Journal of Archaeological Science: Reports 12 (2017) 491–498

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Measuring the potential influence of cooking on the carbon and nitrogen isotopic composition of spawning Chinook salmon

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ARTICLE INFO

Article history:
Received 14 November 2016
Received in revised form 23 February 2017
Accepted 24 February 2017
Available online xxxx

Keywords:
Isotopic analysis
Cooking
Central Alaska
Salmon

ABSTRACT

This study considers the effect of heat treatment (cooking) on muscle tissue from modern spawning Alaskan Chinook salmon (*Oncorhynchus tshawytscha*) and implications for archaeological dietary reconstructions. Here, it is demonstrated that cooking, potentially through exposure to lighter volatiles present in wood smoke, significantly alters the stable carbon ($\delta^{13}C$) isotopic composition of muscle tissue, though the difference may be too slight ($-0.50‰$) to be incorporated into dietary mixing models. Cooking produces no significant change in nitrogen ($\delta^{15}N$) values. Additionally, this study identifies significant differences in stable nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotopic values between previous studies on coastal adult Chinook salmon and the spawning adult Chinook salmon from Central Alaska analyzed in this study, emphasizing the importance of employing isotopic data from local fauna in dietary reconstructions. The data presented here have implications not only for our understanding of general salmon ecology, but also for refining archaeological reconstructions of prehistoric diet in Central Alaska and other regions where smoke-preserved tissue was regularly consumed.

1. Introduction

Alaskan archaeologists have relied largely on a direct analysis of faunal remains to reconstruct prehistoric diet and track dietary changes through time (Goebel, 2011; Hoffecker, 2005; Holmes, 2001; Dixon, 1999). However, there are several limitations on our ability to reconstruct the importance of different dietary items in prehistory using physical remains alone, and this is particularly true for smaller game like fish. The small bones of fish do not preserve well in Central Alaska's acidic soils and tend to pass readily through the standard screen sizes routinely used in excavation (Ping et al., 2005; Thomas, 1969). Preservation conditions are further worsened by high winds and sparse vegetation, which have resulted in very shallow soil deposits across much of the region (Yesner, 1996).

Additionally, unlike the stone tools employed in hunting large game, the nets, traps, and smoking racks used to capture and process fish are typically constructed from organic materials that infrequently survive the conditions described above (Fienup-Riordan, 1986; Schiffer, 1983; McKennan, 1981). Owing in part to these taphonomic and site formational factors, studies of prehistoric subsistence practices in Alaska have primarily focused on the importance of large mammals, such as caribou, bison, wapiti, and moose (Potter, 2016; Graf and Bigelow, 2011; Esdale, 2008; Dixon, 1999), rather than aquatic resources like fish, though they are known to be critical to Central Alaskan subsistence today (Loring and Gerlach, 2010).

Food preservation techniques have also been under-discussed in archaeological reconstructions of Central Alaskan subsistence practices, despite a wealth of ethnographic evidence pointing to the importance of smoked or fermented meats as a winter food for contemporary Alaskans (Fienup-Riordan, 1986; Nelson, 1986). Today, salmon are frequently hot or cold smoked for several days (Buklis, 1999; Ames, 1994; Fienup-Riordan, 1986), driving off moisture and transforming the raw food product into one that is lighter and can be stored for long periods without risk of spoiling (Horner, 1997). This relatively simple technique can greatly enhance the transportability and longevity of the original raw food product.

If cooking—whether through exposure to smoke or heat—has a significant and measurable isotope effect, it may be possible to establish proxies for identifying different cooking techniques. While previous experimental isotopic studies have considered the potential isotopic effects of cooking on fish bones, they have not considered how it may affect the isotopic composition of muscle tissue (Fernandes et al., 2014). Identifying an isotopic proxy for preservation techniques such as smoking would allow archaeologists to better reconstruct critical prehistoric survival strategies and understand the role of long-term climate change in the development of these now-common preservation techniques. An isotopic proxy for such techniques could be used to measure differences in human remains or soil to identify when such a transition occurred.

