Foraging Adaptation of Birds and Humans During the Medieval Climatic Anomaly: Stable Isotope Analysis of Avian Species from CA-ALA-554

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Stable isotope analysis has been widely used to investigate dietary and geographical information of organisms, but few studies have applied it to archaeological avian remains. Through carbon and nitrogen stable isotope analyses of bone collagen, this study examines the diet sources of several wild bird species in an attempt to discover their foraging patterns and associated human hunting behavior. These avian remains are from CA-ALA-554 in the East San Francisco Bay Area and represent a time span of 900 years, partly overlapping with the Medieval Climatic Anomaly (MCA). We compare the isotopic signatures of samples from different windows of time represented at the site to investigate the influence of droughts during the MCA and the responses of birds and humans. Our findings show that in the MCA, geese have larger variance in $\delta^{13}C$ *and* $\delta^{15}N$*, and avian fauna includes a greater range of species. This suggests that birds might have migrated farther and widened their diets, and ancient humans might have expanded their hunting range and diversified their prey, possibly in response to more challenging environmental conditions.*

Introduction

The archaeological site CA-ALA-554 is located in the East San Francisco Bay Area in modern-day Pleasanton, California (Figure 1). It was inhabited by ancestral Ohlone people from approximately 2160 to 180 BP (Greenwald et al. 2016). Artifacts, macrobotanical materials, and faunal remains show that the inhabitants consumed seeds and nuts and hunted for a variety of animals, including large and small mammals, birds, and fish (Estes et al. 2012). In 2011, many avian remains were recovered during the excavation at the site (Figure 2). These bird remains were directly associated with multiple burials and are closely associated with human hunting behavior (Estes et al. 2012). Independent radiocarbon dates associated with each burial indicate that human interments and bird bones were deposited over a period of 900 years (1300-400 cal BP). Parts of this occupation window overlap with the Medieval Climatic Anomaly (MCA), a period of warmer climatic conditions from 1200 to 650 cal BP in North America (Jones et al. 1999). Ancient humans and other organisms might have faced challenges in the MCA due to severe and long-lasting droughts (Stine 2000).

Stable isotopes can be used to evaluate the diet sources of organisms, as the isotopes incorporated into body tissues, including bone, are gained directly through ingested foods (Hobson 1999). Stable carbon isotope ratios ($\delta^{13}C$) provide an estimate of the consumption of marine versus terrestrial food (Farquhar et al. 1989). This is because the marine carbon source, seawater bicarbonate, is approximately 7‰ higher in $\delta^{13}C$ than the terrestrial carbon source, atmospheric CO_2. Such a difference is maintained at the initial photosynthesis and subsequent steps in the food chain (Chisholm et al. 1982). Stable nitrogen isotope ratios ($\delta^{15}N$) reflect the trophic position. Since the heavier ^{15}N is differentially retained during tissue synthesis, $\delta^{15}N$ gradually increases by about 3‰ with each trophic level (DeNiro and Epstein 1981; McCutchan et al. 2003; Minagawa and Wada 1984). Aquatic systems tend to be higher in $\delta^{15}N$ because more trophic levels exist there (Eerkens et al. 2013; Schoeninger 1995). In summary, higher $\delta^{13}C$ reveals a more-marine-food-based diet source, and higher $\delta^{15}N$ indicates a higher trophic position (Hobson 1999).

Stable isotope analysis has been extensively applied in archaeology for reconstructing paleodiets of ancient people (Eerkens et al. 2011; Müldner and Richards 2005) and in modern avian ecology (Hobson and Clark 1992; Hobson et al. 1994). However, application to archaeological avian remains is rare in the published literature, especially using multiple species from the same site. In this study, we use stable isotope analysis to evaluate the effect of MCA and responses of CA-ALA-554 birds and humans to environmental challenges. We analyze bone collagen from seven species and compared $\delta^{13}C$ and $\delta^{15}N$ of individuals in and outside the MCA.

