

Resource depression, climate change, and mountain sheep in the eastern Great Basin of western North America

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Abstract Strontium, oxygen, and carbon stable isotope analysis may be used in conjunction with archaeofaunal data to identify resource depression by demonstrating that prey were obtained from more distant locations. We use fauna from Five Finger Ridge, a Fremont site in central Utah, to demonstrate that relative abundances of mountain sheep (*Ovis canadensis*) declined during a period of increased summer precipitation. Strontium ratio values from this period indicate that sheep were acquired from different locations than the preceding period. Specimens from this period also show a moderate increase in carbon ratio values, suggesting that mountain sheep were acquired from higher altitudes. Oxygen isotopes do not vary between temporal periods, possibly the result of the countering effects of higher oxygen isotope values associated with increased summer temperatures and lower oxygen isotope values present at higher elevations. Collectively, these data support that there were localized population declines of mountain sheep that may be related to either climatic changes or hunting pressure.

Keywords Mountain sheep (*Ovis canadensis*) · Great Basin · Stable isotopes · Resource depression · Climate change

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Introduction

Over the past century, mountain sheep (*Ovis canadensis*) populations have declined throughout North America due to direct and indirect human impacts. The degree that mountain sheep represent Pleistocene relics isolated to high elevations of western North America (Bailey 1980, 1984; Geist 1985; Wehausen 1984) and the influence of increasing temperatures and aridity associated with anthropogenic global warming are critical considerations for the conservation of the species (Epps et al. 2004, 2006). Research by Epps et al. (2006) suggests that climate warming has played a significant role in the twentieth-century extirpations of mountain sheep in southeastern California. Specifically, populations inhabiting low elevation mountain ranges were more likely to become extinct, possibly the result of higher temperatures and shorter growing seasons characteristic of lower mountain ranges. Others contend that mountain sheep have been negatively impacted more directly by people through historic livestock grazing, mining, unrestricted hunting, fence and road construction, and recreational activities (Hansen 1982; Jansen et al. 2009; McCutchen 1981; Papouchis et al. 2001).

The debate regarding human impacts and the influence of climate change on mountain sheep populations can be extended to the prehistoric record. Did prehistoric foragers overhunt mountain sheep? Did Holocene climate change impact the availability of such large game to prehistoric hunters? Both questions require the archaeologist to somehow identify prehistoric local resource abundances and environmental conditions while controlling for a wide range of cultural variables that lead to the deposition of faunal remains. One of the challenges is linking various independent data sets, such as archaeofaunal and paleobotanical records, that are the product of very different histories.

A number of archaeological studies in western North America have investigated temporal changes in local animal

population abundances that occur as a result of interrelated factors such as climate change and human predation (e.g., Broughton 1994a, b; Butler 2000; Byers and Broughton 2004; Cannon 2001; Grayson 1991; Grayson and Cannon 1999; Lyman 2003; Ugan 2005). These studies frequently evaluate such changes using optimal foraging theory (see Bird and O’Connell 2006; Lupo 2007 for review). Following the fine-grained prey choice model (Stephens and Krebs 1986), higher ranked prey should always be acquired on-encounter, while the inclusion of lower ranked resources into the diet will depend on the encounter rates with those that are higher ranked. When encounter rates with higher ranked prey diminish as a result of overhunting, changing geographic ranges, or behavioral changes, lower ranked prey are incrementally added to the diet thereby increasing the forager’s diet breadth and decreasing the taxonomic dominance of higher ranked over lower ranked resources.

Such changes in animal population dynamics are visible in the archaeological record by computing relative taxonomic abundances for a given place and time and may be bolstered with independent lines of evidence. Paleoenvironmental data, such as pollen cores and packrat middens, can demonstrate that changing abundances of prey correspond with local environments and not shifts in cultural practices (e.g., Byers and Broughton 2004; Grayson and Cannon 1999; Ugan 2005). Alternatively, since a reduction in local resource abundances may result in foragers traveling to more distant sources locales, transportation inferences based on skeletal part representation are also used for support (e.g., Broughton 1994a; Nagaoka 2005); parts with low economic value are more likely to be discarded at a kill site as travel costs increase (Binford 1978; Madrigal and Capaldo 1999; Metcalfe and Jones 1988; Morin 2007). A number of factors, such as the number of people available, the kind of animal, various cultural practices for treating raw meat, and the underlying motivations for hunting, are difficult to infer from the archaeological record (Bartram 1993; Lupo 2006; O’Connell et al. 1990). Indeed, Grimstead (2012) found contradictions between skeletal part representation and trace element sourcing data at CA-COL-267 in northern California, suggesting that multiple conditions may explain the transportation of low utility skeletal parts.

Introducing stable isotopes of faunal remains into the equation helps build bridges between multiple datasets by providing fine-grained details regarding an animal’s life history. In a similar fashion to Grimstead (2012; Grimstead and Reynolds 2008), stable isotopes may be used to determine whether hunters were traveling further abroad to acquire large game while providing crucial paleoenvironmental data. Since dental tissues form sequentially and undergo little remodeling once fully developed (Hillson 2005), intra-tooth sampling of teeth permits an individual’s movements to be tracked across the landscape during the time of tooth enamel mineralization, thus allowing for the identification of seasonal and migratory patterns (e.g.,

Balasse 2003; Balasse et al. 2002; Bentley et al. 2004; Britton et al. 2009; Hoppe et al. 1999; Zazzo et al. 2006, 2005).

The expectation is that declining local abundances of prey should result the greater exploitation of distant populations with distinct migratory histories. In the case of mountain sheep, stable isotope values for oxygen, carbon, and strontium should accurately reflect an animal’s movement between summer and winter ranges over the first few years of life. We use data from Five Finger Ridge, a site located in the eastern Great Basin of central Utah, as a test case for this method. Here, local paleoenvironmental pollen records demonstrate that relatively rapid changes at the end of the Medieval Warm Period (ca. AD 1100 to 1350) in the distribution of plant taxa that represent shifts between summer- and winter-dominated precipitation. If mountain sheep are sensitive to increased temperatures, as suggested by Epps et al. (2004, 2006), periods of increased summer monsoonal precipitation should correspond with an increase in the number of distant populations.

