Title

Stable Isotope Bone Chemistry and Human-Animal Interactions in Historical Archaeology

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Abstract

Stable isotope-based paleodietary work is ideally suited for answering questions about a wide variety of human-animal relationships in historical archaeological contexts in the North American northeast and further afield. To date, very few published studies have approached historical animal husbandry and trade from an isotopic perspective. We advocate for increased attention to the possibilities of stable isotope work by: 1) explaining why the technique is well-suited to address some problems of human-animal relations encountered by historical archaeologists, 2) presenting a literature review of previous stable isotope work on human-animal interaction in historical North America, and 3) offering a short case study on the dietary life history of an individual pig raised at the archaeological site of Ferryland, Newfoundland, Canada, based on stable carbon and nitrogen isotope data from serially sectioned dental collagen.

1. Introduction

Stable isotope analysis is a tool routinely employed for reconstructing human diet and past lifeways not only in precontact contexts but increasingly among those studied by historical archaeologists (North American examples include: Carter et al. 2004; Ellerbrok et al. 2012; Goodman et al. 2009; Grimes 2013; Katzenberg 1991a,b; Katzenberg et al. 2000; Katzenberg and Pfeiffer 1995; Krigbaum et al. 2013; Owsley et al. 2006; Page 2007; Price et al. 2012; Schroeder et al. 2009; Sparks et al. 2012; Ubelaker and Owsley 2003; Vanderpool 2011; Varney 2003; Wescott et al. 2010). Equally, stable isotope analysis has the potential to reconstruct animal diets and, for this reason, in some contexts can provide detailed understandings of human-animal interactions in the past (e.g. Guiry 2012; White 2004). Here, we argue that although stable isotope work on faunal materials from historical sites has thus far been smaller in scope relative to other techniques for studying human-animal interactions (see Landon 2005, 2009), isotopic techniques have outstanding potential to enrich understandings of historical life ways and develop and test new methodological approaches in North American historical archaeology. Though we mainly discuss stable isotope work at historical sites in North America, it should also be recognized that similar colonial and historical contexts in other regions of the world as well as the post-medieval period in Europe could also benefit from increased attention.

We first outline why stable isotope work is particularly well-suited for addressing questions about historical human-animal interactions. This is followed by a literature review of the few North American examples of stable isotope work that are explicitly aimed at understanding human-animal relations. Finally, we provide a case study using stable carbon and nitrogen isotope analyses of pig teeth from the English 17th-century site of Ferryland (CgAf-2), Newfoundland, Canada, demonstrating some of the potential information which can be gleaned from relatively simple analyses of historical faunal remains. This case study focuses on a new suite (see Guiry et al. 2012b for previous work) of pilot data from serially sectioned tooth dentine collagen of a pig to reconstruct the dietary life history of an individual animal.

2. Stable Isotope Theory and Methods

The stable isotope composition of archaeologically preserved biological tissues (i.e. bone, tooth, hair, etc) can record the dietary history of the humans or animals that they belonged to based on two key premises: 1) that foods consumed are used by the body to construct or repair tissues, and 2) that different foods can have distinctive isotopic compositions (for review see Katzenberg 2008). In other words, the isotopic composition of ingested foods becomes incorporated into the tissues of the consumer.

Stable carbon isotope values (^{12}C to ^{13}C [$\delta^{13}C$]) from bone and tooth dentine collagen, the analytes in this study, are useful for distinguishing between diets based on C_3 *versus* C_4 plants which are isotopically lighter and heavier, respectively (O'Leary 1988; Van der Merwe and Vogel 1978). Due to differing sources of carbon for plants in aquatic and terrestrial ecosystems, a distinction between foods from marine and terrestrial environments can also be made based on $\delta^{13}C$ data, with the former producing values ~7 ‰ heavier than the latter (Chisholm et al. 1982). As natural edible C_4 plants are not common in the northern climate of Newfoundland and C_4 cultivars such as maize probably did not figure prominently in the local agricultural regime at Ferryland (Bain and Prevost 2010), the $\delta^{13}C$ values of animals raised at the colony will predominantly distinguish between terrestrial C_3 and marine diets. Based on data from previous analyses of terrestrial-fed domesticated herbivores (sheep and cattle; n=16) and marine feeding omnivores (pigs; n=11) at historical Ferryland, $\delta^{13}C$ values for terrestrial and marine diets at the site are expected to be around -21.2±1.0 ‰ and -15.6±0.9 ‰, respectively (Guiry et al. 2012b:2018-2019).

