

Stable isotope analysis of dog, fox, and human diets at a Late Holocene Chumash village (CA-SRI-2) on Santa Rosa Island, California

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ABSTRACT

Stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analyses of dog (*Canis familiaris*), island fox (*Urocyon littoralis*), and human bone collagen from CA-SRI-2 (AD 130–1830) on Santa Rosa Island, California provide a proxy of diet and the relationships between humans and these animals. Carbon isotopic signatures indicate that Native Americans and their dogs at CA-SRI-2 subsisted almost exclusively on marine resources, while the island fox ate primarily terrestrial foods. Nitrogen isotopes and archaeofaunal remains indicate that humans and dogs also ate higher trophic level foods, including finfishes, marine mammals, and seabirds with smaller amounts of shellfish. The CA-SRI-2 island foxes appear to have eaten higher amounts of terrestrial foods, similar to the diets observed in modern fox populations. These data generally confirm the commensal relationship assumed to exist between domesticated dogs and people, but the carbon isotopic composition of dogs is enriched $\sim 2\%$ compared to humans. We hypothesize that the difference in carbon isotopes between dogs and humans may have resulted from a higher consumption of C3 plants with lower $\delta^{13}\text{C}$ values by humans, or less likely from the ingestion by dogs of significant amounts of bone collagen, which is enriched by $\sim 4\%$ over associated muscle.

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1. Introduction

Stable isotope analyses of archaeological materials provide an important technique for investigating a variety of cultural and environmental issues. Studies of ancient carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes in human and animal bone collagen, hair, and other tissues are particularly useful for documenting trends in diet, health, and resource exploitation (Ambrose and DeNiro, 1986; Ambrose and Norr, 1993; Cannon et al., 1999; Choy and Richards, 2009; Hedges and Reynard, 2007; Katzenberg et al., 1993; Lee-Thorp, 2008; Newsome et al., 2004; Schwarcz, 1991; Walker and DeNiro, 1986). For archaeologists working in coastal regions, stable isotope analysis of human remains provides a means to evaluate the relative contribution of marine and terrestrial resources in human diets, as well as associated cultural and environmental developments (Clutton-Brock and Noe-Nygaard, 1990; Fischer et al., 2007; Newsome et al., 2004; Walker and DeNiro, 1986). A number of studies over the last decade or so also have used stable isotopes as a tool to investigate domestic dog (*Canis*

familiaris) diets and the interactions between dogs, humans (*Homo sapiens*), and local ecosystems (Allen and Craig, 2009; Allitt et al., 2008; Cannon et al., 1999; Clutton-Brock and Noe-Nygaard, 1990; Fischer et al., 2007; Germonpre et al., 2009; Schulting and Richards, 2002, 2009; Tankersley and Koster, 2009; White et al., 2001, 2004).

Stable isotope analysis requires the removal and destruction of skeletal remains, and can be objectionable to some Native North Americans and museum curators concerned with the destruction of human remains. Acknowledging these concerns, Cannon et al. (1999) proposed that analyzing stable carbon and nitrogen isotopes from archaeological dog remains may serve as a proxy for reconstructing human diet. Domesticated dogs have been a key companion of anatomically modern humans for millennia, and their subsistence base can generally be expected to largely mirror human diet because they are either provisioned by their owners or they scavenge in kitchen middens/refuse heaps and consume human feces. At the site of Namu (British Columbia), Cannon et al. (1999) observed that changes in dog stable isotopes, indicating a diet heavy in marine foods, tracked changes in the composition of the archaeofaunal remains from the site. This suggests the potential for dog bones to serve as a proxy for human dietary reconstruction.

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Following Cannon et al. (1999), Allitt et al. (2008) analyzed stable isotopes from three dog bones from coastal New Jersey and Pennsylvania, suggesting dogs, and possibly people, consumed maize. Based on the analysis of stable isotope data for 51 dogs (5 archaeological and 46 contemporary/ethnoarchaeological) and five archaeological humans associated with one of the dogs, Tankersley and Koster (2009) argued that dogs and humans had essentially the same isotopic signature. In the Old World, stable isotope data from Mesolithic Europe (Fischer et al., 2007) and South Korea (Choy and Richards, 2009) lend general support to the similarity of human and dog diets. Since dogs are known to eat human feces and prey on other resources (see Allitt et al., 2008; Cannon et al., 1999; Rick et al., 2008), questions remain about the comparability of human, dog, and other animal diets. Consequently, additional data are needed to refine our understanding of the similarities and differences between ancient dog and human diets.

In this paper, we present stable carbon and nitrogen isotope values from Late Holocene (AD 130–1830) domestic dog, island fox (*Urocyon littoralis*), and human remains from CA-SRI-2, a large Chumash village on Santa Rosa Island, California (Fig. 1). When compared to faunal remains from the site these data provide a framework with which to interpret the dietary patterns of these animals and the relationships between humans and canids on the Channel Islands.

2. The Channel Islands and CA-SRI-2

California's Channel Islands are composed of eight islands (San Miguel, Santa Rosa, Santa Cruz, Anacapa, San Nicolas, Santa Barbara, Santa Catalina, and San Clemente). Santa Rosa Island, located about 44 km from the mainland coast is about 217 km² in area and has a number of relatively well-watered streams. Terrestrial ecosystems on the islands are generally diminished in flora and fauna compared to the adjacent mainland. For example, the diminutive island fox currently found on six islands and the island spotted skunk (*Spilogale gracilis*) currently found on two islands were the largest Holocene terrestrial mammals. The distribution of large woody plants such as oak and pine are also more limited (Schoenherr et al., 1999). In contrast, the islands contain diverse and productive marine ecosystems, including kelp forest, rocky

intertidal, sandy beach, and other habitats. Coastal resources including shellfish, finfish, marine mammals, and birds were generally the focus of human subsistence, especially as a source of protein, throughout the known sequence of Native American occupation (Braje, 2010; Kennett, 2005; Rick et al., 2005).