METHODS

This study comprises bone specimens from 27 individual birds: 19 geese (*Anser* sp. & *Branta* sp.), three ducks (*Anas* sp.), one Mallard (*Anas platyrhynchos*), one American Crow (*Corvus brachyrhynchos*), one Red-tailed Hawk (*Buteo jamaicensis*), one Barn Owl (*Tyto alba*), and one gull (*Larus* sp.). Using identification manuals (Cohen and Serjeantson 2015) and avian skeleton collections in the UC Davis Zooarchaeology Lab as references, we identified the species or taxon of each specimen based on their bone features.

Approximately 1-2 g of bone were taken from each sample. We followed a modified procedure of bone collagen extraction (Longin 1971). Each sample was ultrasonically cleaned of exterior and interior (inside the medullary cavity) surface contamination through several five-minute baths in deionized water (dH_2O) and allowed to air-dry. For demineralization, we immersed the sample in 0.5 M hydrochloric acid (HCl) in a refrigerator set at 5°C. The HCl was changed every 48 hours until the reaction with mineral substances ceased. After rinsing the sample with dH_2O, we placed it in 0.125 M sodium hydroxide (NaOH) for 24 hours to remove humic acids. The sample was rinsed again with dH_2O. To solubilize collagen, we added pH3 water to the sample and placed it in an 80°C oven for 24 hours. After removing residual solids by pipetting, we freeze-dried the solubilized collagen to eliminate moisture. 1 ± 0.3 mg of collagen from each sample was weighed into a tin capsule and sent for analysis at the UC Davis Stable Isotope Facility.

The collagen samples were measured for $\delta^{13}C$ and $\delta^{15}N$ by continuous flow isotope-ratio mass spectrometry (PDZ Europa ANCA-GSL elemental analyzer interfaced with PDZ Europa 20-20 isotope-ratio mass spectrometer). We report $\delta^{13}C$ and $\delta^{15}N$ on a per mil (‰) basis relative to the Pee Dee Belemnite standard and the atmospheric N_2 (AIR) standard, respectively, where

$$\delta^{13}C = [(^{13}C/^{12}C)_{\mathrm{sample}} - (^{13}C/^{12}C)_{standard}]/(^{13}C/^{12}C)_{\mathrm{standard}} \times 10^3$$

and

$$\delta^{15}N = [(^{15}N/^{14}N)_{\mathrm{sample}} - (^{15}N/^{14}N)_{standard}]/(^{15}N/^{14}N)_{\mathrm{standard}} \times 10^3.$$

Scatterplots showing $\delta^{13}C$ and $\delta^{15}N$ of individuals and species were created. We also graphed each isotope ratio versus the time cal BP based on previous radiocarbon dating of burial contexts.

RESULTS

The $\delta^{13}C$ and $\delta^{15}N$ values of the individual birds are shown in Table 1 and Figure 3. For the taxa with multiple individuals (goose and duck), the median and standard error were calculated and shown along with other species that involve only one individual (Figure 4).

Table 1. Stable Isotope Results and Radiocarbon Dates of Avian Remains from CA-ALA-554.

Burial	Species	Element	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N Ratio	%C (%)	%N (%)	Median Radiocarbon Date (cal BP)
160	Goose[a]	Humerus, Left	−22.0	6.9	3.2	46.8	16.8	1297
160	Goose[b]	Tarsometatarsus, Right	−20.2	5.1	3.3	43.4	15.6	1297
6	Goose	Sternum	−16.6	5.4	3.2	34.0	12.3	945
107	Goose	Furcula	−21.4	0.4	3.2	61.8	22.2	935
116	Goose	Humerus, Left	−22.2	4.8	3.3	47.0	16.7	934
24	Goose	Humerus, Right	−21.7	5.4	3.4	27.4	9.5	904
57	Goose	Scapula	−22.3	7.8	3.3	61.3	21.9	868
111	Goose	Humerus, Right	−19.8	5.2	3.3	29.2	10.4	861
26	Goose	Sternum	−13.5	10.7	3.3	48.4	17.2	853
82	Goose	Sternum	−18.1	7.3	3.2	32.3	11.6	845
39	Goose	Coracoid, Left	−21.3	4.9	3.2	40.1	14.4	716

