STABLE ISOTOPE ANALYSIS OF DEER REMAINS FROM ALAMEDA COUNTY SHOW THE EFFECTS OF THE MEDIEVAL CLIMATIC ANOMALY

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To date there have been no large-scale investigations of mule deer (Odocoileus hemionus) from a single site using stable isotopes, but CA-ALA-554 provides the perfect opportunity for such research. CA-ALA-554 is an ancestral Ohlone site in modern-day Pleasanton that yielded abundant deer remains across eighty-three burials. AMS radiocarbon dates indicate that people lived here and deposited the deer bones between 400 and 2000 calibrated years before present. Our goal is to document shifts in deer ecology, especially diet and migratory behaviors, across this swath of time using isotopic signals. Analysis of carbon and nitrogen isotopes reveal overall similarity in diet across the sampled population, with slight variation between individuals. Notably, an increase in variation for both $\delta^{13}C$ and $\delta^{15}N$ is observed between 800 and 1000 cal BP, indicating that deer were either diversifying their diet locally or coming to CA-ALA-554 from a greater variety of places during this time than they were either before or after. We argue that the increased variation reflects the ecological stress faced by both mule deer and people during the Medieval Climatic Anomaly (MCA) (650-1220 cal BP), which forced one or both to alter their respective foraging and hunting practices.

SITE INFORMATION

In 2011, William Self Associates, Inc. (WSA) was contracted to recover archaeological data prior to the construction of a shopping mall in Pleasanton, California. During this process, WSA discovered the prehistoric site CA-ALA-554. Archaeologists excavated 187 human burials and 25 features, and in the process recovered thousands of artifacts (e.g. worked bone, shell, and stone) and ecofacts (e.g. faunal and botanical remains) (Estes et al. 2012; Eerkens 2016). Various absolute and relative dating techniques (e.g. AMS radiocarbon, obsidian hydration, stratigraphy, etc.) show that ALA-554 was inhabited for approximately 1600 years, from about 2000 until 370 cal BP (Estes et al. 2012; Eerkens 2016; Greenwald et al. 2016). Within this broad swath of time, radiocarbon dates show that there were three main periods of human interments, the first between 1500 to 1250 cal BP (during the M2 and M3 Periods per Groza et al. 2011), the second between 965 and 720 cal BP (during the Middle-Late Transition), and the third between 630 and 370 cal BP (Late Phase 1; Eerkens 2012). Part of the occupation of the site thus coincides with the Medieval Climatic Anomaly (MCA) (650-1220 cal BP), which saw increased climatic variability and frequent droughts in this part of California (Jones et al., 1999; Stine 2000).

During excavation of the burials, sediment was screened and any associated artifacts or ecofacts were saved. As well, sediment samples were removed and screened through 1/16-inch screens. Eighty-three burials from the site contained the remains of mule deer (*Odocoileus hemionus*). Those deer remains are the subject of the current study. Direct AMS dates on the associated burials, as well as a subsample of deer, provide chronological control for the samples included in this study and show that they were deposited from 2000 until 370 cal BP.

Figure 1. Map of the San Francisco Bay Area (enclosed by the red dashed line), showing the site location.

APPROACH

In the context of dietary studies, carbon isotopes ($^{12}C/^{13}C$, expressed as $\delta^{13}C$) reveal whether a diet is rich in C_3 plants, C_4 plants, or marine foods (Farquhar et al. 1989). C_3 plants, which constitute the majority of plant species across the world, are abundant in California, while the number of C_4 plants within the state is low (Bartelink 2006, 2009). A few important agricultural crops (e.g. maize, sorghum, sugar cane) fall into the C_4 category, but these would not have been consumed by mule deer and are therefore irrelevant to this study. Some C_4 plants do occur in salt marshes, including cordgrass (Spartina sp.) and salt grass (Distichlis sp.) and could have been consumed by deer browsing in San Francisco Bay, but because C_4 plants were generally not consumed by deer near ALA-554, we can use $\delta^{13}C$ values to indicate whether individual deer diets were high in terrestrial- or marine-derived resources. Higher (less negative) $\delta^{13}C$ values reflect a higher concentration of marine organisms in a diet.

It is important to note that perennial plants under water stress will show increased $\delta^{13}C$ in their tissues (Gebrekirstos et al. 2011; Picon et al., 1996; Van de Water et al., 2002). The amount of increase varies depending on the severity of stress but is typically between 1 and 4‰. Deer consuming such water-stressed plants will show higher $\delta^{13}C$ in their own tissues.