The Channel Islands also contain one of the longest coastal archaeological records in the Americas, spanning some 13,000 calendar years through about AD 1822 (Johnson, 1999; Erlandson et al., in press; Kennett, 2005; Kennett et al., 2008; Rick et al., 2005). Late Holocene island Chumash peoples relied exclusively on hunting and gathering wild foods, lived in large villages with up to 400 residents, had sophisticated mainland and island exchange networks using a shell bead currency, employed plank boats and other maritime technologies to pursue a variety of marine fishes, mammals, and other animals, and had hereditary leadership and status differentiation (Arnold, 1992, 2001; Kennett, 2005; Kennett et al., 2009; Rick et al., 2005).

Because of the reduced terrestrial productivity, especially the small number of mammals, Rick et al. (2008, 2009) suggested that dogs and island foxes had an important influence on island ecology, especially the breeding and roosting behavior of birds. The earliest evidence for dogs comes from CA-SNI-11 on San Nicolas Island and CA-SCRI-109 on Santa Cruz Island and indicates that they were introduced to the islands by humans by at least 6000 years ago (Rick et al., 2008). The fox was possibly introduced to the northern Channel Islands by humans or naturally prior to about 7000–6000 years ago and then later translocated to three of the southern Channel Islands (San Clemente, Santa Catalina, and San Nicolas; Collins, 1991a, 1991b; Rick et al., 2009; Vellanoweth, 1998). The stable isotope data presented here provide additional details on the relationship between Late Holocene dogs, foxes, and humans at a single site where variation in habitat and resources can be better controlled.

CA-SRI-2 is a large village and cemetery complex covering about 250 × 200 m of a marine terrace near Tecolote, Garanon, and Arlington canyons (Fig. 2). The site was first excavated by Orr (1968) beginning in the 1940s. Ethnohistoric records and the presence of some 93 historic artifacts suggest that CA-SRI-2 was possibly the historic Chumash village of *Niaqla*, though it could be another named village (*Nimkilkil*) as well (see Glassow, 2010; Johnson, 1999;

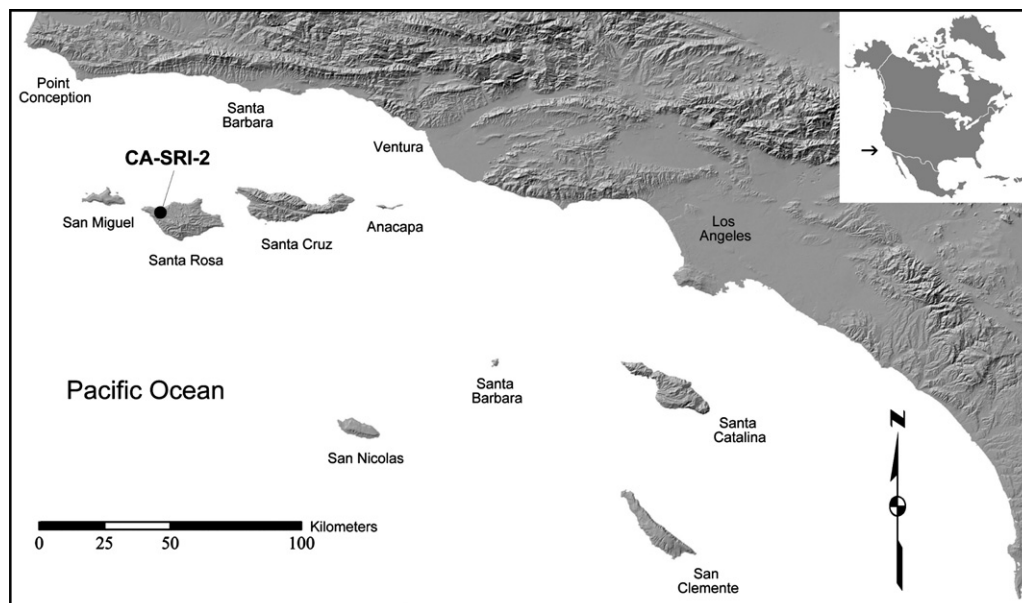


Fig. 1. Location of CA-SRI-2, Santa Rosa Island, and the southern California Coast.

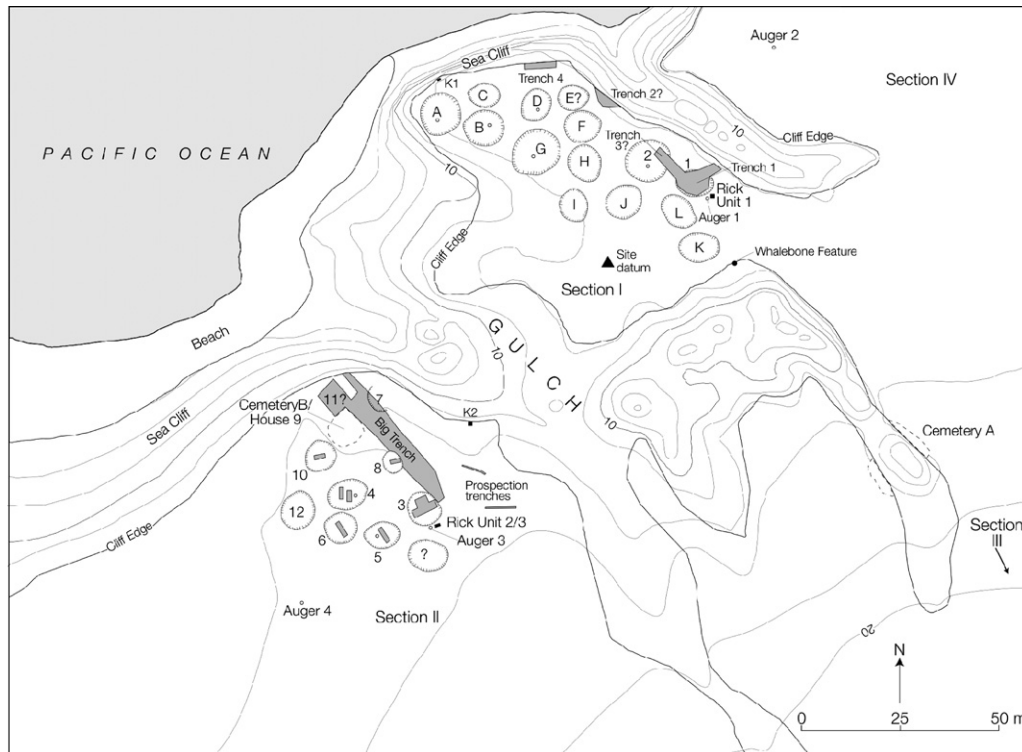


Fig. 2. CA-SRI-2 showing location of excavation units, auger tests, house depressions, and other surface features (contour interval in meters). Note section numbers and house numbers that show general areas where dog, fox, and human remains were found. Adapted from Rick (2007).

