstruction as well.

Stable isotopes are typically measured as the ratio of heavier to lighter isotopes and reported relative to a fixed standard. Since differences in ratios are small, they are typically expressed in parts per mil (‰) as δ values:

$$\delta = [(R_{sample}/R_{standard}) - 1]*1000$$

where $R = {}^{13}C/{}^{12}C$ for the measurement of carbon and ${}^{15}N/{}^{14}N$ for the measurement of nitrogen.

The standards to which samples are compared are Vienna Pee-Dee Belemnite (VPDB) and atmospheric nitrogen (AIR) for carbon and nitrogen, respectively. As most plant and animal tissues have less ${}^{13}C$ than VPDB, $\delta^{13}C$ values are usually negative, while $\delta^{15}N$ values tend to be small and slightly negative to positive.

In terrestrial foodwebs, variation in carbon isotope ratios begins with plants. When CO_2 is taken up by plants during photosynthesis, metabolic processes alter the ratio of ${}^{13}C/{}^{12}C$, depleting plant tissues in ${}^{13}C$ relative to atmosphere ($\delta^{13}C_{atmos} = -7.7‰$). The degree of fractionation associated with photosynthesis depends on the kinetic properties of CO_2 diffusion during carbon uptake and the enzymatic processes associated with carbon fixation during photosynthesis (Farquhar et al., 1989). In terrestrial plants, carbon isotope fractionation depends on which of three photosynthetic pathways (C_3, C_4, CAM) a plant uses to metabolize carbon dioxide.

The overwhelming majority of plants, including cool season grasses, most bushes, tubers, and trees, use C_3 photosynthesis (the Calvin Cycle). In this type of photosynthesis, CO_2 is initially fixed as a three-carbon molecule, 3-phosphoglycerate. The process discriminates most strongly against heavy carbon isotopes and plants using the Calvin Cycle have tissues with an average $\delta^{13}C$ value of $-26.7 \pm 2.7‰$. A small set of forbs, bushes, and tropical grasses including maize (*Zea mays*), millet, and sugarcane use C_4

(Hatch−Slack) photosynthesis. Here CO_2 is initially fixed as oxaloacetic acid, a 4-carbon molecule. This path discriminates less against heavy carbon isotopes and produces average $\delta^{13}C$ values of $-12.5 \pm 1.1‰$. Cacti and some members of the Agavacaea (yucca and agaves) use the CAM pathway, which can shift between C_3 and C_4 photosynthesis and produce varying isotope signatures ($\delta^{13}C$ -27 to $-12‰$).

Fractionation between plant tissues and consumer bone collagen is $5 \pm 1.5‰$ (Hedges, 2003: 72). The bone collagen of individuals with diets comprised primarily of wild C_3 plant foods will exhibit mean $\delta^{13}C$ values between $-24.4‰$ and $-19‰$, while individuals heavily reliant on maize or other C_4 plants will have $\delta^{13}C$ values in the $-8.6‰$ to $-6.4‰$ range (e.g., Coltrain and Leavitt, 2002; Martin, 1999; Matson and Chisolm, 1991; Spielmann et al., 1990). Within this range, more positive values indicate greater reliance on C_4 foods.

Controlled feeding studies of laboratory animals reveal that the carbon isotope signatures of proteins such as collagen predominantly reflect the protein component of the diet, as essential amino acids are preferentially routed from dietary sources and incorporated into body tissues (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). This is also true in humans, and a recent model suggests that 75% of the carbon in bone collagen is derived from dietary protein, with the remainder coming from carbohydrates and fats (Fernandes et al., 2012). Non-essential amino acids, in contrast, may be produced from consumed carbohydrates and lipids, as well as proteins. Thus collagen $\delta^{13}C$ values for agriculturalists highly dependent on plant products may differ substantially from whole diet (Coltrain, 2009) and differences between individuals in the proportion of maize versus C_3 plants in the diet would be more apparent in apatite than in collagen (Harrison and Katzenberg, 2003).

By contrast, bone apatite is derived from circulating bicarbonate (HCO_3^-) and reflects whole diet (Ambrose and Norr, 1993; Kellner and Schoeninger, 2007; Tieszen and Fagre, 1993). Diet-apatite spacing in typically assumed to be on the order of 9.5‰, though observed values in non-human studies and best-fit values for human samples can be more positive (Harrison and Katzenberg, 2003; Hedges, 2003; Krueger and Sullivan, 1984; Passey et al., 2005). Given a 9.5‰ offset, expected apatite ${}^{13}C$ signals for C_3 and C_4 consumers would be on the order of -19.9 to $-14.5‰$ and -4.1 and $-1.9‰$.

In humans, these $\delta^{13}C$ values represent long-term dietary intake, since carbon in adult bone collagen is replaced over a span of ca. 30 years (Stenhouse and Baxter, 1977, 1979: 333; see also Ambrose, 1993; Harkness and Walton, 1972; Hedges et al., 2007; Libby et al., 1964). They also reflect the more negative $\delta^{13}C$ values of modern atmospheric CO_2 caused by the admixture of CO_2 produced by the combustion of fossil fuels (the Suess effect; Francey et al., 1999; Keeling, 1979; Keeling et al., 2010), and would have been 1.5–2‰ more positive prehistorically.

As with carbon, nitrogen isotope chemistry also reflects diet, mediated by the metabolic pathways by which nitrogen is fixed in various tissues (Ambrose, 1993; Ambrose and Norr, 1993; Tieszen and Fagre, 1993). While physiological processes such as starvation, urea recycling, and urea concentration can alter $\delta^{15}N$ values in various taxa (Ugan and Coltrain, 2011: 1418 and references therein), diet is the primary determinant of isotope values. Most animals, including humans, exhibit an approximately +3‰ shift in $\delta^{15}N$ values relative to their diet (the trophic effect: Ambrose, 2000; Hedge and Reynard, 2006; Schoeninger and DeNiro, 1984).

Unlike carbon, maize consumption has no characteristic nitrogen isotope signature. Rather, maize values vary with soil characteristics and nitrogen cycling, as do the nitrogen values of many other wild plants. Data on human nitrogen isotope values were

collected along with the collagen carbon data and are presented here for completeness. While we also comment on some of the observed trends, the focus remains on patterns in carbon isotopes.

5. Resources and isotopes

Knowledge of the underlying ecology of both fauna and flora is fundamental to interpreting human paleodietary information since isotopes from these sources may contribute directly or indirectly to the values of human consumers (Cadwallader et al., 2012; Ugan and Coltrain, 2011). On the one hand there are archaeobotanical and archaeozoological records that provide direct evidence of past human subsistence. On the other there are stable isotope data for subsistence resources and other components of the ecosystem that can provide perspective on the isotope values seen in individual human consumers. Both records are incomplete, but complementary.