Stable isotopes background

Oxygen isotopes

The relationship between climate and stable light isotopes, particularly oxygen and carbon, has been applied extensively to archaeological research (e.g., Balasse et al. 2002; Blaise and Balasse 2011; Coltrain and Leavitt 2002; Emery and Thornton 2008; Fenner 2009; Fricke and O’Neil 1996; Knudson 2009; Sponheimer and Lee-Thorp 1999). At constant temperature, the ratio of $^{18}\text{O}/^{16}\text{O}$ in organically derived apatites such as bone and enamel forms in equilibrium with that of body water (Longinelli 1984; Luz et al. 1984; Luz and Kolodny 1985). Rather than reporting ratios of $^{18}\text{O}/^{16}\text{O}$, however, isotope values are given relative to an international standard ($\delta^{18}\text{O}$) to improve precision (Coplen 1995; Craig 1961). For body water, $\delta^{18}\text{O}$ is systematically related to the isotope values of ingested water sources which are differentiated by processes of evaporation and precipitation. Evaporation of ocean water preferentially removes the lighter isotope, ^{16}O , resulting in isotopically lighter water vapor. Upon moving inland or to high altitudes, the moist air mass cools and condenses such that the heavier ^{18}O preferentially precipitates out. Continuing “rainout” leaves the air mass increasingly depleted in ^{18}O resulting in increasingly low $\delta^{18}\text{O}$ in precipitation (Dansgaard 1964). In general, $\delta^{18}\text{O}$ for a given air mass and its precipitates decreases with lowered temperature, high latitude, and high altitude. Conversely, $\delta^{18}\text{O}$ increases with raised temperatures, low latitude, and low altitude (Bowen and Wilkinson 2002; Gat 1996; Kendall and Coplen 2001).

The countervailing trends of temperature and altitude complicate interpretations of seasonal variation in mountain

sheep enamel because mountain sheep migrate to higher altitudes during the warmer summer months. Nevertheless, some estimates can be derived from a comparison of modern lapse rates for $\delta^{18}\text{O}$ in Unites States precipitation (-2.9‰ km^{-1}) and river water (-4.2‰ km^{-1}) with the oxygen isotope temperature scale ($0.22\text{‰ }^{\circ}\text{C}^{-1}$) (Dutton et al. 2005; Epstein et al. 1953). Assuming seasonal variation in mean temperature broadly comparable with modern values ($\sim 15\text{ }^{\circ}\text{C}$; National Climate Data Center: Kimberly, UT and Fremont Indian State Park, UT stations), an increase in altitude of 1–2 km during the summer months would yield little net change in $\delta^{18}\text{O}$. For higher seasonal migrations, the change in altitude would drive a net decrease in $\delta^{18}\text{O}$. Serial sampling of mountain sheep tooth enamel reflects annual migration between high elevation summer ranges to low elevation winter ranges. Given that mountain sheep summer ranges can be as much as 6.5 km higher than their winter ranges (Epps, personal communication), lower values in the serial $\delta^{18}\text{O}$ data presented here likely represent winter water sources. Additionally, carbon isotope values ($\delta^{13}\text{C}$) can be used in conjunction with oxygen isotopes to further distinguish summer and winter ranges.

Carbon isotopes

Different pathways of photosynthesis explain much of the $\delta^{13}\text{C}$ variation in the biosphere. The use of different enzymes results in differential discrimination against the heavier ^{13}C molecule so that plant tissues have relatively low $\delta^{13}\text{C}$ compared to atmospheric values. Plants that use the Calvin cycle (C3 plants) typically consist of cool season grasses, trees, and herbs and have a mean $\delta^{13}\text{C}$ of approximately -28‰ . The Hatch-Slack cycle (C4) yields a mean $\delta^{13}\text{C}$ of approximately -14‰ and is used by warm season grasses, sedges, and some dicotyledons. Crassulacean acid metabolism is employed by some arid-adapted succulents and epiphytes and results in intermediate $\delta^{13}\text{C}$ values (O’Leary 1988). $\delta^{13}\text{C}$ of biological apatites reflects the relative contribution from each type of plant with an additional fractionation factor that varies based on digestive physiology. Herbivorous ungulates such as mountain sheep demonstrate a range of approximately -13‰ (pure C3 diet) to 1‰ (pure C4 diet) (Ambrose and Norr 1993; Cerling and Harris 1999; Lee-Thorp et al. 1989; Passey et al. 2005; Tieszen and Fagre 1993). In archaeological contexts, however, ranges are offset by approximately 1.5‰ because the modern combustion of fossil fuels has lowered atmospheric $\delta^{13}\text{C}$ (Friedli et al. 1986).

Grassland communities vary according to climate, resulting in changes in isotopic values in grazing herbivores. Minimum summer daily temperature is the strongest predictor for the presence of C4 plants (Teeri and Stowe 1976). In western North America, the abundance of C4 plants corresponds with

mean annual temperature, mean annual precipitation, and the summer seasonality of precipitation (Paruelo and Lauenroth 1996). C4-dominated grasslands ($>50\%$ C4) are common on the Great Plains and Sonoran Desert, and can extend beyond into present-day central Arizona and north towards the Arizona–Utah border (Paruelo and Lauenroth 1996). Coltrain and Leavitt (2002) report $\delta^{13}\text{C}$ values for two *Ovis* individuals recovered from Injun Creek, located on the eastern side of the Great Salt Lake, and found that none of these consumed C4 plants. In contrast, the more southerly location of Five Finger Ridge is situated closer to the modern-day extent of C4 grasslands (Paruelo and Lauenroth 1996), and increased summer precipitation may have resulted in the expansion of C4 grasslands northwards towards central Utah. This should be reflected by more positive $\delta^{13}\text{C}$ values in mountain sheep during periods dominated by summer monsoonal precipitation.