Kennett, 2005; Rick, 2007). Twenty-six radiocarbon dates bracket the CA-SRI-2 occupation between about AD 130–1820, with an ephemeral component also dated to ca. 2400 BC (Table 1). Most of the stable isotope data reported here are from human, island fox, and dog bones collected during Orr's excavations and date between AD 130 and 1820. Rick (2007, in press) reanalyzed some of Orr's original collections from an estimated 343 m³ of deposits, and excavated two test units at the site providing additional artifacts and faunal remains from more controlled contexts and with the use of smaller screen sizes.

3. Materials and methods

3.1. Archaeological materials

Orr (1968) recovered the remains of as many as seven dogs and nine foxes at CA-SRI-2 (Collins, 1991a, 1991b; Rick et al., 2008, 2009). Rick also excavated a partially eroded dog burial at CA-SRI-2 in 2003. In this study, we analyzed bone collagen extracted from mandibles because they were generally better preserved and we could ensure that we were not sampling the same individual twice. Five dog and three fox mandibles were available for this analysis.

Orr (1968) also excavated two cemeteries at CA-SRI-2, recovering over 100 human burials. These human remains have been the subject of detailed osteological analysis, including studies of human health and violence (see Lambert, 1994; Walker et al., 2005). Goldberg (1993:197) conducted stable C and N analysis of 15 individuals from CA-SRI-2, including adults, juveniles, and a single infant. These data indicated a diet strongly focused on marine foods, and provide a comparative dataset comparable in age to the canids. To put the human data into context, Goldberg (1993) also measured the isotopic content of a wide range of modern plant and

animal remains from both the northern and southern Channel Islands, including island foxes, pinnipeds (seals and sea lions), finfish, blue dick, and cacti.

Direct radiocarbon dates for the dog, island fox, and human remains discussed here are not available, but most of the animal and human remains come from areas of the site that have been radiocarbon dated to the last 1000 years (Table 2). Fox specimens UL1 and UL2 are from Section II and House 6 in Section II. Dates for Section II range between cal AD 660 and 1820 and House 6 contains a Historic period needle-drilled shell bead, suggesting at least some of it was occupied during the contact period. Dog specimens CF1 and probably CF2 come from Section I, an area dated to around cal AD 1080–1820. Dog specimen CF5 is from Section III with a single date of around cal AD 930–1220. Fox specimen UL3 and dog specimen CF4 have no known provenience, and dog specimen CF3 may come from Cemetery B dated from about AD 1200 through the Historic period (Rick, 2007). All of the human remains are from Cemetery B and also likely date to between AD 1200 through the Historic period. Collectively, these dates anchor the dog, fox, and human remains between about AD 660 and 1817 when the last baptisms from this community were recorded at the missions. The context of the island foxes and dogs reported here are poorly documented, but at other Channel Island sites foxes and dogs were intentionally buried by humans (Collins, 1991b; Rick et al., 2008; Vellanoweth et al., 2008).

3.2. Stable isotope methods

To maintain comparability, bone collagen was prepared for the dog and fox samples following the general methods used by Goldberg (1993). Systematic differences between Goldberg's data and ours due to instrument-specific issues can not be ruled out, but we assume inter-laboratory errors to be in the common range (i.e., 2–3‰). Bone samples were prepared at the University of

Table 1
Radiocarbon data for CA-SRI-2.^a

Lab # ^b	Provenience	Material ^c	Uncorrected ¹⁴ C Age	¹³ C/ ¹² C Adjusted Age	1 Sigma Age Range (cal AD/BC)
B-158147	Unit 1: 63 cm (R)	BA	170 ± 70	600 ± 70	A.D. 1690–1950
B-158148	Unit 1: 14 cm (R)	CM	310 ± 80	740 ± 80	A.D. 1690–1950
OS-37590	House D, auger, 45–47 cm	CM	–	770 ± 40	A.D. 1690–1840
OS-37589	House 2, auger, 48 cm	BA	–	780 ± 40	A.D. 1680–1830
OS-57591	House 5, auger, 41 cm	BA	–	820 ± 55	A.D. 1660–1810
B-158146	Unit 2: 12 cm (R)	CM	420 ± 70	850 ± 70	A.D. 1630–1720
OS-37244	House 3, level 5	PO	–	920 ± 35	A.D. 1540–1670
UCLA-134	Hearth, 56 cm	Charcoal	330 ± 50	330 ± 50	A.D. 1480–1640
OS-37588	House 4, auger	CM	–	980 ± 40	A.D. 1490–1630
B-120072	Cemetery B, Burial 92	PO	580 ± 60	1010 ± 60	A.D. 1460–1620
OS-33373	Unit 2: 60–61 cm (R)	CM	–	1020 ± 35	A.D. 1470–1540
OS-37146	Cemetery B: Mass Interment	RAB	–	1040 ± 45	A.D. 1450–1530
OS-37245	House 1 Orr collection	PO	–	1060 ± 30	A.D. 1450–1510
UCLA-104	House 1	Wood	400 ± 80	400 ± 80	A.D. 1430–1630
OS-37593	House G, auger 48 cm	CM	–	1140 ± 45	A.D. 1400–1460
S-1286	Burial 11 (long bone)	HBC	865 ± 65	865 ± 65	A.D. 1330–1440
UCLA-102	Burial 13	Seeds	600 ± 70	600 ± 70	A.D. 1300–1410
UCLA-178	Tr. 4B, Level 2, Cem. A	PO	900 ± 100	1330 ± 100	A.D. 1210–1390
OS-35532	Burial 13 or House 8	Seeds	–	735 ± 40	A.D. 1260–1290
OS-32373	Seacliff: 50–60 cm (K)	MS	–	1420 ± 40	A.D. 1170–1280
OS-32372	Unit 2: 20–30 cm (K)	MS	–	1490 ± 30	A.D. 1070–1210
OS-37592	Sec. III auger, 28 cm	CM	–	1560 ± 55	A.D. 1000–1160
B-158145	Unit 2: 120 cm (R)	CM	1190 ± 80	1620 ± 80	A.D. 920–1070
UCLA-103	Postholes, House 3	Wood	1230 ± 60	1230 ± 60	A.D. 690–890
OS-39335	Eastern margin, Sec. IV	CM	–	1990 ± 30	A.D. 610–680
UCLA-135	Midden over Cemetery A	CM	1820 ± 90	2250 ± 90	A.D. 250–460
CT-038	Trench 4, 30 inches	MV	1860 ± 340	2290 ± 340	80 B.C.–A.D. 680
OS-39336	Middle fork, Sec. III	CM	–	4460 ± 35	2450–2300 B.C.