Regional variation in the central western ecosystems of Argentina generated significant variation in the exploitation of resources (Neme and Gil, 2008; Neme et al., 2013; Otaola et al., 2012; Zárate et al., 2010). In general, camelids are the most frequently recorded subsistence resource in highland archaeological sites (Gambier, 2001; Gil et al., 2011c; Neme and Gil, 2008; Otaola et al., 2012; Gasco et al., 2011; Bárcena et al., 1985). Camelids are also important components of lowland sites, but small size prey are more frequent. These include taxa such as fishes, armadillos, birds, rodents, and others (Chiavazza, 2001; Corbat et al., 2012; García Llorca et al., 2012). The scarce archaeological evidence of plant use between 30° and 33° S indicates that algarrobo (*Prosopis* ssp.) was the most common wild species in lowlands and intermontane valleys (Abraham de Vázquez and Prieto 1981, 1989; Roig and Martinez Carretero, 1991). Maize was the most ubiquitous domesticate plant, but there is some records of *Cucurbita* ssp. and *Chenopodium quinoa* (Bárcena, 2001; Chiavazza, 2009; Gambier, 1974, 1977, 1988, 1992, 2000; Gil et al., 2006a; Ots et al., 2011; Roig, 1977, 1992).

Stable isotope data from food resources in central-western Argentina are presented in Table 1 (Cadwallader et al., 2012; Hopkins and Ferguson, 2012; Otaola and Ugan, 2011). These data clearly shows the distinctive $\delta^{13}C$ signature of maize relative to other resources. Maize $\delta^{13}C$ averages close to $-10‰$, while camelids (*ca.* $-17‰$), *Perichtys* ssp. ($-20‰$); *Prosopis* ssp. ($-21‰$) and *Cucurbita* ssp. ($-25‰$) are all more negative. Differences in $\delta^{15}N$ among taxa with more than one sample analyzed are negligible (most falls between 7‰ and 9‰, Table 1).

Table 1
Stables isotopes values ($\delta^{15}N$ and $\delta^{13}C$) for wild plants and animals from central-western Argentina (30°−33° S).

	$\delta^{13}C$ average (‰)	SD	$\delta^{15}N$ average (‰)	SD
Lama sp. (camélids; $n = 49$)	−16.9	2.05	6.1	2.03
Vicugna vicugna (vicuña; $= 4$)	−18.3	0.40	5.9	0.65
Lycalopex griseus (gray fox; $n = 1$)	−14.7	–	11.2	–
Didelphis sp. ($n = 1$)	−16.7	–	15.5	–
Rhea sp. (ostrich; $n = 1$)	−18.3	–	6.7	–
Rhea pennata ($n = 1$)	−18.6	–	7.6	–
Constrictor occidentalis ($n = 1$)	−16.7	–	15.4	–
Perichtys sp. (perches; $n = 4$)	−19.8	3.94	6.3	1.68
Ranidae ($n = 1$)	−16.8	–	10.9	–
Prosopis sp. (algarrobo; $n = 1$)	−21.0	–	2.1	–
Zea mays (maize; $n = 12$)	−10.7	1.40	8.2	4.39
Curcurbita maxima (squash; $n = 4$)	−25.4	1.39	7.6	1.96
Phragmites australis ($n = 2$)	−23.0	0.85	6.8	3.74

6. Materials and methods

In order to assess trends in human isotope values, this paper present new and previously published stable isotope data from human remains in the study area (Fernández et al., 1999; Gil et al., 2006a, 2006b, 2009). The human bone samples come from museum collections recovered during the last 80 years and housed at the Museo Moyano (Gobierno de Mendoza), Facultad de Filosofía y Letras (Universidad Nacional de Cuyo), and Instituto de Investigaciones Arqueológicas y Museo "Prof. Mariano Gambier" FFHA (Universidad Nacional de San Juan). Samples were processed in the Laboratory for Archaeological Science at the University of South Florida (code USF; Gil et al., 2009; Tykot, 2004) and Museo de Historia Natural de San Rafael (code MSR) using well-established procedures for extracting bone collagen and bone and tooth enamel apatite, described below.

Samples processed at MSR follow the laboratory procedures as describe below and were measured at the University of Wyoming Stable Isotope Facility. Two samples included in this paper were processed by other researchers (see Table 2). Collagen extraction started with 1 g of cortical bone that was cleaned of surface contaminants. Samples were demineralized whole in 0.6 N HCl at 4 °C and progress recorded daily. After demineralization the collagen pseudomorph was rinsed to neutrality, treated with 5% KOH to remove organic contaminants, and soaked 24 h in a 2:1:0.8 mixture of methanol, chloroform and water to remove residual lipids. The acid and base extracted collagen pseudomorph was again rinsed to neutrality then lyophilized and weighed to obtain a collagen yield. Approximately 100 mg of lyophilized collagen was gelatinized in 5 ml of acidified water (pH 3) for 24 h at 120 °C. Water-soluble and -insoluble phases were separated by filtration and the water-soluble phase lyophilized. Collagen ^{13}C and ^{15}N were determined by flash combustion to produced CO_2 and N_2 and measured on a Costech 4010 Elemental Analyzer coupled to a Thermo Delta Plus XP IRMS the Stable Isotope Facility at the University of Wyoming. Both stable isotope measurements and sample weight percent carbon and nitrogen were obtained from a single sample combustion. Collagen preservation was evaluated by atomic carbon to nitrogen ratios. The samples all fall within the 2.9 to 3.6 range indicative of adequately preserved bone collagen (Ambrose, 1990). Samples processed at USF follow the laboratory procedures describe in Tykot (2004).

Individuals were further analyzed for bone carbonate $\delta^{13}C$ and $\delta^{18}O$. In this case an outer layer of bone was removed to expose a clean surface. Approximately 100 mg of bone was then ground onto fresh weighing paper, transferred to a clean tube, and the powdered bone soaked 30 min in three percent hydrogen peroxide to remove organic materials. After soaking samples were then rinsed to neutrality and dried. The sample was then washed for 30 min in 0.1 M-buffered acetic acid to remove labile carbonates, rinsed to neutrality and dried again. Finally, samples of clean bone powder were sent to the University of Wyoming Stable Isotope Facility for analysis, where stable carbon and oxygen isotope values are determined using a Thermo Gasbench coupled to a Thermo Delta Plus XL IRMS continuous flow inlet mass spectrometer and reported relative to the PDB standard.

Stable isotope data from 131 human samples are detailed in Table 2. They include 123 collagen $\delta^{13}C$ samples ($\delta^{13}Cco$), 115 collagen $\delta^{15}N$ samples, and 118 $\delta^{13}C$ bone apatite samples ($\delta^{13}Cap$) spanning the last 2500 years. Forty-three samples are directly dated via AMS mostly in Arizona Radiocarbon AMS Facility processing the bone samples with its protocols, but some of them where processed in LATRY and Beta Analytic. The ages of other samples have been assigned by association with directly dated human samples or directly-dated cultural material. Radiocarbon

Table 2
Human samples information from central western Argentina (30°−34° SL) with stable isotope values, radiocarbon dates, calibrated confidence interval median dates and two sigma ranges.