Nitrogen isotopes ($^{15}N/^{14}N$, expressed as $\delta^{15}N$) reveal the average trophic level of foods consumed by an individual and increase about 3-5‰ with each trophic level (Deniro and Epstein 1981; McCutchan et al. 2003; Minagawa and Wada 1984). In California's terrestrial systems, there are three distinct trophic levels: photosynthesizers, herbivores, and carnivores. There are more trophic levels in California's aquatic environments, resulting in higher $\delta^{15}N$ concentrations at the top of the aquatic food chain among large fish, predatory birds, and marine mammals. In general, we expect our isotopic results to reflect herbivorous diets low in both C_4 plants and marine resources among mule deer from ALA-554.

METHODS

Initial preparation of samples took place at the UC Davis Archaeometry Laboratory. To isolate collagen for isotope analysis, a modified Longin procedure was followed (Longin 1971). A diamond drill bit was used to remove surface contamination and surrounding cancellous bone from approximately 1-2 g of cortical bone from each individual. Samples were further cleaned by sonication in deionized water (dH_20) (three to six 5-minute baths, with dH_20 replaced each time). Sonicated samples were left to dry overnight, then weighed. These clean, dry samples were demineralized in vials containing a solution of 0.5M hydrochloric acid (HCL), which was changed every 24 hours until the samples were completely demineralized (1-2 weeks). Samples were rinsed 3 times with dH_20 and then soaked in a solution of 0.125M sodium hydroxide (NaOH) for 24 hours to remove humic contaminants. Residual NaOH was removed by rinsing 3 times with dH2O. Vials were then filled with pH3 water and placed in an 80°C oven to solubilize the collagen. After emerging from the oven, the pH3 solution was pipetted into a clean vial. This process was repeated until the entire sample was solubilized (1-3 times). Finally, samples were placed in a freeze dryer to remove the water and isolate the collagen.

Approximately 1 ± 0.3 milligrams of collagen from each sample were weighed into tin capsules and submitted to the UC Davis Stable Isotope Facility. The collagen samples were measured for $\delta^{13}C$ and $\delta^{15}N$ by continuous-flow mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer). Carbon

isotope ratios ($\delta^{13}C$) are expressed in permil notation (parts per thousand) relative to the Pee Dee Belemnite Standard ($\delta^{13}C = [(^{13}C/^{12}C)sample - (^{13}C/^{12}C)standard]/(^{13}C/^{12}C)standard \times 10^3$) and nitrogen isotope ratios ($\delta^{15}N$) are expressed relative to N_2 in modern atmospheric air ($\delta^{15}N = [(^{15}N/^{14}N)sample - (^{15}N/^{14}N)standard]/(\delta^{15}N/^{14}N)standard \times 10^3$). Scatterplots showing $\delta^{13}C$ and $\delta^{15}N$ of individuals were created. We also graphed each isotope ratio versus the time cal BP based on previous radiocarbon dating of burial contexts.

RESULTS

Table 1 provides a breakdown of the deer sampled by burial and associated radiocarbon dates, along with the $\delta^{13}C$ and $\delta^{15}N$ isotope data.

Table 1. Stable Isotope Results and Radiocarbon Dating for Deer from ALA-554.

Deer Associated with Burial #	Median 14C Date (cal BP)	2 Sigma Radiocarbon Range	Deer $\delta^{13}C$ (‰)	Deer $\delta^{15}N$ (‰)	Deer C:N
1	496	329-547	-20.3	5.2	3.3
5	526	497-552	-20.4	4.2	3.3
8	492	327-550	-19.9	3.9	3.2
9	592	520-645	-19.7	4.3	3.5
10	485	328-538	-20.3	3.5	3.3
10	485	328-538	-19.6	4.3	3.2
11	917	795-959	-19.4	7.5	3.2
11	917	795-959	-19.2	5.3	3.3
13	596	525-645	-19.8	4.2	3.2
13	596	525-645	-19.9	3.8	3.5
13	596	525-645	-20.4	3.9	3.3
16	1170	1064-1278	-19.8	4.4	3.2
16	1170	1064-1278	-19.7	4.6	3.3
18	944	832-1054	-20.1	4.6	3.2
22	504	455-540	-20.0	4.6	3.3
26	853	750-953	-20.6	4.8	3.2
26	853	750-953	-19.6	4.7	3.4
26	853	750-953	-20.2	4.2	3.4