^a All dates were calibrated using Calib 5.0.1 (Stuiver and Reimer, 1993) and applying a ΔR of 225 ± 35 years for all shell samples. Beta-158147 is just beyond the calibration range of Calib 4.3. The calibrated age range provided for Beta-158147 is the same as Beta-158148. ¹³C/¹²C ratios were determined by the radiocarbon labs, or an average of +430 years was applied. K indicates units excavated by D. Kennett and R denotes units excavated by T. Rick. The human bone date was calibrated using 50% terrestrial and 50% marine carbon, applying a ΔR of 225 ± 35 years (see Walker et al., 2005).

^b B = Beta, OS = NOSAMS, S = Saskatchewan.

^c CM = California mussel, BA = black abalone, PO = *Olivella* shell, RAB = red abalone bead, HBC = human bone collagen, MS = marine Shell, MV = marine vegetation.

Oregon's Archeometry Facility. Samples ranging from ~250 to 750 mg dry weight were removed with single-use Dremel cut-off wheels that were discarded between each sample to minimize contamination. To further reduce cross-contamination, cutting was done under a hood onto aluminum foil that was disposed of along with the dust after each sample was taken, and the work area was wiped down with 70% ethanol. Samples were physically cleaned of adhering sediment and the outer surfaces of the bone were scraped away with an X-acto blade. Bone was demineralized over 2–5 days in 0.5 N HCl at ~5 °C in scintillation vials. Lipids were removed by soaking demineralized bone in a chloroform–methanol solution (2:1) and rinsed in multiple baths of de-ionized water while being sonicated. A weak base solution (0.1 N NaOH) was used to extract

Table 2
Summary of provenience and age of dog and island fox remains analyzed in this study.^a

Specimen Number	Provenience ^b	Estimated Age
<i>Domestic dog</i>		
CF1 (SI-101)	Section I	AD 1080–1820
CF2 (SBMNH 3893)	Section I	AD 1080–1820
CF3 (SBMNH 131.2B)	Cemetery B?	AD 1200–1820
CF4 (SBMNH 3546)	Unknown	Late Holocene
CF5 (SBMNH 3971)	Section III	AD 930–1220
<i>Island fox</i>		
UL1 (SBMNH 4313)	Section II	AD 660–1820
UL2 (SBMNH 4296)	Section II, House 6	Historic period
UL3 (no cat #)	Unknown	Late Holocene

^a All human remains are from Cemetery B and likely date to AD 1200–Historic period.

^b See Fig. 2 for approximate locations.

humic acids at room temperature for less than 1 h. The resulting pseudomorph was then gelatinized in weak (0.01 N) HCl for 12 h at 70 °C, lyophilized and weighed, and %collagen yield was determined. Subsamples of 1.0 ± 0.2 mg of lyophilized, extracted collagen were packed into tin capsules and submitted to the UC Davis Stable Isotope Facility (Dept. of Plant Sciences) where C and N stable isotope concentrations were analyzed using a PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20–20 isotope ratio mass spectrometer. Sample isotope ratios are reported as $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values, where $\delta R_{\text{sample}} = [(R_{\text{sample}}/R_{\text{standard}}) - 1] \times 1000$, and R_{sample} and R_{standard} are the ¹³C/¹²C and ¹⁵N/¹⁴N ratios of measured samples and standards, respectively. Results are reported in ‰ notation (per mil or parts per thousand) with respect to Pee Dee Belemnite (PDB) for $\delta^{13}\text{C}$ and atmospheric N₂ for $\delta^{15}\text{N}$. Measurement precision is $\pm 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $\pm 0.3\text{‰}$ for $\delta^{15}\text{N}$.

All samples produced usable collagen, ranging from 13 to 24% by weight, and C:N ratios between 3.22 and 3.45. C:N in these ranges reflect good preservation for isotopic analyses (Ambrose, 1990; DeNiro and Weiner, 1988; van Klinken, 1999).

4. Results

Analysis of stable isotopes from 5 dogs, 3 island foxes, and 15 humans from CA-SRI-2 provides insight into the diets of the three largest Holocene terrestrial mammals on the Channel Islands (Table 3). As depicted in Fig. 3, human and dog stable isotopes are highly enriched compared to foxes: human $\delta^{13}\text{C} = -12.4$ to -14.7‰ , $\delta^{15}\text{N} = 15.1$ – 21.2‰ ; dog $\delta^{13}\text{C} = -10.7$ to -12.9‰ , $\delta^{15}\text{N} = 17.1$ – 18.6‰ ; fox $\delta^{13}\text{C} = -17.8$ to -18.9‰ , $\delta^{15}\text{N} = 7.7$ – 11.4‰ .