Further, $\delta^{13}\text{C}$ values of C3 plants are influenced by altitude and mean annual precipitation. Increases in altitude and relative water stress correspond with increased $\delta^{13}\text{C}$ (Diefendorf et al. 2010; Kohn 2010). For example, carbon isotope values for plants sampled from 2,500 to 5,600-m elevations have mean $\delta^{13}\text{C}$ values of -26.15‰ compared to a lowland average of -28.80‰ (Körner et al. 1988). Consequently, the relatively arid, high elevation summer ranges of mountain sheep should manifest as high $\delta^{13}\text{C}$ in serial tooth enamel samples. In addition, significant long-term changes in summer precipitation and temperature may result in more positive values reflecting an increased dominance of C4 grasslands.

Strontium isotopes

Strontium isotope analysis is commonly used to establish prehistoric human migration, identifying the origins of plant and animal remains, and other applications (see Benson et al. 2006; Bentley 2006; Hoppe 2004 for other examples). The isotopes of strontium used in archaeological provenience studies (^{87}Sr and ^{86}Sr) are relatively heavy and have negligible relative mass differences. Consequently, they do not fractionate as they move through the environment (but see Knudson et al. 2010 for a discussion of $\delta^{88/86}\text{Sr}$). For that reason, animals, plants, water, and sediment from a given region will tend to have similar $^{87}\text{Sr}/^{86}\text{Sr}$. Strontium isotope ratios in animals are determined by the biologically available (soluble) $^{87}\text{Sr}/^{86}\text{Sr}$ in food and water, which in turn is determined by the age and type of rocks or sediment in the local geology. Though variability in plants, sediments, and waters of a given region can be relatively large, the values are averaged at each trophic level such that animals will typically exhibit a relatively narrow range biased towards food and water sources with higher strontium concentrations (Hodell et al. 2004; Price et al. 2002). As long as the geologic region provides heterogeneous isotopic compositions, strontium isotope signatures

may be used to identify different populations of animals on the landscape. Mountain sheep migration routes are relatively stable and conservative, with only changes in the timing of migrations that depend on local climate and resources (Geist 1999; Shackleton 1985). The annual migration of mountain sheep is expected to cross-cut multiple geological formations given that there is sufficient geologic heterogeneity in the region (Fisher 2010). Strontium ratio values may also be used to track different populations of animals, as each population migration route would encompass varying geological formations. Regional biologically available $^{87}\text{Sr}/^{86}\text{Sr}$ are presently unavailable for proveniencing mountain sheep, but changes in mountain sheep residence or Fremont hunting grounds will still manifest as differences in $^{87}\text{Sr}/^{86}\text{Sr}$.

The Five Finger Ridge assemblage

Faunal remains from Five Finger Ridge, located in the Clear Creek Canyon, Utah (Fig. 1), were analyzed to identify diachronic shifts in taxonomic abundance that may be reflective of changing climate or foraging decisions. Five Finger Ridge sits atop an alluvial knoll with ridges ranging from 1,814 to 1,829 m above sea level (Janetski 1998; Janetski et al. 2000; Talbot et al. 2000). Chronometric dates suggest the site was

occupied at the end of the Fremont Period, from ca. AD 1100 to 1350 (Talbot et al. 2000). Occupation of the site can be subdivided into four temporal periods: Period 1 (prior to AD 1200), Period 2A (AD 1200 to 1250), Period 2B (AD 1251 to 1300), and Period 3 (post-AD 1300).

The Fremont culture was present in the eastern Great Basin and adjacent Colorado Plateau regions between ca. AD 400 and 1300 (Madsen 1989; Madsen and Simms 1998; Talbot and Wilde 1989). The appearance of the Fremont coincides with a period of increased summer temperatures and summer moisture, and warm and wet winters (Grayson 2006; Rhode 2000; Wigand and Rhode 2002). These conditions supported the cultivation of crops including maize, and greater grass abundance supported local bison populations that moved into the Great Basin from adjacent regions (Grayson 2006). The Fremont, bison, and maize all disappear when monsoonal storm patterns weaken around AD 1300 (Grayson 2006; Janetski 1994; Madsen and Simms 1998).

Pollen sequences obtained from the Cave of 100 Hands, located ca. 1 km northeast of Five Finger Ridge, provide paleoenvironmental data that largely corroborate data from elsewhere in the region (Newman 2000; Fig. 2). This record indicates a decrease in grasses and pine relative to *Artemisia* shortly before AD 1100, representing increased winter precipitation, and a subsequent increase in grass and pine