Site number	Code	Precedence	Sex	Age	Years ^{14}C BP	Associated chronology	Min cal	Media cal	Max cal	Code	Corr. δ^{13}Ccol	Corr. δ^{15}N	Wt% N*	Wt% C*	Atomic C/N	Code	δ^{13}Cap	Reference
1	Ent 4	Arq 43 Gualcamayo	F	40−50	LP-2210: 2360 ± 60		−702	−468	−377	MSR19	−17.1	5.5	14.69	40.48	3.2	MSR114	−11.4	Durán et al., in press
1	Ent 3	Arq 43 Gualcamayo	F	>35	LP-2363: 2270 ± 90		−409	−315	−197	MSR18	−18.3	5.8	12.97	36.20	3.3	MSR107	−12.4	Durán et al., in press
1	Ent 1	Arq 43 Gualcamayo	ND	16−21	LP-2315: 1920 ± 90		−20	87	214	MSR16	−16.5	7.7	14.85	40.81	3.2	MSR104	−11.6	Durán et al., in press
1	Ent 5 Conjunto 3	Arq 43 Gualcamayo	ND	>35	LP-2347: 1860 ± 90		32	159	313	MSR30	−16.7	6.3	13.06	36.13	3.2	MSR103	−11.5	Durán et al., in press
1	Ent 5 Ind 2	Arq 43 Gualcamayo	F?	35−49		1792 ± 45	140	233	322	MSR21	−16.8	6.8	13.04	36.13	3.2	MSR102	−11.4	Durán et al., in press
1	Ent 5 Ind 6	Arq 43 Gualcamayo	M	40−56		1792 ± 45	140	233	322	MSR24	−16.3	7.4	10.69	30.65	3.3	MSR111	−11.9	Durán et al., in press
1	Ent 5 Ind 7	Arq 43 Gualcamayo	F	22−30		1792 ± 45	140	233	322	MSR25	−17.0	6.4	14.50	39.69	3.2	MSR108	−11.7	Durán et al., in press
1	Ent 5 Ind 10	Arq 43 Gualcamayo	Ind	40−45		1792 ± 45	140	233	322	MSR26	−16.3	6.6	13.19	36.41	3.2	MSR110	−11.3	Durán et al., in press
1	Ent 5 Ind 13	Arq 43 Gualcamayo	ND	16−21		1792 ± 45	140	233	322	MSR27	−16.9	7.1	14.70	40.22	3.2	MSR106	−10.6	Durán et al., in press
1	Ent 5 Conjunto 1	Arq 43 Gualcamayo	ND	>35		1792 ± 45	140	233	322	MSR28	−17.5	5.6	14.12	38.52	3.2	MSR109	−10.9	Durán et al., in press
1	Ent 5 Conjunto 2	Arq 43 Gualcamayo	ND	>35		1792 ± 45	140	233	322	MSR29	−17.3	5.8	14.89	40.74	3.2	MSR113	−11.9	Durán et al., in press
1	ENT 5 Conjunto 4	Arq 43 Gualcamayo	ND	>35	LP-2349: 1750 ± 90		142	280	392	MSR31						MSR115	−11.9	Durán et al., in press
1	Ent 5 Ind 5	Arq 43 Gualcamayo	F	25−30	LP-2192: 1640 ± 90		265	409	537	MSR23	−17.1	5.5	14.42	39.07	3.2	MSR139	−11.5	Durán et al., in press
1	Ent 5 Ind 1	Arq 43 Gualcamayo	M	22−26	LP-2249: 1170 ± 70		772	853	962	MSR20	−15.6	7.1	13.51	37.74	3.3	MSR100	−10.8	Durán et al., in press
1	Ent 5 Ind 3	Arq 43 Gualcamayo	M	>50		1113 ± 55	783	922	995	MSR22	−16.4	7.1	12.03	33.58	3.3	MSR112	−11.7	Durán et al., in press
1	Ent 2	Arq 43 Gualcamayo	M	20−22	LP-2285: 1020 ± 90		899	1016	1152	MSR17	−14.9	8.2	14.93	40.53	3.2	MSR105	−9.9	Durán et al., in press
2	SJ3-ENT3	Punta del Barro		A	BETA-161362: 590 ± 40		1310	1350	1406	USF7111	−13.3	9.5				USF7110	−9.8	Gambier, 2003
3	SJ10-ENT1	Angualasto	F	A		590	1310	1350	1406	USF7386	−12.3	9.9				USF7159	−8.2	Gambier, 2003
3	SJ4-ENT 2	Angualasto		A	BETA-134392: 650 ± 40		1286	1346	1389	USF7384	−13.8	10.1				USF7142	−10.3	Gambier, 2003
4	Pozo Testigo A	Villa Mercedes				630 ± 40	1295	1349	1391	MSR86	−10.9	8.8	15.24	42.36	3.2	MSR187	−6.3	Michieli, pers com.
5	NUM 11	Bella Vista					1200	1330	1460	MSR87	−9.3	10.2	13.36	36.66	3.2	MSR188	−5.2	Michieli, 2009
5	Bella Vista	El Arenal-Bella Vista Casa Vedia		A		850	1286	1346	1389	MSR222	−15.7	10.0	13.39	36.02	3.1		−13.2	Michieli, 2009
6	Num 8	El Despunte- Villa Corral				970 ± 50	1019	1086	1152	MSR82	−12.1	7.3	14.77	40.31	3.2	MSR173	−6.0	Michieli, 2008
6	Num 9	El Despunte- Villa Corral		0.1		800 ± 50	1192	1228	1273	MSR83	−11.2	10.8	9.18	25.92	3.3	MSR163	−9.5	Michieli, 2008
7	SJ2	Calingasta	M	A		880	1051	1157	1216	USF7382	−13.8	9.5				USF7106	−10.1	Michieli, 2009
8	AV-G11-T4	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR76	−13.0	7.6	14.89	40.91	3.2	MSR 185	−6.6	Gambier, 2001
8	AV-G11-T3	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR75	−13.2	9.5	14.56	39.42	3.2	MSR 184	−8.6	Gambier, 2001
8	AV-G11-T5	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR77	−12.9	7.9	14.03	38.34	3.2	MSR 186	−6.5	Gambier, 2001
8	AV-G11-T6	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR78	−12.7	8.8	15.11	41.16	3.2	MSR 160	−6.9	Gambier, 2001
8	AV-G11-T2	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR79	−12.1	9.6	14.90	40.97	3.2			Gambier, 2001
8	AV-G11-T1	Alto Verde Gruta 11				1110 ± 50	885	927	992	MSR80	−12.8	9.6	13.69	37.47	3.2	MSR 183	−7.6	Gambier, 2001
9	SJ5-ENT2	Cerro Calvario		A		880 ± 40	1050	1157	1216	USF7152	−18.0	14.0						Gambier, 2003