Recent discoveries of the earliest evidence for salmon fishing in Central Alaska at the archaeological site of Upward Sun River have

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http://dx.doi.org/10.1016/j.jasrep.2017.02.028
2352-409X/

demonstrated the potential for isotopic analysis to address these gaps in our understanding of Alaskan prehistory (Choy et al., 2016; Halffman et al., 2015). Rather than basing dietary reconstructions on faunal analysis alone, these studies established the presence of salmon in archaeological contexts by comparing ancient DNA of salmon remains to isotopic signatures from ancient and modern salmon bone (Halffman et al., 2015), and constructing isotopic mixing models based on modern and archaeological faunal isotopic data, including salmon, to reconstruct the contents of ancient hearths found at the site and show evidence for cooking salmon (Choy et al., 2016).

Both of the Upward Sun River studies (Halffman et al., 2015; Choy et al., 2016) relied in part on small modern comparative isotopic datasets to draw these important conclusions, demonstrating the potential value of additional comparative isotopic profiles of local salmon within Central Alaskan archeology. While all five species of coastal Alaskan salmon have been comprehensively sampled (Johnson and Schindler, 2009), salmon in the Yukon River watershed have not. Thus, potentially significant regional differences between the isotopic compositions of these populations have yet to be assessed.

The two central goals of this study are (1) to identify potential isotopic changes generated by heat processing (i.e. cooking) in muscle tissue and (2) to develop an isotopic profile for Central Alaskan Chinook salmon that can be employed in future paleodietary reconstructions. Eleven adult Chinook salmon (six females and five males) were cooked following a variety of techniques to evaluate any potential isotopic changes produced and detectable through analysis of stable carbon and nitrogen isotopes. While this study does not include archaeological human tissue, it potentially provides a key component in human dietary reconstruction by determining the effects of cooking on muscle tissue that can be incorporated into isotopic mixing models.

1.1. Isotopic studies in archaeology

Isotopic data have been successfully utilized in archaeological dietary reconstructions for decades (Coltrain et al., 2016; Kusaka et al., 2015; Bonsall et al., 1997; Clementz et al., 2009; Newsome et al., 2004; Richards and Hedges, 1999). This is possible because body tissues reflect the isotopic signals of individuals' diets. By carefully measuring the isotopic signature of both food items and human tissues, dietary mixing models can be constructed to identify specific types of foods that contributed to the isotopic composition of the sampled human tissue. DeNiro and Epstein (1976:834) succinctly summarized this relationship as, "you are what you eat (plus a few per mil)."

Within the context of dietary reconstruction, archaeological organic human tissue (typically collagen) is most frequently sampled for stable carbon and nitrogen isotopes. Stable carbon and nitrogen isotopes are defined in relation to an international standard, Vienna Pee Dee Belemnite (V-PDB) or atmospheric nitrogen (AIR), respectively, as a ratio of $^{13}C/^{12}C$ and $^{15}N/^{14}N$. These ratios are expressed in delta units, $\delta^{13}C$ or $\delta^{15}N$ (‰, parts per mil).

Stable carbon and nitrogen isotopes have both been extensively employed in general discussions of prehistoric subsistence. It has been demonstrated that C_4 plants, like warm, arid-adapted grasses, have significantly higher $\delta^{13}C$ values than C_3 plants (shrubs, woody plants, cool weather grasses), and many archaeological and paleoanthropological studies have relied on this difference to determine prehistoric dietary trends (e.g., the transition to maize agriculture; Sponheimer and Cerling, 2014; Vogel and Van Der Merwe, 1977), though it is worth noting that C_4 plants are quite rare throughout Alaskan prehistory (Zazula and Wooller, 2008). Values of $\delta^{15}N$ generally vary as a function of trophic level, legume consumption, terrestrial vs. aquatic diets, aridity, and physiological stress, and are again employed by archaeologists to track dietary differences between and within populations (Schoeninger, 2014; Kelly, 2000).