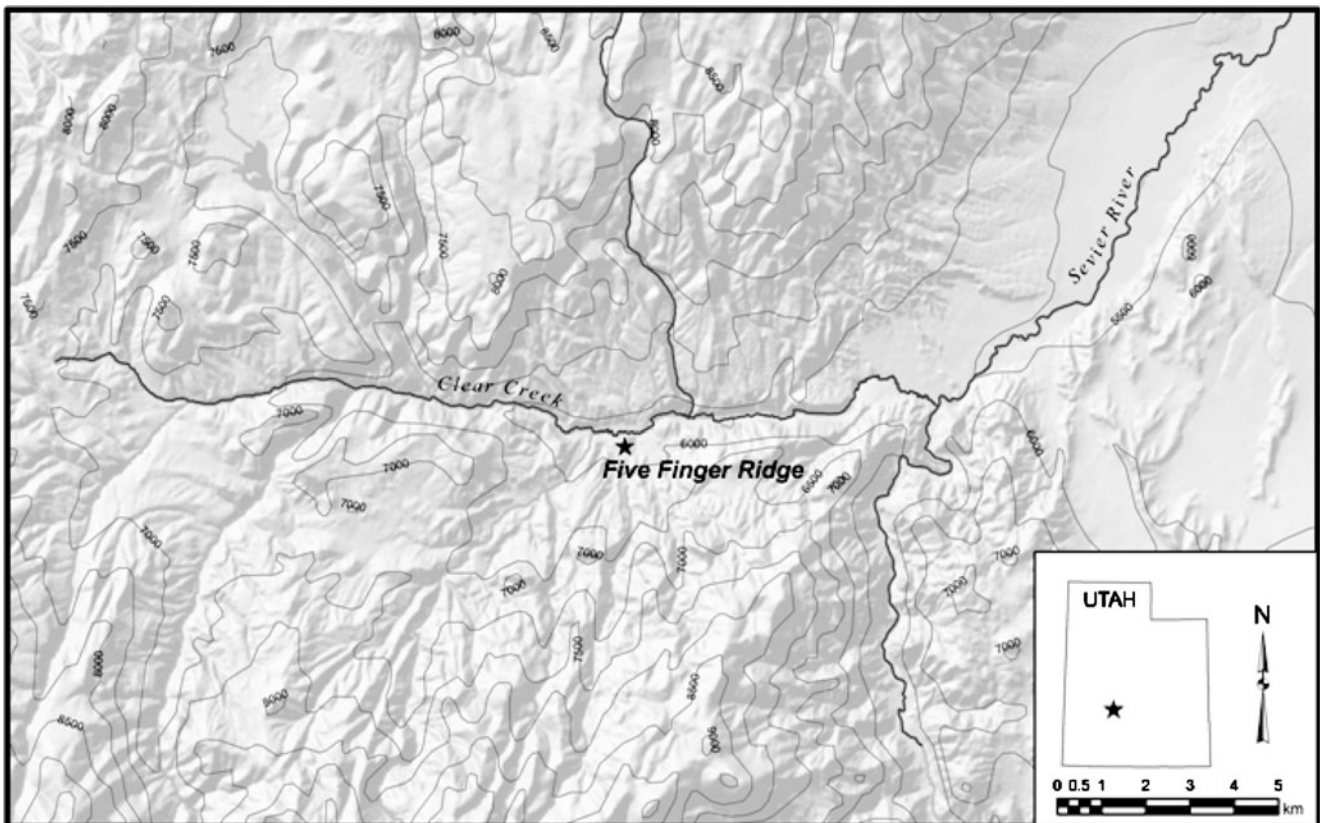


Fig. 1 Location of Five Finger Ridge, Clear Creek Canyon, Utah

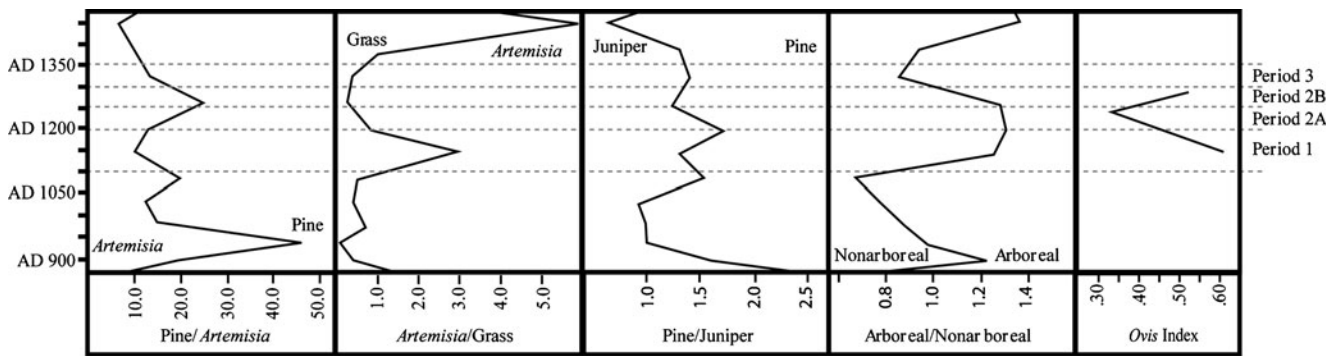


Fig. 2 Paleoenvironment data from Cave of 100 Hands and relative frequency of mountain sheep to deer (*Ovis* Index)

pollen, peaking by the end of Period 2A ca. AD 1250. This pattern signifies a shift towards greater summer precipitation. The ratio of sagebrush to grass pollen increases slightly ca. AD 1250 during Periods 2B and 3, while the ratio of pine to sagebrush decreases more radically during this time. This suggests cooler spring temperatures and increased winter precipitation, reflecting a shift from the Medieval Warm Period to the Little Ice Age.

Archaeobotanical remains recovered from Five Finger Ridge support the more regional findings from Cave of 100 Hands (Talbot et al. 2000). The relative abundance of *Zea mays* macrofossils fluctuates in relation to other plant taxa; while relatively high in Period 1 (6.99 %, $N=186$), *Z. mays* is most dominant during Period 2A (25.89 %, $N=282$), and declines substantially in Period 2B (1.30 %, $N=6,473$). The high number of identified macrofossils in Period 2B is being driven by cheno-ams ($n=3,453$) and *Nicotiana* ($n=2,233$); when these are removed, Period 2A still has significantly more maize ($\chi^2=49.04$, $p<.001$). The peak in *Z. mays* during Period 2A supports that this was a period of increased summer precipitation that favored maize horticulture.

Methods

Relative taxonomic abundances

Changing relative abundances of the artiodactyl species present at Five Finger may be indicative of localized resource depression caused by hunting pressure or climate change. Faunal specimens were identified to taxon, element, portion, and side, along with various data on cultural and natural markers (Fisher 2010). To determine whether the relative abundances of mountain sheep changed diachronically at Five Finger Ridge, we compared the frequencies of sheep and deer (*Odocoileus* sp.) using the number of identified specimens (NISP). Chi-square analysis was used to determine whether there are any significant differences in the frequencies of the two species by temporal period. To simplify the data graphically, the *Ovis* Index is used by

dividing the total number of *Ovis* specimens by the sum total of *Ovis* and *Odocoileus* specimens.