N	Sample	Site	Sex	Age	Date	cal 1	cal 2	cal 3	Code	δ13C	val	val	val	C:N	Code 2	val	Reference
10	RW-RM-HU2	Barrio Reina Mora			520 ± 50	1328	1408	1441	MSR84	−16.1	9.0	13.87	37.38	3.1	MSR161	−10.3	Michieli, pers com.
10	RW-RM-HU1	Barrio Reina Mora			520 ± 50	1328	1408	1441	MSR95	−14.9	8.5	14.16	37.89	3.1			Michieli, pers com.
11	ZO-PA-HU-10	Zonda Paredón			520 ± 50	1329	1406	1435	MSR73	−13.4	9.5	13.39	36.67	3.2	MSR190	−8.7	Michieli, pers com.
11	ZO-PA-HU8	Zonda Paredón			520 ± 50	1329	1406	1435	MSR85	−12.8	8.9	14.77	40.42	3.2	MSR189	−7.9	Michieli, pers com.
11	ZO-PA-HU1	Zonda Paredón			520 ± 50	1329	1406	1435	MSR88	−12.8	9.1	14.09	38.42	3.2	MSR191	−8.3	Michieli, pers com.
11	ZO-PA-HU2	Zonda Paredón			520 ± 50	1329	1406	1435	MSR89	−13.2	9.3	14.31	38.72	3.2	MSR180	−8.2	Michieli, pers com.
11	ZO-PA-HU5	Zonda Paredón			520 ± 50	1329	1406	1435	MSR90	−12.7	8.1	14.52	38.84	3.1	MSR179	−7.9	Michieli, pers com.
11	ZO-PA-HU4	Zonda Paredón			520 ± 50	1329	1406	1435	MSR91	−13.2	9.0	14.64	39.48	3.1	MSR178	−8.2	Michieli, pers com.
11	ZO-PA-HU3	Zonda Paredón			520 ± 50	1329	1406	1435	MSR92	−12.8	8.4	15.13	41.46	3.2	MSR181	−8.1	Michieli, pers com.
11	ZO-PA-HU6	Zonda Paredón			520 ± 50	1329	1406	1435	MSR93	−12.7	9.0	14.25	38.08	3.1	MS176	−7.5	Michieli, pers com.
11	ZO-PA-HU7	Zonda Paredón			520 ± 50	1329	1406	1435	MSR94	−12.3	8.2	14.52	38.91	3.1			Michieli, pers com.
11	ZO-PA-HU9	Zonda Paredón			520 ± 50	1329	1406	1435	MSR96	−14.0	9.1	14.41	38.35	3.1	MSR174	−9.7	Michieli, pers com.
12	SJ6-ENT8	Los Morrillos Gruta 1	F	A	GAK-4809: 1280 ± 90	657	753	864	USF7385	−17.3	8.1				USF7380	−14.0	Gambier, 1985
12	ind 9	Los Morrillo Gruta 1							MSR54						MSR162	−13.1	Gambier, 1985
12	SJ1-ENT 7	Los Morrillos Gruta 1		A					USF7381	−17.3	9.7				USF7104	−13.1	Gambier, 1985
13	MMy-1180	El Rincón	ND	>35	AA-101148: 840 ± 44	1164	1198	1252	MSR214	−19.7	9.7	15.81	43.75	3.2	MSR312	−13.1	Rusconi, 1962
14	MM-1183	Laguna del Rosario	ND	>35	AA-90281: 1338 ± 44	648	682	765	MSR14	−18.4	9.8	13.65	37.76	3.2	MSR130	−14.1	Rusconi, 1962
14	MM-1199	Laguna del Rosario	ND	>35	AA-101147: 1063 ± 47	899	974	1020	MSR13	−19.4	9.8	13.86	38.52	3.2	MSR122	−14.1	Rusconi, 1962
15	MMy-1201	Alto La Echuna	M?	>35	AA-101149: 1036 ± 43	903	998	1030	MSR208	−17.6	7.9	2.09	5.78	3.2	MSR309	−14.3	Rusconi, 1962
16	MMy-1474	Nueva California	F?	10−12 años					MSR209	−13.6	9.6	14.37	39.53	3.2	MSR316	−7.9	Rusconi, 1962
17	Esq.1 Bolsa 126	Vaqueria			AA-90288: 2038 ± 47	−108	−49	22	MSR33	−15.00	8.4	13.08	35.88	3.2			Chiavazza, 2010
17	Esq. 2 Bolsa 120	Vaqueria							MSR32	−14.7	8.0	13.47	37.27	3.2			Chiavazza, 2010
18	MMy-259	Uspallata	F?	16−21	AA-66558: 1922 ± 52	16	82	133	USF8292	−15.6	9.9				USF8303	−6.6	Rusconi, 1962
18	MMy-1452-55b	Uspallata	ND	>35											MSR310	−15.1	Rusconi, 1962
18	Mmy-1452-55a	Uspallata	ND	>35											MSR311	−15.5	Rusconi, 1962
18		Finca Alí			AA-101143: 1862 ± 35	88	153	214	MSR433	−18.0	9.0	11.45	31.35	3.2	MSR382	−7.4	This paper
19	ind 1	Barrio Ramos	ND	35−40	AA-98708: 583 ± 43	1310	1351	1410	MSR296	−15.9	10.1	15.23	41.23	3.2	MSR355	−9.4	Fernández et al., 1999
19	BPA-1	Barrio Panella	ND	>35	AA-101144: 1902 ± 40	31	104	138		−18.5					MSR383	−7.1	This paper
20	MMy-284	Potrero Las Colonias	F	30−45	AA-66564: 568 ± 38	1316	1353	1415	USF8296	−11.0	10.0				USF8309	−4.2	Rusconi, 1962
20	MM-1203	Potrero Las Colonias	M	30−35		1316	1353	1415	MSR7	−14.7	8.9	14.93	40.63	3.2	MSR129	−9.6	Rusconi, 1962
20	MM-1219	Potrero Las Colonias	F	35−45		1316	1353	1415	MSR8	−14.7	8.5	14.95	41.18	3.2	MSR121	−9.3	Rusconi, 1962

Table 2 (*continued*)