Table 3
Stable isotope data from dog, island fox, and human remains from CA-SRI-2.^a

Sample #	Description	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	C/N ratio	% Coll	$\mu\text{g C}$	$\mu\text{g N}$
CGH280	Burial # 260034, Adult male rib	-12.1	19.9	3.1	22.1	—	—
CGH281	Burial # 260064, female rib	-12.8	18.4	3.2	20.3	—	—
CGH282	Burial # 260066, juvenile female rib	-14.3	15.1	3.2	21.5	—	—
CGH283	Burial # 260018, Adult male rib	-14.6	15.4	3.2	20.3	—	—
CGH284	Burial # 260073, female rib	-13.7	18.0	3.2	14.5	—	—
CGH285	Burial # 260001, juvenile rib	-14.7	15.2	3.2	18.6	—	—
CGH286	Burial # 260055, adult male rib	-13.5	16.9	3.2	12.6	—	—
CGH287	Burial #, 260075, juvenile rib	-12.6	18.5	3.2	19.8	—	—
CGH288	Burial # 260065, Female rib	-12.7	18.8	3.2	18.2	—	—
CGH289	Burial # 260059, infant rib	-14.3	21.2	3.2	18.4	—	—
CGH291	Burial # 260074, female rib	-13.6	17.7	3.1	14.8	—	—
CGH292	Burial # 260076, female rib	-13.8	16.8	3.2	17.4	—	—
CGH293	Burial # 400005, female rib	-14.5	15.4	3.2	14.6	—	—
CGH294	Burial # 400006, female rib	-13.1	17.1	3.2	19.2	—	—
CGH295	Burial #400016, female rib	-13.1	16.6	3.2	17.6	—	—
UL1	<i>Urocyon littoralis</i> left mandible, Cat. # 4313, Section II	-18.9	7.7	3.3	18.2	449.7	160.7
UL2	<i>Urocyon littoralis</i> left mandible, Cat # 4296, House 6, Section II	-17.8	11.4	3.3	20.6	404.0	141.8
UL3	<i>Urocyon littoralis</i> left mandible, Unknown cat #, no provenience	-18.1	9.4	3.3	19.5	435.5	154.4
CF1	<i>Canis familiaris</i> , Cat # SI-101, Sea Cliff in Section 1	-11.1	18.6	3.5	17.3	570.5	193.0
CF2	<i>Canis familiaris</i> left mandible juvenile, Cat # 3893, Trench 3	-11.1	18.4	3.3	18.5	535.3	189.0
CF3	<i>Canis familiaris</i> burned left mandible, Cat # 131.2b, cemetery b area?	-11.8	17.1	3.2	16.9	500.6	181.2
CF4	<i>Canis familiaris</i> right mandible, Cat # 3546, unknown provenience?	-12.9	17.2	3.2	19.7	417.4	150.1
CF5	<i>Canis familiaris</i> left mandible, Cat. # 3971, Section III	-10.7	18.0	3.3	13.1	497.9	174.1

^a Human data obtained from Goldberg (1993).

(Fig. 3). This indicates that human and dog diets were heavily dependent on sources of marine protein. Because marine food chains are more complex than terrestrial ones, greater trophic enrichment occurs, which produces the wide isotopic separation

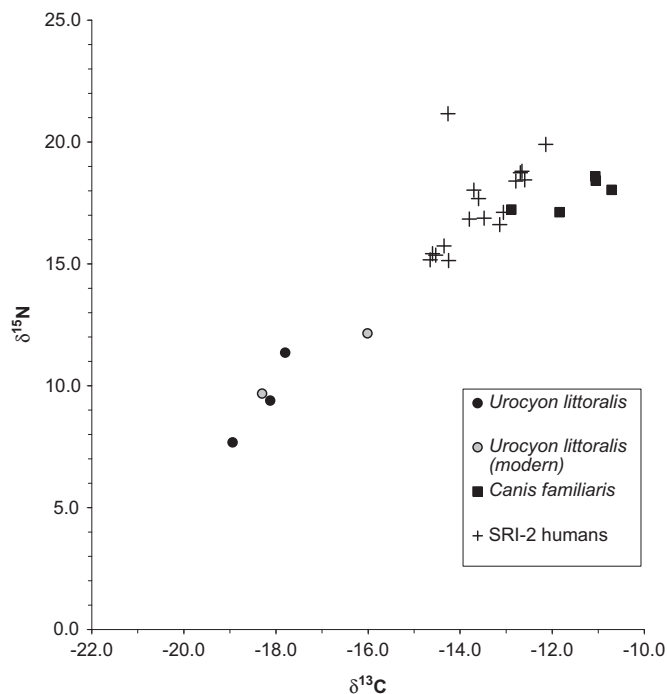


Fig. 3. Plot of stable C and N values for dogs, island foxes, and humans from CA-SRI-2. Humans and modern island fox (San Clemente Island) are from Goldberg (1993).

between a terrestrial omnivore (i.e., the island fox) and a high-level marine predator (i.e., the maritime Island Chumash). A clear marine–terrestrial gradient is evident on the scatter plot, similar to that observed previously in human populations for the Santa Barbara Channel mainland and islands by Walker and DeNiro (1986). With the removal of one human outlier, a regression of $\delta^{15}\text{N}$ against $\delta^{13}\text{C}$ for foxes and humans reveals a tight linear correlation between the isotopes ($R^2 = 0.967$, $y = 1.6328x + 39.185$, $se_m = 0.07$, $se_b = 1.01$), and with a regression line that is nearly superimposed on the Walker and DeNiro (1986) gradient (Fig. 4; data from their Table 3). The inclusion of dedicated herbivores (mule deer, *Odocoileus hemionus*) and marine piscivores (pinnipeds and cetaceans) in the plot helps to put the new data into context by providing end members of feeding behavior in the Santa Barbara Channel region.