Relative skeletal abundances

Relative skeletal abundance is used to identify long distance transportation of large-bodied animals by people, with the general assumption that low-quality portions of prey are less likely to be transported to the residential base (Bartram 1993; Binford 1978; Faith and Gordon 2007; Lupo 2001; Metcalfe and Jones 1988; O'Connell et al. 1990). The effects of differential survivorship of skeletal elements (Fisher 2010) were circumvented by using anatomical body portions instead of individual skeletal element portions since each anatomical portion is equally represented by high density skeletal portions (Stiner 2002). The categories follow Stiner (2002) with some exceptions (antler and horn are included with the head; a category for teeth formed). Neonatal and culturally modified bone (e.g., bone tools) specimens were removed from analysis. Anatomical region counts are based on the NISP values of each composite skeletal part, normed by the number of instances that part is found in the skeleton (Grayson and Frey 2004).

Shannon evenness values were calculated for the relative skeletal abundances of each taxon to provide a quantitative measure of relative skeletal abundance (Faith and Gordon 2007; Magurran 1988). The expectation is that taxa that were transported more completely to Five Finger Ridge should be represented by a more even distribution of anatomical parts. Chi-square tests were used to determine differences in the frequency of anatomical parts between temporal periods.

Stable isotopes

The specimens selected for isotopic analysis are presented in Table 1 along with spatial context, temporal period, and age data for each individual. Mandibular specimens were selected based on the presence of well-preserved dentition, their association with dated contexts, and the minimum number of individuals based on age, side, and provenience. Seven

Table 1 *Ovis* specimens sampled for stable isotopes with provenience and temporal data

Specimen	Provenience	Period	Tooth	Individual age (years)
8208-001	Pithouse 29	1	M ₂₋₃	3.5
8220-001	Pithouse 28	1	M ₂	5+
8225-001	Pithouse 28	1	M ₂₋₃	4
8304-001	Pithouse 5	2A	M ₂	1
10249-023	Activity Area 24	2A	M ₂₋₃	5+
8099-001	Pithouse 3	2B	M ₂₋₃	4
8102-001	Pithouse 3	2B	M ₂₋₃	4

mandibles met these criteria; all seven were sampled. The lower second and third molar were used to capture the latest migration sequence recorded in the enamel for each individual. Mountain sheep have hypsodont teeth that develop over relatively long durations of time. Although the timing of development is presently unknown, it is expected that tooth formation follows approximately the same timeline as *Ovis aries* (domestic sheep) based on similar eruption times. The development of the second and third molar takes approximately 1 and 2 years, respectively, in *O. aries* (Balasse et al. 2005; Weinreb and Sharav 1964).

Teeth were removed from the mandibular body using a Dremel power tool fixed with a diamond cutting blade to cut a window through the buccal side of the lateral ramus around the second and third molar. The buccal portion of the anterior loph of M₂ and the posterior loph of M₃ were sampled since these tend to have the largest surfaces that would provide the greatest sample. These surfaces were mechanically abraded using a tungsten carbide burr to remove any adhering cementum and other potential contaminants. Each tooth was encapsulated using tape and plastic wrap with an open window around the sampling surface to prevent potential contamination from loose sediment and organic material that could not be removed through abrasion.

We followed the serial sampling methodology provided by Balasse and others (Balasse 2003; Balasse et al. 2002, 2006, 2005; Britton et al. 2009; Zazzo et al. 2006, 2005). Although this method does not sample discrete growth increments, it does provide a chronological sequence of development (Balasse 2003). Each sample was removed as powder using a dental drill under magnification in bands approximately 1.0–1.5-mm thick and placed at approximately 4-mm intervals (see [Electronic supplementary material](#)).

Sample processing for strontium was conducted at clean lab facilities in the Department of Geological Sciences, University of Florida, following the same protocols listed in Valentine et al. (2008). Strontium isotopic ratios were measured using a Nu-Plasma multiple-collector inductively-coupled-plasma mass spectrometer. The long-term reproducibility of the TRA-measured ⁸⁷Sr/⁸⁶Sr of NBS 987 is 0.71024±0.00005.

Samples for carbon and oxygen were pretreated according to Koch et al. (1997) and analyzed using a VG micro-mass PRISM mass spectrometer with an Isocarb common acid bath preparation device. Analytical precision is better than ±0.1‰ for δ¹³C and 0.1‰ for δ¹⁸O.

Results

Mountain sheep abundances through time

Mountain sheep are relatively common in the Five Finger Ridge assemblage (*Ovis* NISP=917, total NISP=16,793), outnumbered by only cottontail rabbits (*Sylvilagus* spp. NISP=8,732) and jackrabbits (*Lepus* sp. NISP=1,729). Of the total *Ovis* NISP, 190 specimens could be placed in a temporal period based on their association with dated site contexts. Deer are also well represented in the assemblage (*Odocoileus* NISP=838), with 180 specimens from dated contexts.

As seen in Table 2, there are significant differences in the relative abundances of *Odocoileus* and *Ovis* between temporal periods ($\chi^2=16.69$, $p<.001$; Period 3 removed due to small sample size). Mountain sheep are more frequent than deer in Periods 1 and 2B, with a conspicuous decline in the species during the intermediate Period 2A. Figure 2 displays pollen profiles from Cave of 100 Hands alongside the *Ovis* Index to illustrate the relationship between local paleoenvironment changes and the relative abundance of mountain sheep.