27	783	725-905	-19.5	5.9	3.2
27	783	725-905	-20.1	3.3	3.2
33	519	484-549	-20.4	3.9	3.2
35	Indeterminate	Indeterminate	-19.8	4.5	3.3
36	1333	1298-1376	-20.5	4.6	3.3
40	859	786-955	-19.6	5.0	3.2
41	500	447-530	-21.4	5.1	3.8
41	500	447-530	-20.7	3.9	3.3
54	1364	1306-1408	-20.5	4.6	3.2
57	868	741-973	-19.9	3.7	3.2
60	604	549-648	-20.3	3.9	3.2
62	891	697-1174	-18.7	3.9	3.3
63	602	548-654	-20.9	3.6	3.3
80	597	527-649	-21.3	3.8	3.2
82	845	748-919	-22.4	10.2	4.7
82	845	748-919	-22.1	4.9	4.7
82	845	748-919	-20.4	3.0	3.2
84	519	493-545	-20.0	3.9	3.2
87	958	919-1054	-20.3	7.3	3.4
87	958	919-1054	-20.2	4.8	3.4
89	532	504-622	-20.6	4.4	3.2
90	555	514-632	-20.1	4.0	3.2
95	774	691-903	-20.4	4.3	3.2
97	721	649-901	-20.1	4.4	3.2
104	858	740-957	-19.8	4.1	3.2
105	551	509-633	-20.5	4.9	3.2
106	633	546-716	-20.1	4.5	3.2
111	861	793-953	-20.7	4.9	3.3

116	934	798-1049	-20.4	3.9	3.2
125	832	693-955	-20.0	4.7	3.3
127	516	441-625	-19.8	3.0	3.2
128	Indeterminate	Indeterminate	-20.0	3.8	3.3
139	401	312-494	-20.6	3.5	3.2
141	1244	1176-1300	-19.9	7.9	3.3
142	1295	1179-1347	-18.8	4.9	3.2
146	860	792-953	-20.1	3.8	3.3
164	530	502-618	-19.9	4.2	3.3
167	1314	1285-1351	-20.2	3.6	3.3

DISCUSSION AND CONCLUSIONS

In general, the isotopic data points to diets high in terrestrial C_3 plants. A lack of statistically significant outliers for either $\delta^{13}C$ or $\delta^{15}N$ suggests a relatively homogenous diet across the sampled population. This homogeneity was expected, since all sampled individuals belong to the same species and lived in the same general area of California. The slight observable variation between individuals can thus be attributed to regional differences in diet and/or changes in climate across time.

Interestingly, one individual presented with notably elevated $\delta^{15}N$ (10.2%; Figure 3), which suggests that it may have been a juvenile deer, since nursing young feed at a higher trophic level than adults and are therefore enriched in $\delta^{15}N$ (Eerkens et al. 2011). Visual examination of the pre-processed bone supports this conclusion.

When plotted against time, the isotopic data reveals the effects of the Medieval Climatic Anomaly (MCA). The MCA (650-1220 cal BP) was characterized by general warming and prolonged droughts along the west coast of the United States (Stine 1994; Jones et al., 1999). The period between 800 and 1000 cal BP in our data set shows a slight increase in mean $\delta^{13}C$ levels in deer compared to the period after 600 cal BP (Fig. 4). As discussed earlier, elevated $\delta^{13}C$ levels are consistent with consumption of higher amounts of water-stressed plants (Picon et al., 1996; Van de Water et al., 2002). However, a T-test comparison of $\delta^{13}C$ between the two time periods is not significant ($p=0.23$), likely due to the small sample sizes.