The island fox isotope values, though lower than humans and dogs, are consistent with a primary terrestrial carnivore at roughly a trophic level above the deer samples (i.e., $\delta^{15}\text{N}$ enriched 3–5‰ vs. a herbivore; Hedges and Reynard, 2007). This is congruent with the dietary habits of many contemporary island foxes, which generally eat insects, fruits, deer mice (*Peromyscus maniculatus*), and carrion (Moore and Collins, 1995). The CA-SRI-2 foxes are comparable to modern island foxes from San Clemente Island analyzed by Goldberg (1993). They are also similar to isotope data from plasma blood samples from modern island foxes from Santa Cruz Island provided by Caut et al. (2006). It is possible that the spread in the fox data indicates variable, though probably rare, access to marine protein, perhaps through scavenging dead seabirds, pinnipeds, or marine fishes.

Although the plots suggest that dogs group more closely with humans than with their canid cousins the foxes, they fall below the classic Santa Barbara Channel marine–terrestrial gradient, showing significantly higher mean $\delta^{13}\text{C}$ values than humans ($-11.5 \pm 0.8\text{‰}$ vs. $-13.5 \pm 0.7\text{‰}$; $t(6) = 4.66$, $p = 0.0034$) with similar mean $\delta^{15}\text{N}$

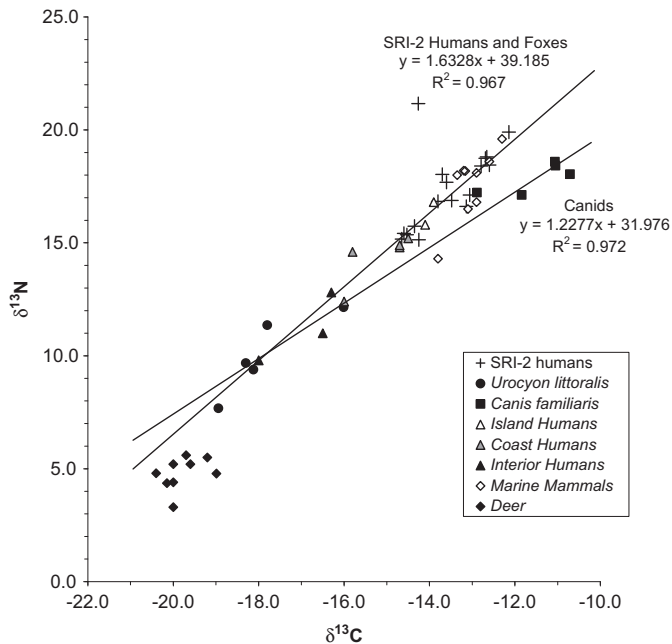


Fig. 4. The Santa Barbara Channel marine–terrestrial isotopic gradient. Stable C and N values for dogs, island foxes, and humans from CA-SRI-2, augmented with data on humans, sea mammals, and deer from Island, Coastal Mainland, and Interior Mainland archeological sites as reported Goldberg (1993) and Walker and DeNiro (1986:Table 3). Linear regression of SRI-2 humans and foxes falls closely on that gradient, whereas a regression of dogs and foxes falls below, suggesting a metabolic or dietary difference between dogs, humans, and foxes. One human outlier has been removed from regression analysis.

values ($17.9 \pm 0.5\text{‰}$ vs. $17.4 \pm 3.1\text{‰}$; $t(18) = 0.96$, $p = 0.3512$; using a t -test assuming unequal variances, Ruxton, 2006). The disparity in $\delta^{13}\text{C}$ could result from metabolic differences between dogs and humans, or from a substantial food source in the dog diet not found in the human or fox diet, specifically one that is notably enriched in ^{13}C compared to ^{15}N . A similar regression through the canids alone also produces a strong linear correlation ($R^2 = 0.972$, $y = 1.2277x + 31.976$, $se_m = 0.07$, $se_b = 1.11$), but the regression line diverges widely from the Santa Barbara Channel gradient. An analysis of covariance on the two groups (i.e., humans and foxes vs. foxes and dogs) indicates the slopes of the regression lines are significantly different ($df = 1$, $P = 0.0002$), as are the intercepts ($df = 1$, $P = 0.0005$). We take this to mean that the dogs are the isotopic outgroup with respect to the “natural” or “wild” diets (for lack of better terms) on the Late Holocene Channel Islands.

5. Discussion

The dog, fox, and human isotope data presented here provide insight into Late Holocene diets of the three largest Holocene mammals on the Channel Islands. Our analysis suggests that dogs were primarily scavenging the refuse of foods leftover from human consumption and processing and/or were being fed many of the same types of foods that people were eating. Given the dearth of

terrestrial foods available on the Channel Islands, not surprisingly these data demonstrate that people and their dog companions were consuming high quantities of marine foods. These data are further supported by archaeofaunal remains from CA-SRI-2 that are dominated by marine fishes and shellfish (Table 4) and other Late Holocene Chumash sites that are overwhelmingly dominated by marine resources, especially finfishes (Kennett and Kennett, 2000; Kennett, 2005; Rick et al., 2005). The fish remains analyzed from CA-SRI-2 include rockfish (*Sebastes* spp.), surfperch (Embiotocidae), cabezon (*Scorpaenichthys marmoratus*), California sheephead (*Semicossyphus pulcher*), and other mostly kelp forest or rocky intertidal species. The shellfish are dominated by California mussels (*Mytilus californianus*), with smaller amounts of *Tegula*, abalones (*Haliotis* spp.), sea urchins (*Strongylocentrotus* sp.), and other species that, due to their lower trophic level signature, likely represented smaller amounts of the overall human and dog diet than marine fishes. A smaller number of seabird, sea otter (*Enhydra lutris*), billfish (Xiphidae), and pinniped remains have also been identified at CA-SRI-2 (Rick, in press).