Relative skeletal abundances

Evenness values for *Ovis* relative skeletal abundances decrease from Period 1 ($e=0.736$) and Period 2A ($e=0.741$) to Period 2B ($e=0.672$), but this change is not statistically

Table 2 Frequency (NISP) of *Ovis*, *Odocoileus*, and total medium-bodied artiodactyls with *Ovis* Index values across temporal periods with chi-square adjusted residuals

	<i>Ovis</i>	<i>Odocoileus</i>	Total artiodactyl	Total NISP	<i>Ovis</i> Index
Period 1	86	55	340	1,486	.61
Adj. res.**	+2.91	-2.91			
Period 2A	26	54	231	872	.33
Adj. res.*	-3.81	+3.81			
Period 2B	78	71	341	1,271	.52
Adj. res.	+0.32	-0.32			
Period 3	0	5	16	120	–
Adj. res.	–	–			

* $p<.001$; ** $p<.01$

significant (Period 1–2B, $t=1.29$, $df=67$, $p=0.20$). A chi-square test found significant differences in the relative abundance of anatomical units among temporal periods ($\chi^2=42.5$, $p<.001$; Table 3). Based on the adjusted residuals, Period 2A has a higher abundance of head and feet portions compared to the adjacent temporal periods. These anatomical parts have somewhat low utility values based on standardized FUI values (Metcalf and Jones 1988), with the exception of the mandible. Conversely, the frequency of upper limb (moderate FUI values) and lower front limb (low FUI values) portions drops in Period 2A. There is also a trend of decreasing numbers of axial and upper hind limb parts from Period 1 through Period 2B; the axial skeleton contains some moderately high FUI values, such as the innominate (FUI=49.3), and the upper hind limb has the highest utility. Conversely, there is a clear trend of increasing lower hind limb portions, which contains both moderately low utility (tarsals, metatarsals) and high utility (tibia) elements. In sum, there is no transparent trend in the representation of high versus low utility parts between the temporal periods.

Stable isotopes

Oxygen

Oxygen isotope ratio values ranged from -10.4 to 1.2 (Fig. 3). The range within each individual mountain sheep sampled was from 1.1 to 9.8% , with the lower value resulting from a smaller sample size ($n=3$) from specimen 8304–001a. There are no significant differences in mean $\delta^{18}\text{O}$

Table 3 Frequency (NISP) and chi-square adjusted residuals for *Ovis* anatomical units among temporal periods

	Period 1	Period 2A	Period 2B
Head	10	7	8
Adj. res.	-0.5	+2.4***	-1.1
Teeth	4	1	2
Adj. res.	+0.7	+0.1	-0.7
Axial	11	1	2
Adj. res.	+2.6**	-0.7	-2.2***
Upper front limb	3	0	6
Adj. res.	-0.7	-1.2	+1.6
Lower front limb	30	6	23
Adj. res.	+1.1	-0.8	-0.5
Upper hind limb	1	0	0
Adj. res.	+1.1	-0.4	-0.8
Lower hind limb	11	3	33
Adj. res.	-3.50*	-1.60	+4.60*
Feet	12	6	2
Adj. res.	+1.40	+2.40***	-3.1**

* $p<.001$; ** $p<.01$; *** $p<.05$

values among temporal periods (one-way ANOVA $F(2, 63)=1.737$, $p=.184$).

Annual variation in $\delta^{18}\text{O}$ values is present among individuals that had sufficient number of samples taken from both M_2 and M_3 , with one annual cycle observed in M_2 and two annual cycles observed in M_3 (Fig. 4). In such individuals, interannual variation may be noted. For example, the third molar of specimen 8102–001 (Period 2B) has two peaks at 0.1 and -0.1% , while the second molar peaks at -1.4 . Similar interannual differences are present in specimens 8208–001 (Period 1) and 8099–001 (Period 2B). Such interannual variation may be the result of changing altitudinal ranges or climate.

Carbon

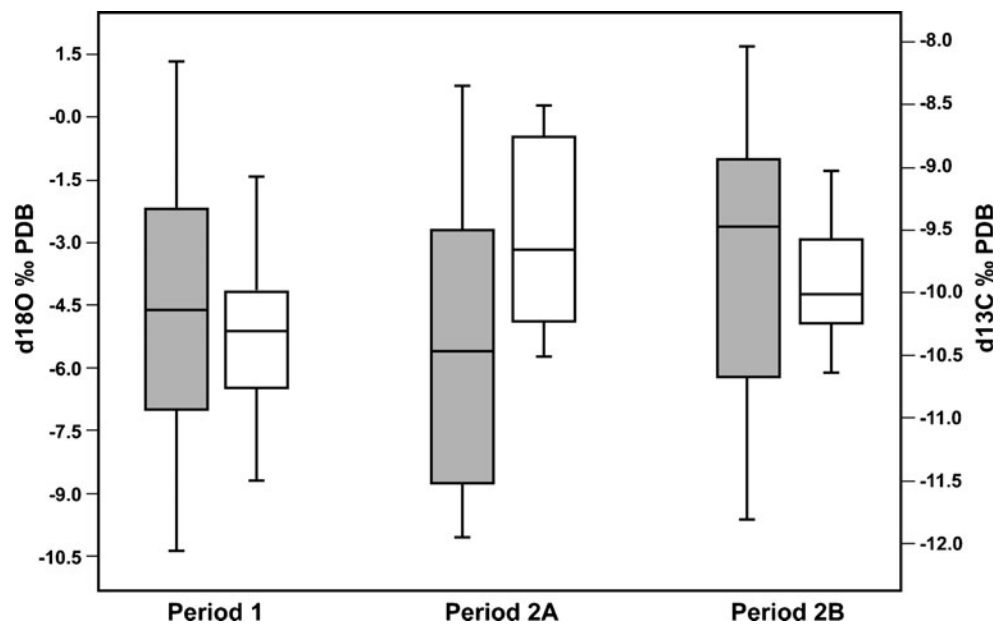
Carbon isotope ratio values range from -8.5 to -11.5% in the mountain sheep samples (Fig. 3). The range within each individual mountain sheep was from $.02$ to 1.7% , with the lower value due to the small sample size ($n=3$) from specimen 8304–001a. Mean $\delta^{13}\text{C}$ values differ significantly among temporal periods (one-way ANOVA $F(2, 63)=8.332$, $p=.001$); post hoc tests using Tukey's Honestly Significant Difference (HSD) indicate that the mean values for Periods 1 and 2A differ significantly ($p<.001$); the mean values are not significantly different between Period 1 and 2B ($p=.08$) or Period 2A and 2B ($p=.08$).