Site number	Code	Precedence	Sex	Age	Years ^{14}C BP	Associated chronology	Min cal	Media cal	Max cal	Code	Corr. δ^{13}Ccol	Corr. δ^{15}N	Wt% N*	Wt% C*	Atomic C/N	Code	δ^{13}Cap	Reference
20	MMy-293	Potrero Las Colonias	M?	>35			1316	1353	1415	MSR210	−10.4	9.6	15.65	42.92	3.2	MSR305	−4.2	Rusconi, 1962
20	MMy-440	Potrero Las Colonias	ND	>35			1316	1353	1415	MSR213	−11.7	9.5	15.45	42.56	3.2	MSR307	−4.0	Rusconi, 1962
21	MM-242	Tumulo II-Uspallata	M	18–23	1230 ± 27		715	786	866	MSR6	−10.5	9.7	14.71	40.20	3.2	MSR124	−5.00	Rusconi, 1962
21	MMy-239	Túmulo II Uspallata	F	>50	AA-66561: 1269 ± 35		685	730	769	MSR4	−11.9	8.7	15.00	41.25	3.2	USF8304	−7.50	Rusconi, 1962
21	MMy-243	Túmulo II Uspallata	F	35–49	AA-66565: 1178 ± 41		775	844	890	USF8293	−12.1	10.1				USF8306	−6.50	Rusconi, 1962
21	MM-240	Túmulo II Uspallata	M?	40–49	1230 ± 27		715	786	866	MSR2	−11.9	9.1	14.80	40.50	3.2	MSR123	−7.40	Rusconi, 1962
21	MM-241	Túmulo II Uspallata	ND	35–45	1230 ± 27		715	786	866	MSR3	−11.8	9.9	14.69	40.65	3.2	MSR120	−7.0	Rusconi, 1962
21	MM-244	Túmulo II Uspallata	F	39–45	1230 ± 27		715	786	866	USF8294	−11.9	8.8				MSR125	−8.8	Rusconi, 1962
21	MMy-245	Túmulo II Uspallata	M	35–45	1230 ± 27		715	786	866	USF8292	−12.4	9.8				USF8305	−6.6	Rusconi, 1962
21	MMy-229	Túmulo I Uspallata	Ind	>50	AA-66568: 977 ± 35		1018	1084	1150	USF8294	−16.4	9.7				USF8307	−11.0	Rusconi, 1962
21	MMy-203-204b	Tumulo I Uspallata	ND	>35			1018	1084	1150	MSR220	−15.7	10.1	13.52	37.37	3.2	MSR314	−11.8	Rusconi, 1962
21	MM-220	Túmulo I Uspallata	ND	>35			1018	1084	1150	MSR1	−13.3	10.1	14.73	40.05	3.2	MSR117	−8.3	Rusconi, 1962
21	MMy-203-204a	Túmulo I Uspallata	ND	>35			1018	1084	1150	MSR219	−15.8	10.0	15.10	41.54	3.2	MSR313	−11.7	Rusconi, 1962
21	MMy-1097	Túmulo III Uspallata	ND	>35	AA-66566: 671 ± 40		1279	1317	1386	USF8297	−11.2	7.8				USF8310	−3.4	Rusconi, 1962
21	MM-1164	Túmulo III Uspallata	ND	>35			1279	1317	1386	MSR5	−11.4	10.2	13.94	37.84	3.2	MSR116	−6.5	Rusconi, 1962
21	MMy-1156-57a	Túmulo III Uspallata	ND	>35			1279	1317	1386	MSR215	−11.8	9.4	12.98	35.61	3.2	MSR302	−4.3	Rusconi, 1962
21	MMy-1156-57b	Túmulo III Uspallata	ND	inf?			1279	1317	1386	MSR216	−11.3	10.3	11.60	31.90	3.2	MSR303	−5.9	Rusconi, 1962
21	MMy-1156-57c	Túmulo III Uspallata	ND	ad?			1279	1317	1386	MSR217	−11.9	9.9	15.22	41.49	3.2	MSR304	−6.7	Rusconi, 1962
22	S/C	Uspallata Usina Sur			AC-1050: 580 ± 97		1298	1361	1421		−13.5	9.8				−		Fernández et al., 1999
23	S/C	C° Aconcagua	M	6–8	GX-19991: 370 ± 70		1451	1540	1631	S/C	−10.8	10.4				−		Fernández et al., 1999
24	S/C	Agua de la Cueva		>3	UGA-8660: 2480 ± 50		−761	−620	−540	UGA-8660	−14.6					−		Durán and García, 1989
24	S/C	Agua de la Cueva			UGA-8660: 2480 ± 50		−761	−620	−540		−13.9	13.3	14.84	39.88	3.1	MSR381	−5.9	Durán and García, 1989
25	MMy-n.d.	Potrerillos	ND	>35	AA-90282: 2181 ± 47		−357	−260	−176	MSR15	−17.5	10.3	14.31	38.96	3.2	MSR128	−12.0	Cortegoso, 2004
26	MMy-757	Papagayos	F	10–12 años						MSR211	−12.4	8.1	15.69	43.66	3.2	MSR308	−6.8	Rusconi, 1962
27	MM-1488	Odisa	M?	>35	AA90284: 529 ± 42		1328	1406	1435	MSR12	−12.0	9.0	13.81	38.69	3.3	MSR101	−7.5	Rusconi, 1962
27	MM-1485	Odisa	ND	>35		529	1329	1406	1435	MSR11	−12.3	9.3	14.54	40.43	3.2	MSR119	−8.1	Rusconi, 1962
28	MM-1215	Zanjón de los Ciruelos	ND	>35	AA-90280: 2068 ± 46		−165	−89	−40	MSR36	−19.0	9.0	14.12	38.74	3.2	MSR132	−13.7	Rusconi, 1962
28	MM-1212	Zanjón de los Ciruelos	ND	>35	AA-90279: 1536 ± 45		430	512	575	MSR35	−13.6	8.6	12.91	35.59	3.2	MSR127	−9.1	Rusconi, 1962
28	MM-1217	Zanjón de los Ciruelos	ND	>35		1796 ± 32	141	226	317	MSR37	−13.0	8.9	13.77	37.63	3.2	MSR135	−8.8	Rusconi, 1962
29	MMy-1501	Campo Gorgoni	ND	>35	AA98704: 2025 ± 36		−88	−27	25	MSR293	−18.3	9.3	15.16	41.37	3.2	MSR357	−11.6	Rusconi, 1962
30	B6-ind.9	Barrancas B6	ND	10–11		2251 ± 49	−390	−288	−211	MSR223	−16.1	10.6	15.26	42.31	3.2	MSR199	−12.2	Novellino et al., 2013
30	B6-ind 16	Barrancas B6	M?	11–12		2251 ± 49	−390	−288	−211	MSR224	−17.5	9.0	12.17	32.92	3.2	MSR192	−12.0	Novellino et al., 2013