One difference between human and dog isotopes is that the dog $\delta^{13}\text{C}$ values are enriched $\sim 2\text{‰}$ compared to humans. This disparity could result from metabolic differences between dogs and humans, from a substantial food source in the dog diet not found in the human or fox diet, specifically one that is enriched in ^{13}C compared to ^{15}N , or from a food source that is diminished in ^{13}C consumed by humans but not dogs. We propose three hypotheses to explain this $\delta^{13}\text{C}$ enrichment. First, human and animal feces are often cited as a dietary source for dogs that is not shared by their human counterparts, especially in the absence of domesticated swine to serve the same waste disposal purpose (e.g., Cannon et al., 1999; Tankersley and Koster, 2009; White et al., 2001). While relatively little is known about the isotopic content of feces, following Minagawa and Wada (1984), Cannon et al. (1999) suggest that because urine is relatively depleted in ^{15}N compared to dietary constituents that feces may be as well. This accords physiologically with the observed trophic level effect for $\delta^{15}\text{N}$ (e.g., DeNiro and Epstein, 1981; Hedges and Reynard, 2007; Minagawa and Wada, 1984), and depletion would be expected during C metabolism where it is exhaled as ^{13}C -depleted CO_2 (e.g., DeNiro and Epstein, 1978). Without knowing the magnitude of depletion, we could assume it to be lower than the original food source by some amount, and then we should expect $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of dogs primarily eating feces to be somewhat lower (possibly only slightly lower) than their human owners.

Given that ^{13}C enriched feces seems to be an unlikely candidate to explain the isotopic divergence of the dog specimens, we propose that bone collagen itself may have been a distinct protein source accounting for this difference. Empirical studies reported by Ambrose and Norr (1993) indicated that mammal bone collagen $\delta^{15}\text{N}$ values are in equilibrium with muscle $\delta^{15}\text{N}$, but collagen $\delta^{13}\text{C}$ is $\sim 4\text{‰}$ higher than muscle $\delta^{13}\text{C}$. In situations where humans are preferentially taking the muscle meat from their vertebrate prey, and leaving the bones, viscera, and integument for the dogs, the observed $\delta^{13}\text{C}$ enrichment of $\sim 2\text{‰}$ for dogs, corresponding to $\sim 50\%$ of dietary protein from bone collagen, might be reasonable, and there would be no expected difference in $\delta^{15}\text{N}$. This is

Table 4

Summary of faunal data from late Holocene components at CA-SRI-2, showing taxonomic richness and density of faunal classes by weight or NISP (Rick, in press).

Component/Age	Shellfish N^a	Shellfish kg/m^3	Fish N	Fish NISP/m^3	Bird N	Bird NISP/m^3	Mammal N	Mammal NISP/m^3
Unit 2, Str. III AD 920–1070	25	55	15	56,636	1	681	–	2523
Unit 2, Str. II AD 1470–1540	30	61	14	220,130	–	143	2	1159
Unit 2, Str. I AD 1630–1720	26	109	16	109,167	2	268	5	1495
Unit 1 AD 1690–1820	30	148	20	137,166	5	401	4	3021

^a N = Richness measured by number of taxa (family, genus, or species) identified in each sample.

supported by evidence of canid gnawing on bones in several Channel Island archaeological sites (Rick et al., 2008:1083). For example, Noah (2005:102) noted dog gnawing and evidence of bone digestion on pinniped, swordfish, and dolphin remains from three sites on Santa Cruz Island. A swordfish vertebra with evidence of gnawing was also recovered by Rick from CA-SRI-2 in 2000. Human skeletal data from CA-SRI-2 and other sites also demonstrate that island populations were undergoing declines in health and increased violence (Lambert, 1994) that could also have acted as a factor for increased dog consumption of bone collagen while eating scraps. The consumption of bone collagen is a convenient explanation and one that fits with known canid behavior, but this should be considered hypothetical until controlled feeding studies determine whether this is realistic, i.e., are domestic canids physiologically capable of subsisting on a diet of 50% bone collagen and the high loads of calcium phosphate that implies.

A final explanation is that humans were consuming higher amounts of terrestrial C3 plants (native C4 plants are absent on the Channel Islands) than dogs. Goldberg (1993) presented $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for a variety of Channel Island plants, including acorns and prickly pear fruit that may have been consumed by the Island Chumash. Prickly pear fruit has $\delta^{13}\text{C}$ values comparable to the marine foods likely consumed by humans and dogs at approximately -13.3‰ . However, acorns vary between about -23.9‰ and -27.5‰ , with a variety of other leaves and seeds having values all well below -20‰ (Goldberg, 1993). Consumption of these plants by humans may have helped reduce human $\delta^{13}\text{C}$ signatures relative to dogs that were not given access to those plant resources. Given the significantly lower $\delta^{13}\text{C}$ values for Native Americans on the mainland (Walker and DeNiro, 1986), islanders were still consuming considerably higher amounts of marine protein, but probably enough terrestrial plants like acorns to help lower their $\delta^{13}\text{C}$ values relative to dogs.

Outside of the Channel Islands, $\delta^{13}\text{C}$ enrichment was not observed in the dogs at Namu, British Columbia where human and dog isotopes are available (Cannon et al., 1999:402). At the Nukdo shell midden in Korea, one of three dogs is enriched in ^{13}C compared to a large number of humans, while the other two are comparable to the human values (Choy and Richards, 2009). At Mesolithic sites in Denmark there is variability in $\delta^{13}\text{C}$ between dogs and humans (Fischer et al., 2007). For instance, at the Bodal site $\delta^{13}\text{C}$ values from eight dogs and two humans indicate that some of the dogs are higher and others are lower compared to the two divergent human values. At Holmgard four humans and a single dog are comparable with the dog about 1‰ enriched. At Ulkestrup Lyng a single dog is diminished by $\sim 2\text{‰}$ relative to the one human, and at Argus a single dog contains comparable $\delta^{13}\text{C}$ values relative to the seven humans (Fischer et al., 2007: 2128–2134). At 33Ha419 in the Ohio River Valley, a single dog contains a $\delta^{13}\text{C}$ isotope value nearly identical to five of the six human values reported for the site and five humans and 24 dogs from ethnoarchaeological contexts in Nicaragua were variable (Tankersley and Koster, 2009:366, 368). Collectively, these sites suggest no overarching pattern in dog and human $\delta^{13}\text{C}$ isotope values with some $\delta^{13}\text{C}$ values enriched, comparable, or depleted.