60	Goose	-	−20.8	5.7	3.3	43.2	15.3	604
105	Goose	Humerus, Right	−21.2	6.7	3.3	37.2	13.3	551
7	Goose	Humerus, Left	−20.7	6.1	3.3	39.7	14.2	529
127	Goose	Sternum	−23.3	5.6	3.3	47.4	16.9	516
41	Goose[a]	Coracoid, Right	−21.2	1.8	3.2	31.3	11.3	500
41	Goose[b]	Coracoid, Right	−21.4	1.1	3.3	23.2	8.1	500
10	Goose[a]	Sternum	−17.5	5.4	3.3	40.3	14.4	485
10	Goose[b]	Sternum	−21.2	4.2	3.3	56.3	19.9	485
146	Duck	Coracoid, Left	−22.2	7.0	3.3	29.5	10.5	860
82	Duck	Coracoid, Left	−16.8	8.8	3.4	14.0	4.8	845
139	Duck	Coracoid, Right	−22.6	8.3	3.3	44.6	16.0	401
104	Mallard	Humerus, Right	−22.2	8.7	3.4	16.2	5.6	858
146	American Crow	Sternum	−19.4	7.8	3.3	55.4	19.8	860
26	Red-tailed Hawk	Talon	−19.7	7.6	3.3	54.0	19.3	853
20	Barn Owl	Humerus, Right	−19.3	7.3	3.3	34.9	12.3	918
39	Gull	Humerus, Left	−14.5	11.7	3.3	40.0	14.3	716

Note: Three burials contained more than one bird individual of the same taxon; [a] individual one; [b] individual two.

DISCUSSION

Geese show high variation in $\delta^{15}N$ and $\delta^{13}C$ with several potential outliers. However, they are generally lower in $\delta^{15}N$, indicating a more plant-based diet source. The mallard and ducks are very low in $\delta^{13}C$ and higher in $\delta^{15}N$, which suggests that they belonged to a terrestrial freshwater system and consumed more animal-based foods, such as insects and snails. The hawk, owl, and crow also show high $\delta^{15}N$, suggesting they were carnivores and omnivores and higher in trophic position. The gull had the highest $\delta^{15}N$ and $\delta^{13}C$, consistent with our expectations, as gulls are piscivorous seabirds. Overall, the measured $\delta^{13}C$ and $\delta^{15}N$ of each species were consistent with previous knowledge about bird ecology and diet (Hobson 1999). Herbivorous birds (geese) were low in $\delta^{15}N$, while omnivorous (ducks, mallard, crow) and carnivorous (owl, hawk, gull) birds were higher. Freshwater waterfowl showed lower $\delta^{13}C$ and higher $\delta^{15}N$. Piscivorous seabirds were high in both $\delta^{13}C$ and $\delta^{15}N$.

We found that during the Medieval Climatic Anomaly, there was larger isotopic variance and higher species diversity. Geese from 1000-800 cal BP, within the MCA, displayed higher variance in both $\delta^{13}C$ and $\delta^{15}N$ compared to geese from periods outside the MCA. Furthermore, individuals from various other bird taxa appeared more frequently in the MCA period, including the mallard, crow, hawk, owl, gull, and two ducks, whereas they were not discovered in other periods except for one duck (Figure 5).

Although few literatures have studied the relationship between faunal remains' isotopic signatures, ancient animals' behavior, and abnormal environmental conditions, our study was modeled based on stable isotope studies that have been done on humans (Bartelink et al. 2020; Eerkens et al. 2011; Eerkens et al. 2013; Greenwald et al. 2016; Müldner and Richards 2005). The pattern in isotopic variation and taxon diversity we found can be explained from both the birds' and ancient humans' perspectives. Higher variance in geese $\delta^{13}C$ and $\delta^{15}N$ during the MCA might indicate that the geese migrated across a larger geographic area and ate a wider variety of food to better survive during this extended period of droughts. Similarly, since these avian remains were closely associated with human hunting behavior, it is also possible that humans traveled farther to hunt in both terrestrial and marine environments, leading to greater isotopic variation within species, and capturing a broader range of bird taxa.