30	B6-ind 5	Barrancas B6	F	39–49		2251 ± 49	−390	−288	−211	MSR225	−18.8	7.8	13.76	37.89	3.2	MSR300	−11.8	Novellino et al., 2013
30	B6-ind 3	Barrancas B6	M	40–50		2251 ± 49	−390	−288	−211	MSR226	−18.0	9.2	13.72	37.60	3.2	MSR198	−11.2	Novellino et al., 2013
30	B6-ind 10	Barrancas B6	ND	>35		2251 ± 49	−390	−288	−211	MSR227	−18.1	8.3	13.98	38.60	3.2	MSR195	−12.7	Novellino et al., 2013
30	B6-ind 4	Barrancas B6	F	20–22		2251 ± 49	−390	−288	−211	MSR228	−18.1	7.8	13.90	38.23	3.2	MSR197	−11.6	Novellino et al., 2013
30	B6-ind 14	Barrancas B6	M?	40–45		2251 ± 49	−390	−288	−211	MSR229	−18.0	7.5	13.98	38.55	3.2	MSR194	−12.2	Novellino et al., 2013
30	B6-ind 1	Barrancas B6	M	35–45		2251 ± 49	−390	−288	−211	MSR230	−17.9	8.4	6.36	16.72	3.1	MSR196	−11.6	Novellino et al., 2013
30	B6-ind 2	Barrancas B6	M?	40–45		2251 ± 49	−390	−288	−211	MSR231	−17.3	8.6	13.97	38.05	3.2	MSR193	−10.9	Novellino et al., 2013
30	B6-ind 12	Barrancas B6	F?	35–45		2251 ± 49	−390	−288	−211	MSR232	−17.9	9.0	14.72	40.08	3.2	MSR301	−12.1	Novellino et al., 2013
31	MMy-1263	Barrancas yac. 2	M	>45	AA-66560: 2084 ± 40		−163	−107	−51	USF8289	−18.0	9.9				USF8302	−13.6	Rusconi, 1962
31	MM-1332	Barrancas yac. 2	M	40–50		2084 ± 40	−163	−107	−51	MSR9	−18.6	8.8	13.56	37.37	3.2	MSR118	−13.0	Rusconi, 1962
31	MMy-1258	Barrancas yac. 2	F	30–40		2084 ± 40	−163	−107	−51	MSR297	−12.7	7.2	15.28	41.54	3.2			Rusconi, 1962
31	MMy-1241	Barrancas yac. 1	F	17–20		1597 ± 38	413	473	535	USF8288	−10.8	8.0				USF8301	−5.0	Rusconi, 1962
31	MMy-1254	Barrancas yac. 1	ND	21–30	AA98705: 1597 ± 38		413	473	535		−14.3					MSR362	−5.7	Rusconi, 1962
32	MMy-1477	Finca Furlotti	M	40–45	AA-98706: 378 ± 50		1448	1523	1625	MSR282	−15.5	8.3	15.41	41.89	3.2	MSR364	−8.8	Rusconi, 1962
33	MMy-1471	Alto Verde	ND	>35	AA-66563: 1736 ± 49		244	301	379	USF8295	−15.9	6.9				USF8308	−10.0	Rusconi, 1962
34	MMy-1464	Tunuyán	ND	>35						MSR212	−14.2	8.0	15.55	43.06	3.2	MSR306	−9.3	Rusconi, 1962
35	ind2	Capiz Alto	F	40–45			1492	1560	1632	USF6226	−14.9	11.70	−	−		USF6227	−10.6	Durán and Novellino, 2003
35	ind2	Capiz Alto	F	40–45	AA-101145: 246 ± 44		1525	1658	1800	MSR 418	−15.9	12.38				MSR371	−12.5	Durán and Novellino, 2003
35	ind2	Capiz Alto	F	40–45			1492	1560	1632	UGA8663	−15.9	−	−	−		−		Durán and Novellino, 2003
35	ind6	Capiz Alto	M	35–45	AA-101146: 423 ± 41		1431	1467	1610	UGA8661	−15.6	−	−	−		MSR372	−10.3	Durán and Novellino, 2003
35	ind1	Capiz Alto	F	45–49			1492	1560	1632	UGA8662	−16.7	−	−	−		−		Durán and Novellino, 2003
35	ind1	Capiz Alto	F	45–49			1492	1560	1632	MSR 419	−15.4	12.00	14.20	39.07	3.2	MSR375	−12.8	Durán and Novellino, 2003
35	ind4	Capiz Alto	ND	1–1.5			1492	1560	1632							MSR374	−9.9	Durán and Novellino, 2003
35	ind19	Capiz Alto	ND	5–6			1492	1560	1632	MSR 414	−13.6	9.66	13.84	38.11	3.2	MSR370	−9.3	Durán and Novellino, 2003
35	ind12	Capiz Alto	F	14–16			1492	1560	1632	MSR 415	−15.1	11.60	13.75	36.90	3.1	MSR376	−11.4	Durán and Novellino, 2003
35	ind8	Capiz Alto	F	11–12			1492	1560	1632	MSR 416	−15.8	11.24	14.23	38.81	3.2	MSR377	−11.3	Durán and Novellino, 2003
35	ind11	Capiz Alto	nd	1.5–2			1492	1560	1632	MSR 421	−14.9	14.31	12.88	35.97	3.3			Durán and Novellino, 2003
35	ind18	Capiz Alto	M	45–49			1492	1560	1632	MSR 422	−14.9	11.63	13.82	37.74	3.2	MSR369	−11.3	Durán and Novellino, 2003
35	ind16	Capiz Alto	nd	35–49			1492	1560	1632							MSR380	−6.2	Durán and Novellino, 2003
35	ind17	Capiz Alto	F	20–24			1492	1560	1632							MSR373	−9.3	Durán and Novellino, 2003
35	ind15	Capiz Alto	nd	4–5			1492	1560	1632							MSR379	−7.6	Durán and Novellino, 2003

Table 2 (continued)

Site number	Code	Precedence	Sex	Age	Years ^{14}C BP	Associated chronology	Min cal	Media cal	Max cal	Code	Corr. δ^{13}Ccol	Corr. δ^{15}N	Wt% N*	Wt% C*	Atomic C/N	Code	δ^{13}Cap	Reference
36	MM-1186	San Carlos	M	39–41		162 ± 26	1669	1771	1809	MSR10	−15.3	11.68	13.63	37.56	3.2	MSR131	−10.9	Rusconi, 1962
36	MMy-1223	San Carlos	F	19–23	AA-66562: 177 ± 34		1666	1773	1808	USF8287	−17.9	10.70				USF8300	−10.2	Rusconi, 1962
36	MMy-1189	San Carlos	F?	14–16 años		162 ± 26	1675	1807	1879	MSR221	−17.9	9.79	15.49	42.67	3.2	MSR315	−12.8	Rusconi, 1962
36	MMy-1221	San Carlos	M	40–49	AA-66567: 142 ± 41		1757	1807	1857	USF8298	−18.7					USF8311	−12.3	Rusconi, 1962
37	MMy-1197	Viluco	M	40–45	AA-66559: 208 ± 38		1650	1769	1802	USF8286	−17.2					USF8299	−12.9	Rusconi, 1962
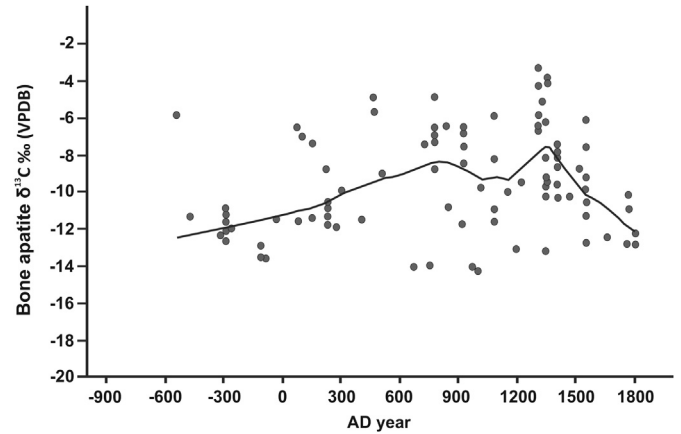
Fig. 2. Loess curve showing temporal trends in δ^{13}C values from human bone apatite.

dates were calibrated using the OxCal/Intcal13 curve and reported as median ages plus or minus 68.7‰ probability (Telford et al., 2004). Temporal trends in the isotope data were examined by plotting a smooth, Loess curve through the data points using the software PAST (Baxter, 2003; Hammer et al., 2001). In additional to isotopic and chronological information, Table 2 also details the age and sex of all individuals for whom such information is available. These determinations were made following the osteological criteria described by Buikstra and Ubelaker (1994).

7. Results

The δ^{13}C values of bone collagen samples vary between −19.7‰ and −9.3‰ over the temporal span sampled. During the same period, apatite δ^{13}C values vary between −15.5‰ and −3.4‰ and δ^{15}N values between 5.5‰ and 14.3‰. The correlation between δ^{13}Cco and δ^{13}Cap is significant ($r = 0.84$, $p < 0.01$), indicating the two measures are reflecting the same dietary trend. Apatite-collagen spacing averages of 5.3 ± 1.5‰, suggest similar isotopic contributions from protein and non-protein dietary sources (Tykot et al., 2009). Given that hydroxyapatite δ^{13}C is a better reflection of the whole diet (Ambrose and Norr, 1993), we focus on this variable throughout the rest of the text.