Muscle tissue is extremely rare in the archaeological record, but these isotopic values can be retrieved from remains that preserve more reliably, such as bone collagen, using contemporary estimates for the offset between these two substrates (Schwarcz, 1991). Often, there is a significant (2–3‰) offset between different biological substrates such as bone collagen or tooth enamel and muscle tissue that must be considered before prehistoric diet can be reconstructed (Sholto-Douglas et al., 1991). Additionally, $\delta^{13}C$ values from modern tissue samples must be corrected for post-industrial effects of increased atmospheric CO_2, known as the Suess effect (Sonnerup et al., 1999).

To date, human dietary reconstructions using stable nitrogen and carbon isotopes have assumed that heat processing, or cooking, items in the diet does not affect $\delta^{13}C$ or $\delta^{15}N$ values in muscle tissue. However, it has been shown that $\delta^{18}O$, another commonly sampled isotope, significantly increases (+1.8‰) when tissues are exposed to heat for long periods of time, as when boiled (Brettell et al., 2012). Further, it has been shown that the isotopic effect of heating food increases with cooking duration (Brettell et al., 2012), which could be used to model different cooking techniques.

When cooked, food items lose nutrients and mass in predictable ways through evaporation and dripping, suggesting that the heavier constitutive stable isotopes of carbon and nitrogen may be preferentially lost as well (Goñi and Salvadori, 2010; Wrangham, 2009). It has also been shown that fish muscle tissue undergoes a predictable loss of lipids, consisting of chains of carbon and nitrogen, when exposed to heat for long periods (Mai et al., 1978). It has yet to be determined whether these represent wholesale or preferential losses at the isotopic level, and what effect this might have on the isotopic content of the remaining tissue. Based on these findings, if an isotope effect exists that causes the preferential loss of lighter isotopes, it is reasonable to suggest that $\delta^{13}C$ and $\delta^{15}N$ values may increase within the tissue of Chinook salmon when exposed to heat for long periods of time (Fernandes et al., 2014; Carmody and Wrangham, 2009).

If $\delta^{13}C$ and $\delta^{15}N$ values increase when exposed to heat due to the preferential loss of lighter stable isotopes as $\delta^{18}O$ values do, it should be possible to refine dietary reconstructions and conduct future analyses on the antiquity of cooking. If $\delta^{13}C$ and $\delta^{15}N$ values increase at a predictable rate with increasing duration of heat exposure, it may be possible to reliably model different heat treatment techniques. Identifying such a difference could aid our ability to pinpoint when smoke processing was employed during Alaskan prehistory, and allow for a more nuanced understanding of subsistence practices through time relative to environmental or other cultural transition.

1.2. Chinook salmon life history

Chinook are the largest species of salmon and occupy the highest trophic level of all salmon species in the Pacific (Johnson and Schindler, 2009). Salmon hatch in the freshwater streams of Central Alaska and begin their lives migrating to the sea. As adults, they grow and feed on a variety of ocean resources, such as squid, small fish, copepods, euphausiids, amphipods, and myctophids, and these shape the isotopic profiles of salmon muscle tissues (Davis, 2003; Brodeur, 1990). After they reach maturity, typically between three and five years of age, adult Chinook salmon begin their long journey upstream to return to their spawning grounds in Central Alaska (Myers, 1996). It has been demonstrated that both Pacific and Atlantic salmon rely on stores of fat, accumulated from their marine diet, during their long journey into spawning grounds (Jonsson et al., 1997; Groot et al., 1995), and that they derive their energy almost exclusively through catabolysis, or the breakdown of their own tissues upon entering freshwater (Kadri et al., 1995).

While several isotopic studies have focused on coastal Chinook salmon populations (Johnson and Schindler 2009; Kaeriyama et al., 2004; Satterfield and Finney, 2002; Piorkowski, 1995), no studies have offered a comprehensive isotopic profile of Central Alaskan Chinook salmon collected from the same location during the same year from the Yukon River watershed. Many factors could distinguish coastal