There are several limitations to our study. First, our sample size is small, especially for the species other than geese. Since the bird remains were likely the prey of ancient humans, the common prey species were sampled most often. However, finding more individuals from the uncommon species would be greatly helpful for us to gain more comprehensive information regarding the paleoenvironment and paleoclimate, as we would be able to make more comparisons across time. Moreover, considering the different life histories and habits of different taxa, we could further study how the environment might influence each species in a different way.

A second limitation relates to our bird species identification process. Since only very limited materials and information get preserved after the extended period of burial (i.e., there were no soft tissues left from which we could easily obtain DNA), we were only able to identify the species based on the bone features. Bird bones are fairly similar across species, and it is extremely difficult to identify to the species level for some families, such as geese. Furthermore, most avian bones are fragmentary and lack identifiable features even for identification to the family level. One of the reasons for the large variance in $\delta^{13}C$ and $\delta^{15}N$ of geese could be that we did not identify the exact species of those geese since the diets of different goose species can be very different. For the goose individual with very high $\delta^{13}C$ and $\delta^{15}N$ (Figure 3, top right corner), it is possible that we misidentified a seabird as a goose.

In addition to solving these problems, employing $\delta^{34}S$ would also be great for future research. Sulfur in organisms is assimilated from oceanic and/or soil sulfur. Since sulfur at different locations shows distinctive signatures based on their different geological history and composition, $\delta^{34}S$ can also be used to infer the geolocation from a geological viewpoint (Nehlich 2015). Together with carbon and nitrogen isotopes, this will provide a more accurate evaluation of the consumption of marine, terrestrial, and freshwater food (Richards et al. 2001). We are currently waiting for the sulfur isotope result from the Stable Isotope Facility and will incorporate it into a future report.

It would also be interesting to compare our results with other sites that ancient people occupied during the MCA to see if there is a shared pattern regarding animal and human responses to the MCA. Meanwhile, acquiring more information from studies, if any, done on CA-ALA-554 humans would be ideal. This could help with determining which one of our two possible explanations (or both) might be more accurate.

Lastly, we found three geese with an unexpected diet as potential outliers (Figure 3). They showed very low $\delta^{15}N$, below values reported in modern geese, suggesting an unusual, extremely plant-based diet. This might indicate a unique subspecies or dietary adaptation that no longer exists today.

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REFERENCES CITED

Bartelink, Eric J., Melanie M. Beasley, Jelmer W. Eerkens, Karen S. Gardner, Randy S. Wiberg, and Ramona Garibay
2020 Stable Isotope Evidence of Diet Breadth Expansion and Regional Dietary Variation Among Middle-to-Late Holocene Hunter-Gatherers of Central California. *Journal of Archaeological Science: Reports* 29: 102182.

Chisholm, Brian S., D. Erle Nelson, and Henry P. Schwarcz
1982 Stable-Carbon Isotope Ratios as a Measure of Marine Versus Terrestrial Protein in Ancient Diets. *Science* 216: 1131-1132.

Cohen, Alan, and Dale Serjeantson
2015 *A Manual for the Identification of Bird Bones from Archaeological Sites*. Archetype Publications, London.

DeNiro, Michael J., and Samuel Epstein
1981 Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45: 341-351.

Eerkens, Jelmer W., Ada G. Berget, and Eric J. Bartelink
2011 Estimating Weaning and Early Childhood Diet from Serial Micro-Samples of Dentin Collagen. *Journal of Archaeological Science* 38: 3101-3111.

Eerkens, Jelmer W., Madeline Mackie, and Eric J. Bartelink
2013 Brackish Water Foraging: Isotopic Landscapes and Dietary Reconstruction in Suisun Marsh, Central California. *Journal of Archaeological Science* 40: 3270-3281.