As with the oxygen isotope ratio values, annual cycles in $\delta^{13}\text{C}$ values are present (Fig. 4). The specimens dating to Period 2A exhibited the most positive $\delta^{13}\text{C}$ values, about 0.6% greater than the highest values seen in Periods 1 and 2B. While Period 1 and 2B $\delta^{13}\text{C}$ values ranged from -9.0 to -11.5 , the values for Period 2A ranged from -8.5 to -10.5 .

Strontium

Strontium isotope ratio values range from 0.7080 to 0.7110 , with a range within individuals from 0.00003 to 0.00166 . Four of the specimens appear to cluster at a range of $.7100$ and $.7110$, and there is generally an overlap between each of these individuals. In contrast, the three remaining specimens (8304, 10249, and 8099) fall significantly below this range of strontium values. Two of the three specimens are from Period 2A, and these specimens do not differ greatly from one another. The two specimens from Period 2B have ranges that are distinct from one another with no overlap of values. The second individual, represented by Specimen 8102, has a mean strontium ratio value that is indistinguishable from Specimen 8208 from Period 1. Mean strontium ratio values differ significantly among temporal periods (one-way ANOVA $F(2, 63)=75.209$, $p<.001$); post hoc tests using Tukey's HSD indicate that the mean values for all three periods differ significantly from one another ($p<.001$ in all cases). As with

Fig. 3 Box and whisker plot for oxygen (*grey*) and carbon (*white*) isotope values by temporal period



the oxygen and carbon isotope ratio values, some variation within individual teeth represent annual cycles, although the patterns are not nearly as clean as those seen in the light isotopes (Fig. 4).

Discussion

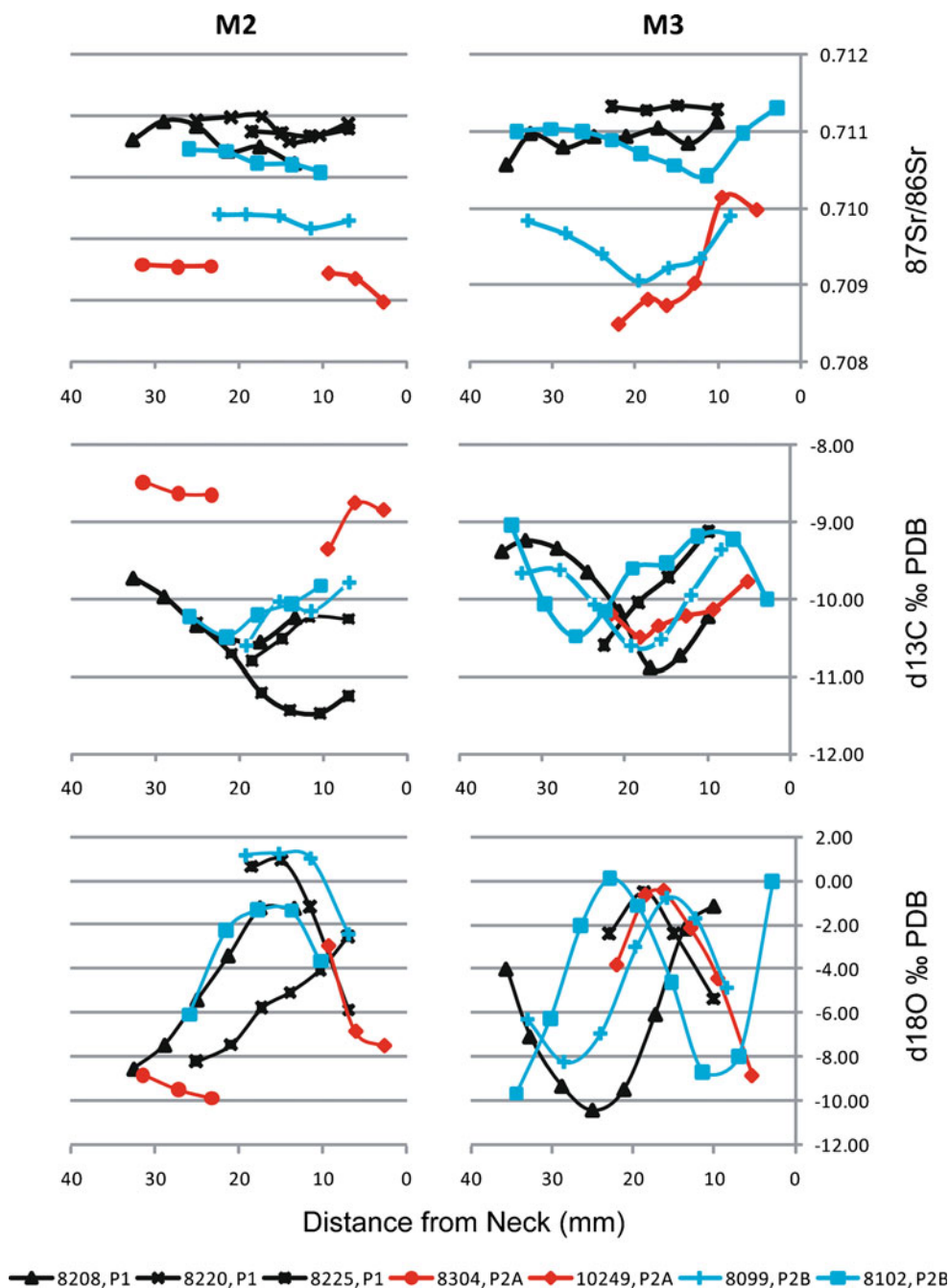
While the sample size for the isotopic studies is relatively small and lacks the comparative data that could be obtained by sampling local flora and fauna, the congruence of multiple datasets provides a comprehensive story that can be used for further hypothesis development and testing elsewhere.