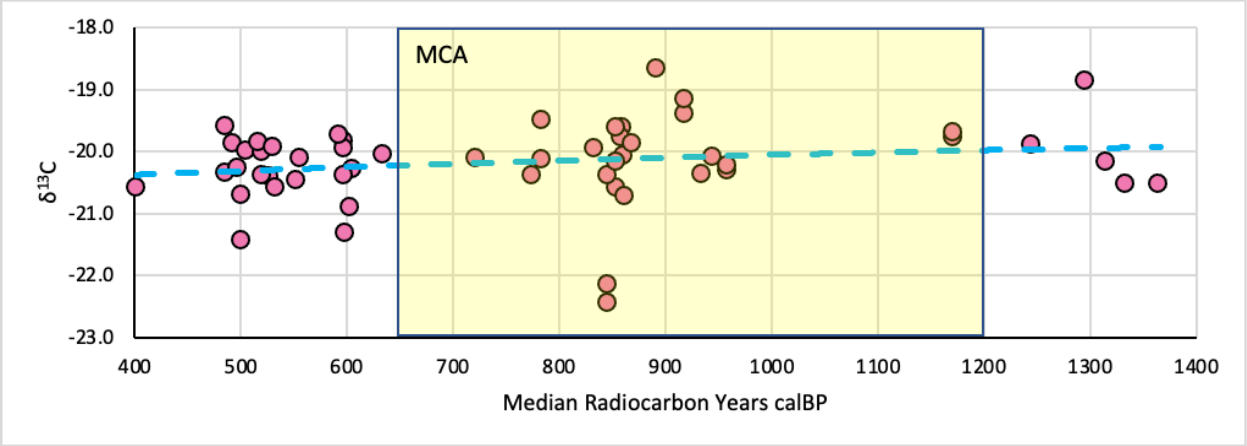

Figure 2. δ^{13}C Isotope Change over Time.

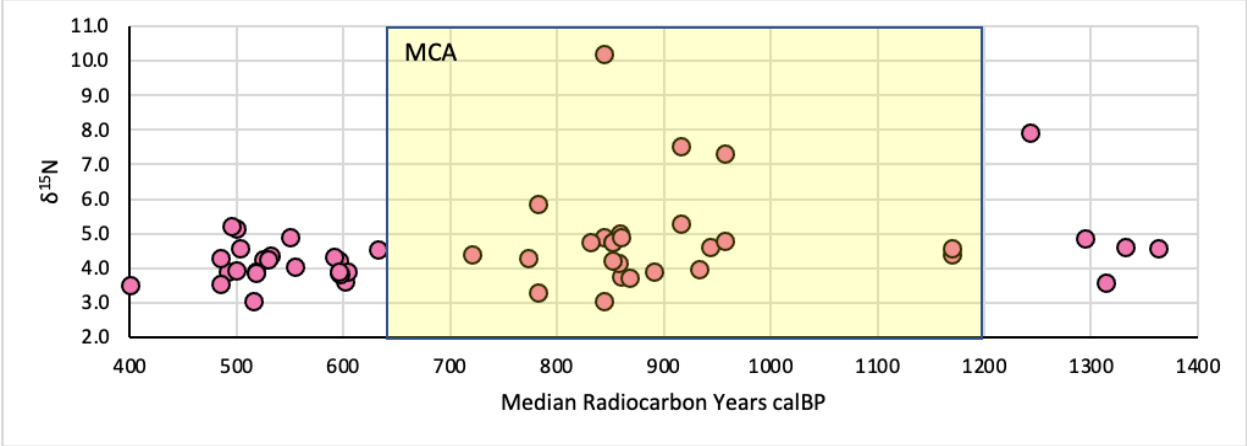

Figure 3. δ^{15}N Isotope Change over Time.

The greatest variation in both δ^{13}C and δ^{15}N values occurs between 800 and 1000 calBP (Figure 2 and Figure 3). This suggests that deer had the greatest diversity in diets during this period, indicating that they increased their diet breadth, or were coming to ALA-554 from a greater variety of places. If the latter, it would indicate either that deer from elsewhere expanded their foraging ranges into the region near ALA-554, or that humans from ALA-554 expanded their hunting ranges outward during this time. Either way, it is clear that people and animals altered their behaviors and diets, likely in response to environmental change. Together, all of this data supports the conclusion that the MCA had tangible effects on the region's paleoecology, and therefore influenced both deer and human behavior.

FUTURE DIRECTIONS

Sulfur (δ^{34}S) results from the Stable Isotope Facility at UC Davis are pending. Sulfur isotope ratios are another important tool for paleo-environmental and paleo-dietary reconstructions. Due to differences in underlying geology, regions may have distinctive sulfur

signatures (Nehlich 2015). These differences can serve as a marker of changes in residency and/or migration. We will use the $\delta^{34}S$ data from the remains of small, sedentary animals (e.g. rabbits, squirrels) from ALA-554 to identify a baseline sulfur signature for the region near the site. Once this baseline has been established, we will compare it to the $\delta^{34}S$ values from the deer in order to determine whether or not each individual deer was local to the site. When the deer have been grouped into two distinct categories (local vs. non-local), we will compare the $\delta^{34}S$ data of all non-local deer to the sulfur baselines of nearby sites to help estimate their points of origin on the larger map of northern California. It would also be interesting to compare our results with data from other sites in the San Francisco Bay area, to see if there is a similar pattern among deer across the region within similar time periods.

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