Estes, Allen, Melanie A. Medeiros, and James Allan (editors)
2012 *Report on Archaeological Data Recovery at CA-ALA-554, Pleasanton, California. Volume I: Data Recovery*. William Self Associates, Orinda, California.

Farquhar, Graham D., James R. Ehleringer, and Kerry T. Hubick
1989 Carbon Isotope Discrimination and Photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology* 40: 503-537.

Greenwald, Alexandra M., Jelmer W. Eerkens, and Eric J. Bartelink
2016 Stable Isotope Evidence of Juvenile Foraging in Prehistoric Central California. *Journal of Archaeological Science: Reports* 7: 146-154.

Hobson, Keith A.
1999 Tracing Origins and Migration of Wildlife Using Stable Isotopes: A Review. *Oecologia* 120: 314-326.

Hobson, Keith A., and Robert G. Clark
1992 Assessing Avian Diets Using Stable Isotopes I: Turnover of ^{13}C in Tissues. *The Condor* 94: 181-188.

Hobson, Keith A., John F. Piatt, and Jay Pitocchelli
1994 Using Stable Isotopes to Determine Seabird Trophic Relationships. *Journal of Animal Ecology* 63: 786-798.

Jones, Terry L., Gary M. Brown, L. Mark Raab, Janet L. McVickar, W. Geoffrey Spaulding, Douglas J. Kennett, Andrew York, and Phillip L. Walker
1999 Environmental Imperatives Reconsidered: Demographic Crises in Western North America During the Medieval Climatic Anomaly. *Current Anthropology* 40: 137-170.

Longin, Robert
1971 New Method of Collagen Extraction for Radiocarbon Dating. *Nature* 230: 241-242.

McCutchan, James H., Jr., William M. Lewis Jr., Carol Kendall, and Claire C. McGrath
2003 Variation in Trophic Shift for Stable Isotope Ratios of Carbon, Nitrogen, and Sulfur. *Oikos* 102: 378-390.

Minagawa, Masao, and Eitaro Wada
1984 Stepwise Enrichment of ^{15}N Along Food Chains: Further Evidence and the Relation Between δ^{15}N and Animal Age. *Geochimica et Cosmochimica Acta* 48: 1135-1140.

Müldner, Gundula, and Michael P. Richards
2005 Fast or Feast: Reconstructing Diet in Later Medieval England by Stable Isotope Analysis. *Journal of Archaeological Science* 32: 39-48.

Nehlich, Olaf
2015 The Application of Sulphur Isotope Analyses in Archaeological Research: A Review. *Earth-Science Reviews* 142: 1-17.

Richards, Michael P., Benjamin T. Fuller, and Robert E. M. Hedges
2001 Sulphur Isotopic Variation in Ancient Bone Collagen from Europe: Implications for Human Palaeodiet, Residence Mobility, and Modern Pollutant Studies. *Earth and Planetary Science Letters* 191: 185-190.

Schoeninger, Margaret J.
1995 Stable Isotope Studies in Human Evolution. *Evolutionary Anthropology: Issues, News, and Reviews* 4: 83-98.

Stine, Scott
2000 On the Medieval Climatic Anomaly. *Current Anthropology* 41: 627-628.

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

Figure 2. Examples of avian remains from CA-ALA-554. (A) The proximal end of the right humerus of the goose from Burial 105. (B) The right coracoid of a goose (individual one, denoted by [a]; see Table 1 for more information) from Burial 41.

Figure 3. $\delta^{13}C$ *and* $\delta^{15}N$ *of each individual (n = 27).*

Figure 4. Median ± standard error of $\delta^{13}C$ *and* $\delta^{15}N$ *of each species or taxon.*

Figure 5. $\delta^{13}C$ *and* $\delta^{15}N$ *changes over time. Note the species diversity and large variance in goose isotopic signatures in the MCA.*