Our isotope data demonstrate that island foxes at CA-SRI-2 were consuming very different foods than both dogs and humans, namely an abundance of terrestrial foods, with smaller contributions of marine foods. These data suggest that the island foxes at CA-SRI-2 likely had diets focused on insects, deer mice, and other foods similar to contemporary populations (Collins, 1991a, 1991b). Although a distinct species related to mainland gray foxes (*Urocyon cinereoargenteus*), island foxes and Chumash and Gabriellino peoples on the Channel Islands were closely intertwined. Island foxes were revered by the Chumash, used in rituals, often found in

cemeteries, and may have been pets or semi-domesticates (Collins, 1991b; Rick et al., 2009), although at CA-SRI-2 they were generally not consuming the same foods as people or domestic dogs. They may have also been important for helping with pest management by keeping down mice populations.

Most scholars agree that the Chumash deliberately introduced the island fox to the southern Channel Islands (Collins, 1991a, 1991b; Vellanoweth, 1998). Although significant questions remain, there is support that ancient peoples may also have introduced foxes to the northern Channel Islands sometime prior to about 7000 years ago (see Rick et al., 2009). The data presented here, however, suggest that at least during the last 1000 years or so at CA-SRI-2 foxes were not being fed marine foods by the Chumash and were not scavenging around Chumash sites. Island foxes are known to eat marine foods, especially carrion, and the absence of a marine signature in these bones is somewhat surprising given the coastal context in which they were recovered. Studies of other canids (i.e., coyotes) living near the coast of Baja California document a heavy reliance on coastal foods and higher population densities compared to nearby inland animals (Rose and Polis, 1998). It is possible that the CA-SRI-2 foxes were hunted or scavenged by the Chumash in the island's interior, or that island foxes had limited access to marine foods during the Holocene because of competition with people and/or dogs. Few isotope studies of archaeological island fox bones have been conducted or are available for comparison. Preliminary $\delta^{13}\text{C}$ data from two foxes directly dated to the last 1000 years from San Miguel Island are similar to the data from CA-SRI-2 (-18.4‰ and -19.5‰ ; Rick et al., 2009). More recent values obtained for these specimens are comparable to the preliminary values and support a terrestrial diet ($\delta^{13}\text{C} \approx -18\text{‰}$, $\delta^{15}\text{N} \approx 15\text{‰}$ and $\delta^{13}\text{C} \approx -18\text{‰}$, $\delta^{15}\text{N} \approx 9\text{‰}$; Thomas Stafford, personal communication, 2010). Newsome et al. (2010:Fig. 3) also report isotope data from an island fox bone recovered from an historic bald eagle nest on San Miguel Island, which is in line with the CA-SRI-2 and San Miguel Island data ($\delta^{13}\text{C} \approx -18\text{‰}$, $\delta^{15}\text{N} \approx 9\text{‰}$). Preliminary AMS measured data from a roughly 6300 year old specimen from San Miguel Island had a high marine $\delta^{13}\text{C}$ signature (-11.6‰ ; Rick et al., 2009), but another value recently obtained from the same bone suggests a terrestrial diet comparable to the CA-SRI-2 foxes ($\delta^{13}\text{C} = -17.0\text{‰}$ and $\delta^{15}\text{N} = 6.7\text{‰}$; Thomas Stafford, personal communication, 2010). These data document some continuity in ancient and modern island fox diets, but given the dearth of archaeological fox isotope data, most of which are from the last 1000 years, it is difficult to determine what these patterns mean for broader fox, human, and dog interactions on the Channel Islands.

6. Conclusions

Our analyses of dog, fox, and human isotopes add to a growing body of literature that illustrates the utility of isotope analyses for enhancing our understanding of ancient human environmental dynamics (e.g., Cannon et al., 1999; Choy and Richards, 2009; Fischer et al., 2007; Schulting and Richards, 2002, 2009; White et al., 2001, 2004). In the case of Santa Rosa Island, dogs and humans were clearly living in close proximity to one another and subsisting largely on the same foods, with the possibility that dogs were eating scraps, perhaps consuming significant amounts of bone collagen, and people were likely consuming more terrestrial plant foods. The three island foxes in our study were clearly separate from the dogs and humans, subsisting largely on terrestrial foods with little to no contribution of marine foods.

The empirical data from Santa Rosa Island suggest that archaeological dog remains can serve as a useful proxy for associated human diet in terms of $\delta^{15}\text{N}$, which for marine settings implies

trophic level and therefore degree of dependence upon marine dietary resources. A caveat is that $\delta^{13}\text{C}$ values may be higher than for their human counterparts, and might overestimate the marine contribution to diet if used on its own. The similarity between human and dog isotopes at CA-SRI-2 lends support to Cannon et al.'s (1999) work at Namu that suggests stable isotope analysis of dogs may be used as proxy for human diets. While this is not as ideal as conducting isotope analysis directly on human remains, it is important in areas of North America and elsewhere where destruction of human bones is sometimes objectionable or not allowed. The similarities between dog and human diets were further confirmed by isotope analyses of dog and human remains from the Danish Mesolithic (Fischer et al., 2007) that show a focus on similar resources at both coastal and inland sites. Similarities between human and dog isotopes were also noted in a site from the Ohio Valley (Tankersley and Koster, 2009) and White et al. (2001, 2004) speculated that dog diets in Maya sites mirror changes in human diets. We caution that on the Channel Islands, where prehistoric resources were limited largely to marine protein and where plant and animal domesticates (aside from dogs) were absent, dietary patterns may be more simple than in continental areas where terrestrial and marine resources are both exploited and may reflect greater dietary variability. Further analysis of mainland dogs and human isotopes should be performed to determine if such variability exists and how it may influence similarities and differences between dog and human diets.

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