Fig. 2 shows the temporal distribution of δ^{13}C values in years A.D. The trendline in Fig. 2 (and Fig. 3) was generated with the
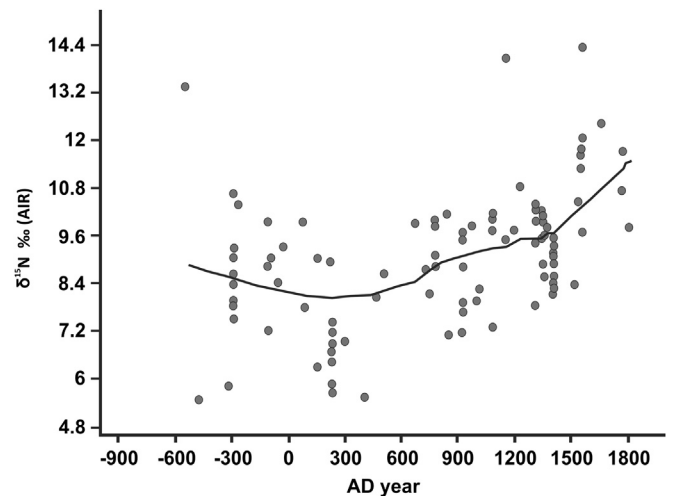
Fig. 3. Loess curve showing temporal trends in δ^{15}N values from human bone collagen.

"Loess" function in PAST using a 0.4 smoothing parameter. Starting at 600 years B.C., $\delta^{13}C$ values show a diet high in C_3 resources, with human $\delta^{13}Cap$ values average near −10.7‰. C_4 inputs and human $\delta^{13}C$ values then increase slowly until A.D. 800, reaching approximately −8‰ (ca. 50% C_4 resources). They fluctuate around this level for the next 600 years (until A.D. 1400), at which point they begin to decline. During this time the $\delta^{13}Cap$ is in average −8.5‰. After this date they are again −12‰, indicating an almost entirely C_3-based diet and similar to levels not recorded since maize was initially registered in the region. The last group has an average $\delta^{13}Cap$ −10.6‰. There is a significant difference between middle and late group of samples in the $\delta^{13}Cap$ (one way ANOVA 0.00035, $F = 13.91$).

Fig. 3 shows the trend in $\delta^{15}N$ across the same time frame. Average value begins at circa 9‰ at 600 B.C. and dip another 1‰ between that time and A.D. 300. After this date, human isotope value begins to climb throughout the rest of the sequence, peaking around 12‰ at Spanish contact.

Observing a temporal and spatial distribution of samples no a bias in the presence or absence of human samples was observed. But it is noted the unequal sample issue where proportionally more representation in 30°−32° SL human samples (42%) were analyzed in the middle temporal groups (800 AD−1400 AD) than in 32°−34° SL. But the pattern remains the same even if one subsamples the intermediate temporal period with equal numbers of individuals from the northern and southern areas was performed. Thus the pattern (Figs. 2 and 3) does not result from a bias in the geographic representation of individuals in each time period.

8. Discussion

The data presented in Figs. 2 and 3 discard the previously accepted idea by regional archaeologist that human subsistence over the last 2500 years in central-western Argentina was homogeneous and rich in maize. What we see here is that human $\delta^{13}C$ and $\delta^{15}N$ values and, by inference, their diets, show great variability over time, with at least three periods of different maize intake. It confirms a recent isotopic study where an heterogeneous diet was proposed (Gil et al., 2009).

From the beginning of the record to A.D. 800 there is a shift from diets dominated by C_3 resources to one where C_4 resources make up approximately 50% of total intake. The archaeobotanical record for this period is dominated by algarrobo (Abraham de Vázquez and Prieto 1981, 1989; Roig and Martinez Carretero, 1991), an economically important wild C_3 plant. Other significant resource was guanaco, a camelid with a wide geographic distribution and mean $\delta^{13}C$ values of −17‰. Other wild resources contribute to the dietary record, but camelids and algarrobo are most frequently found (Abraham de Vázquez and Prieto 1981, 1989; Chiavazza, 2009; Roig and Martinez Carretero, 1991). Domesticates appear in the region at *ca.* 2000 years ago (Gambier, 1974, 1977, 1988, 1992, 2000; García, 1992; Gil, 2003; Lagiglia, 1980, 2001; Roig, 1977, 1992). The most frequently reported plant is maize, but there are records of *Cucurbita* ssp, *Chenopodium quinoa* and *Lagenaria* ssp. (Bárcena, 2001; Lagiglia, 2001). The trend in human $\delta^{13}C$ values is consistent with a minor role for maize around the time it is first reported, and a moderate increase in its importance thereafter.

Between AD 800 and 1450 human apatite $\delta^{13}C$ values fluctuate around −8‰, consistent with a mixed diet containing substantial C_4 contributions. However they do not reach the levels of dedicated agriculturalists in other regions, such as the Puebloan or Basketmaker cultures of the American Southwest (e.g., Coltrain and Janentski, 2013; Coltrain et al., 2006, 2007). The archaeological record of the region also shows little evidence for substantial investment in habitation structures, ceramic technologies, or other

trappings of a sedentary, agricultural society. This is particularly true in the central and southern part of the region, between (Gil and Neme, 2012; Ugan et al., 2012).

After A.D. 1450 the human isotope record shows a dramatic decline in C_4 inputs to the diet. Collagen $\delta^{13}C$ values drop from −13.5‰ to −15.6‰ and apatite values from −8.5‰ to −11‰. If the Inka mummy sample from the Aconcagua is removed (being almost assuredly non-local; Fernández et al., 1999), the difference is still larger ($\delta^{13}C$ −16‰). There is also a significant increase in $\delta^{15}N$, which reaches its highest levels at this time (ca. 11.1‰) during this period. The first approach to understand this increase in $\delta^{15}N$ is a change in the significance of meat in the human diet (see below). This drop in $\delta^{13}C$ indicates that C_4 plants played only a small role in later human diets during this time and a much reduced one in comparison to the middle-period samples. This occurs at exactly the same time the region sees occupation by the Inka (ca. A.D. 1480−1540; Bárcena, 1991-1992; Cahiza and Ots, 2005; Gambier and Michieli, 1992) and subsequent settlement by the Spanish in Mendoza (founded A.D. 1561; Michieli, 1996) and San Juan (founded A.D. 1562; Michieli, 1996). Moreover this decline was not associated with a simple return to the same subsistence regimes seen early on. Although carbon isotope values during the early and late periods are similar, the stable nitrogen record indicates that diets were substantially different. It can be proposed a human diet with a higher component of meat during these late human samples than in the early human samples mentioned. Increase in the significance of fish meat and/or incorporation of domestic animal meat with the Spanish are documented historic facts in the region and in the historic archaeological record. But $\delta^{15}N$ enrichment could be caused by many factors other than diet (Coltrain et al., 2007; Szpak et al., 2014). For this reason actually the $\delta^{15}N$ are used as indicating different trophic and/or other human induced change between early and late human samples.

Counterintuitively, the isotope data suggests that maize was more important to prehistoric peoples before Inka and Spanish occupation. A similar isotopic pattern has been found in the trans-cordilleran region of Central Chile, where Falabella et al. (2007) show a decline in $\delta^{13}C$ values between the Aconcagua archaeological culture (pre-Inka assemblages, ca. A.D. 900−1450) and the Inka period. Average collagen values there fall from −11.6‰ in pre-Inka samples to −13‰ during the Inka Period, while apatite samples fall from −6.6‰ to −7.4‰. The decline in central-western Argentina is even greater. The data presented in this paper thus confirm the previous temporal pattern, even with fewer human samples (Gil et al., 2009). Moreover, the change in human diet implied by the stable isotope data was not necessarily a consequence of the Spanish conquest, and other causes need to be explored.