The patterns seen in the relative taxonomic abundances and stable isotope values appear to reflect changing resource availability of mountain sheep to the residents at Five Finger Ridge. There is a significant decline in the relative frequency of mountain sheep to deer observed in Period 2A, and this decrease may represent a reduction in local sheep population densities resulting from resource depression, climate change, or a combination of the two factors. Alternatively, the lower frequency of mountain sheep seen in Period 2A may reflect an increase in local encounter rates for deer. Indeed, there is a moderate increase in the relative abundance of deer to all other taxa during Period 2A (Table 2), suggesting that local deer populations may have increased during this time period. If the observed changes in the *Ovis* Index are being driven by a decline in mountain sheep populations, and not by increases in deer populations, greater transportation costs are expected as hunters travel to extralocal patches to obtain mountain sheep. Typically, the use of more distant hunting grounds is inferred using relative skeletal part abundances with the expectation that there would be increased selectivity based on food utility to

reduce transportation loads. The relative skeletal abundance data from Five Finger Ridge show no clear pattern across temporal periods, potentially due to a number of confounding factors that influence the decisions regarding transportation of body parts. Here, we tested the use of strontium as an independent measure for transportation to bypass these problems, and the more depleted values present in Period 2A suggest that mountain sheep being acquired from new locations during this time. This incongruence between the strontium data and skeletal part data is not surprising considering Grimstead's (2012) similar results using trace element analysis in northern California.

The local paleovegetation and light isotope data help complete this story. Period 2A coincides with an increase in pine over sagebrush pollen that may indicate a spread of denser woodlands to higher elevations; mountain sheep will move into such woodlands, but only when the density of the vegetation does not limit their visibility (Krausman et al. 1999). Additional evidence that there was increased density of vegetation near Five Finger Ridge comes from the relative frequencies of three leporid species at the site; *Sylvilagus nuttallii* (mountain cottontail) became more abundant relative to *S. audubonii* (desert cottontail) and *Lepus* sp. (jackrabbits) from Period 1 through Period 2B (Fisher 2012), and this species tends to be limited to timbered areas of the Transition life zone in this area (Chapman 1975; Chapman and Willner 1978; Durrant 1952; Hall 1946, 1951, 1981; Harmon 1961; Hoffmeister 1986). However, while the leporid data show a gradual trend throughout the occupation of the site, mountain sheep decline only during Period 2A; this difference may relate to differing responses to climate change by each taxon, or are alternatively, local (leporid) versus more distant (mountain sheep) vegetation changes that are not reflected in the pollen profiles from Cave of 100 Hands.

Fig. 4 Strontium, carbon, and oxygen isotope values for individual mountain sheep specimens, arranged by temporal period. *Black* Period 1, *red* Period 2a, *blue* Period 2b



The Cave of 100 Hands pollen record also shows an increase in grass pollen from Period 2A through Period 3, and it is possible that C_4 grasses became more abundant during this time. However, more positive carbon values that could be reflective of sheep grazing on such grasses are limited to Period 2A. Instead, we believe that the modest increase in carbon values is the result of mountain sheep being obtained from higher elevations during Period 2A (Körner et al. 1988), which may also explain why no differences in oxygen values were observed among the temporal periods as higher summer temperatures and precipitation may have negated any change in oxygen values related to

higher elevations. Clearly, sampling of modern fauna and flora would help support these conclusions by establishing a baseline of changes related to geography and climate. Combined with the decreased abundance of sheep and the lower strontium values in Period 2A, the data collectively suggest that hunters were acquiring game from more distant, higher elevations away from Five Finger Ridge. Concomitantly, there is an increase in the relative abundance of deer during Period 2A that may be due to increased encounter rates due to favorable conditions for this species (Byers and Broughton 2004), a response to the declining encounter rates with sheep, or a combination of these two

factors. The travel costs of hunting sheep likely increased, resulting in fewer hunting expeditions, yet some hunters clearly continued to hunt sheep throughout the occupation of the site despite these increased costs, while other hunters may have increasingly targeted the more locally available deer populations. Why hunters may have continued to hunt sheep despite possible increases in deer populations is a matter of debate regarding energetics and the underlying motivations for hunting (Fisher 2010).

While the link between climate conditions and changes in sheep exploitation is supported by the data, exactly what happened to local, lower elevation sheep populations is less clear. Sheep may have actively shifted their ranges to higher altitudes in response to increases in temperature, precipitation, or vegetation change, but it is also possible that populations limited to lower elevations simply declined in a manner observed during the twentieth century by Epps et al. (2004). It should be emphasized, however, that the evidence here does not counter the possibility that mountain sheep populations were also being locally depressed by hunters, as a weakening of more local, lower elevation populations may have been exacerbated by overhunting from Five Finger Ridge and elsewhere.

Conclusions

This study provides the beginning of a larger dataset on isotopic values for mountain sheep populations in western North America. Despite the limited number of individuals sampled, this research successfully demonstrated that stable isotope analysis may be employed for identifying mountain sheep responses to climate change. The data presented here support the use of stable isotope analysis as an independent line of evidence to archaeofaunal data to show whether a change in relative abundance is ultimately related to local prey population levels. Future isotopic analysis of sediments or microfauna with limited home ranges would provide necessary data for identifying the sources of large game (Bentley 2006). This cannot be done with modern artiodactyl populations as historic migration and home ranges have been affected by modernization (e.g., fencing, domestic livestock), and the current climate is not comparable to the conditions present during Fremont times. Indeed, the isotopic data presented here provide insights on otherwise unknown prehistoric animal movements.

The use of archaeofaunal data was particularly insightful for mountain sheep populations that may be currently threatened by increasing temperatures and aridity resulting from anthropogenic global warming. Future research may be used to identify similar responses by mountain sheep in other regions and during climatic periods dissimilar to the Medieval Warm Period, such as the middle Holocene.

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