9. The little ice age and maize consumption

To explore our hypothesis suggesting that maize production in the region during pre-Spanish times was strongly linked to variations in temperature, we compare the isotopic changes in human bones with existing records of temperature variations in the region over the past millennium. However, given the marked arid conditions prevailing in the region, biological productivity in the central Andes is strongly linked to water supply. As a consequence, most paleoenvironmental records based on biological indicators, such as tree rings, provide useful estimates of past changes in precipitation rather in temperature (Boninsegna et al., 2009; Villalba et al., 2009).

Presently, the reconstruction of summer temperature (December to February) variations derived from the quantitative analysis of pigments in sediments of Laguna Aculeo (von Guten et al., 2009) represents the most detailed record of temperature fluctuations in Central Chile (33° S), extending back to the year AD
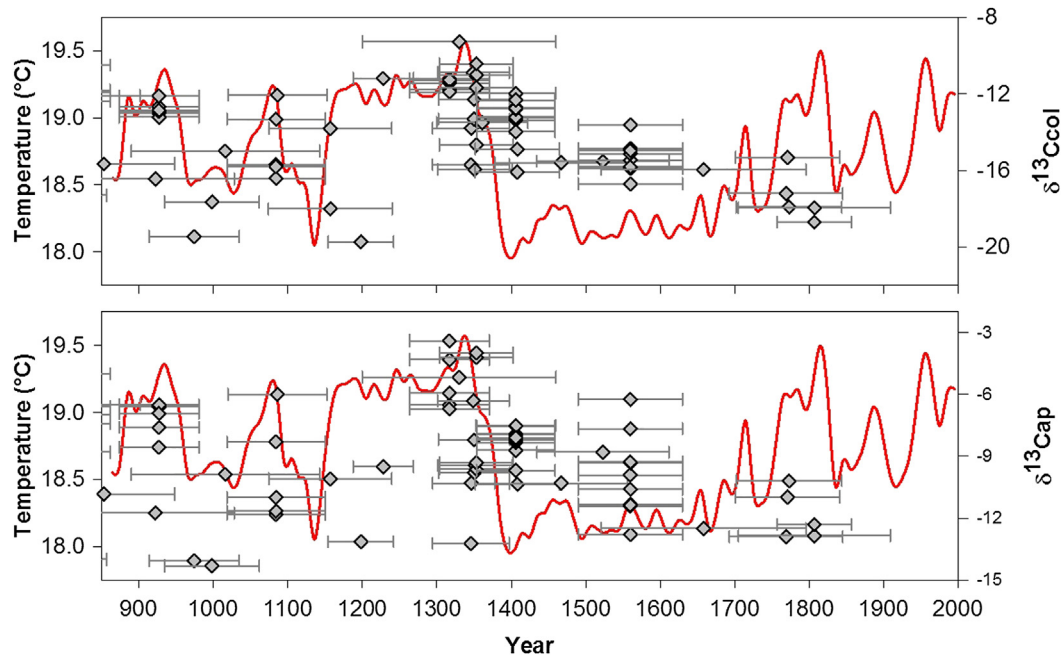
Fig. 4. Reconstruction of summer temperature variations from Laguna Aculeo, Central Chile, and variations in the human bone stable isotopes $\delta^{13}C$.

850 (Fig. 4). Although this record does not cover the entire temporal extent of our human isotopic record, it is sufficiently long to provide a valid comparison. The spatial correlation pattern between the Laguna Aculeo reconstruction and gridded temperature over South America show a coherent pattern of summer temperature variations all across the Central Andes of Chile and Argentina (von Guten et al., 2009), giving additional support for the comparison of this temperature reconstruction with the isotopic records.

The Laguna Aculeo record is characterized by a period with significant positive anomalies in summer temperature between AD 1150 and AD 1370. After that, a marked decrease in summer temperature larger than 1 °C is recorded from AD 1370 to AD 1750 (AD 1150−1369 average mean temperature = 19.21 °C versus AD 1370−1750 = 18.19 °C). Cold conditions prevailed until the end of 17th century. This cold interval, consistent with the Little Ice Age event recorded in other South American proxies (Espizúa and Pitte, 2009; Neukom et al., 2011, Villalba et al., 2003), is the most severe cooling even during the last 1000 years. The comparison between the temperature and the isotopic records show that peaks in the isotopic record around AD 800, AD 1080 and during the interval AD 1250−1370 are consistent with positive anomalies in summer temperature. In particular, the period AD 1300−1350 which recorded the highest isotopic values in the whole record is coincident with the 50-year warmest interval in the last 1000 years (mean summer temperature = 19.37 °C). Consistent with the marked decreased in temperature after AD 1370−1390, isotopic values for the more recent part of the record remain substantially low after AD 1400 and never again reached the levels recorded from AD 800−1400.

Reduced summer temperatures, increases in the occurrence of late frosts, and reductions in the length of the growing season would have seriously affected maize production. Analogous impacts of the Little Ice Age on European agriculture were quite significant (Fagan, 2000; Groven, 1988; Richerson et al., 2001) and in extreme years caused notable famines (Richerson et al., 2001). The Little Ice Age may have been just as significant in terms of increased variability as changes in average climate itself (Mann, 2002; Morgan, 2009).

Prior to AD 1400, human diets in central western Argentina were clearly based on maize, with individual diets containing as much as 80% maize. Favorable weather conditions in the Central Andes of Argentina during the 1150-1370 warm period favored the cultivation of maize in most dry areas where small streams or rivers provided water for irrigation. Low summer temperatures and an increase in decadal variability clearly transformed maize farming into a high-risk activity with high frequencies of bad economic years (Halstead and O'Shea, 1989; Richerson et al., 2001). In this context, alternative strategies introduced some of them during the Spanish settlement, were quickly incorporated by local populations in the area. By AD 1500 the incorporation of wheat and others Europeans resources such as cattle and goats is recorded in the documentary and archaeological record (Chiavazza and Mafferra, 2011; Michieli, 2012). Maize was never consumed by local communities at the high levels seen before AD 1400.

10. Conclusion

This study examines changes in human diets over the last 2500 years in central-western Argentina. Maize enters the archaeological record at the beginning of this period. It quickly increases in dietary importance, stabilizing at approximately 50% of the overall diet between the AD 800 and 1400. These data suggest that the most significant increase in maize consumption predated Inka occupation, coinciding with a similar trend in central Chile (Falabella et al., 2007). Presumably, favorable climatic conditions associated with the long-term warm period from AD 1150−1370 facilitated the cultivation of maize in the region. After this time, the onset of cold conditions associated with the Little Ice Age induced changes in human diets in Central western Argentina and Central Chile.

Declining stable isotope values after AD 1400 indicate a decrease in C_4 inputs and, by extension, a drop in maize consumption. We propose that climatic conditions associated with a two-century long period of warm summers followed by the Little Ice Age had a significant role in that change. Without doubt, the arrival of the Inka and the Spanish impacted the physical and social environment as well, but all of these factors should be understood within a

broad, ecological framework in order to generate a productive explanation of this variable time in our history. The incorporation of new resources, a diversification in subsistence strategies, mostly from the Europe (Chiavazza and Mafferra, 2011; Michieli, 2012; Bárcena and Ots, 2012), and the changing role of preexisting ones can each be explored as possible subsistence responses to a time of sharp climatic change, and were undoubtedly only one part of a sweeping social and behavioral adjustments occurring at this time.

Acknowledgments

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