Stable nitrogen isotope values (^{14}N to ^{15}N [$\delta^{15}N$]) become elevated by 3 to 5 ‰ at each step ascending a food chain (Ambrose and DeNiro 1986; DeNiro and Epstein 1981; for review see Hedges and Reynard 2007). For this reason, they are typically used for the differentiation of herbivorous, omnivorous, and carnivorous diets and for the identification of breast feeding relations between mothers and infants (who are separated by one trophic level during nursing. e.g. Schurr 1998). Finally, as freshwater and, particularly, marine ecosystems can have greatly extended food chains, $\delta^{15}N$ values also serve as an indicator of marine-oriented (as opposed to terrestrial-based) diets (Schoeninger et al. 1983). Based on available data from previous analyses of terrestrial-fed domesticated herbivores (sheep and cattle; n=16) and marine feeding omnivores (pigs; n=11) at Ferryland, $\delta^{15}N$ values for terrestrial and marine diets at the site are expected to be around 6.3±1.2 ‰ and 16.3±1.8 ‰, respectively (Guiry et al. 2012b:2018-2019). While terrestrial feeding omnivores or carnivores from Ferryland have not yet been analyzed, it is reasonable to assume that a pig raised at Ferryland based on a purely terrestrial diet would have a $\delta^{15}N$ value elevated by up to 3 to 5 ‰ over terrestrial herbivores.

Bone and tooth dentine collagen preserve dietary signatures reflecting the nature and timing of incorporation of dietary constituents used in their construction. As a protein, collagen stable isotope values disproportionally reflect dietary protein relative to lipid and carbohydrate contributions (Ambrose and Norr 1993; Tieszen and Fagre 1993). As bone remodels over the life of an animal, collagen produces stable isotope signatures reflecting a long-term dietary average. Tooth dentine, alternatively, is thought to undergo very limited remodelling after it is laid down. As dentine collagen is grown generally perpendicular to the axis of a tooth, analyses of serial sections that crosscut the tooth growth axis (i.e. from crown to root tip) may provide a diachronic overview of an individual's diet during the time of tooth formation (e.g. Ballasse et al. 2002; Eerkens et al. 2011; Fuller et al. 2003). It is important to note that due to the uneven morphology of dentine growth, this sampling protocol produces collagen samples that may include material from more than one dentine growth interval and, for this reason, provides a rough approximation of diet over time.

3. Complementing Historical Faunal Analyses with Stable Isotope Work

The development of historical zooarchaeology since the 1960s has provided a wealth of information on historical diet and human-animal relations including trade, husbandry, and other non-dietary uses (Landon 2005, 2009). Interpretations based on these faunal analyses are enabled or limited by a number of factors including taphonomy, preservation, the nature and content of available collections as well as developments in zooarchaeological techniques (c.f. Reitz and Wing 2008). The integration of techniques from the archaeological sciences such as ancient DNA analyses and other biomolecular approaches have significantly widened the breadth and scope of questions that can be addressed through the analyses of archaeological faunal records (e.g. Buckley et al. 2010; Kefi 2011 [see also Section 4]).

Stable isotope work in particular can access information about animal husbandry and trade that may otherwise be unobtainable. Yet despite growth in the number of well-contextualized faunal collections from various historical sites (for overview see Landon 2009), stable isotope work has rarely been applied directly to questions of historical human-animal relations (see Section 4). For this reason, the accumulated faunal collections from historical sites in North America represent an unrealized wealth of potential in terms of enhancements of historical archaeological understandings and opportunities for the advancement of stable isotope methodology.

There are several reasons to anticipate that stable isotope work on historical faunal remains would be highly productive, perhaps even more so than similar work conducted in precontact, and particularly pre/non-agricultural contexts. A significant factor and opportunity when considering faunal collections from historical contexts is their frequent emphasis on domesticated species. Domesticates share a different kind of relationship with humans than their wild counterparts. The life histories of domestic animals are intricately connected with a variety of human activities and, more generally, are reflective of ecological, symbolic, and cultural adaptations to a wide range of physical and social environments. Important aspects of animal husbandry include human control over, or provisioning of, food stuffs as well as (though not necessarily in all cases) human control over animal movement. Traditional faunal analyses are not always able to address these key features of the human-animal relationship (e.g. Noël 2010: 132; Sportman et al. 2007; Tourigny 2009: 166). For this reason, stable isotope analyses, with their capacity to differentiate dietary regimes and mobility patterns at intra-individual as well as intra-and inter-population levels, are ideally suited to answer questions about the potential variety of ways that humans influenced animal diets and movement and, in so doing, reveal previously hidden aspects of specific human intentions relating to food production and trade.

Another mutually attractive aspect of applying stable isotope analyses to historical faunal collections relates to the textual record that can speak to human-animal interactions. While textual records may fill-in some details about how and why humans kept certain animals, historical information should be confronted with what is found in the archaeological record. Stable isotope analyses, and the direct evidence for diet and mobility they provide, have the capacity to verify or call into question a variety of historical accounts of human-animal relations. From an alternative perspective, the textual record can provide an ideal context in which to test stable isotope approaches to various archaeological questions in a relatively controlled way (Katzenberg et al. 2000:2). For instance, the highly specific information about the transport of meat products (e.g. Staniforth 2000) could provide an ideal context in which to test isotopic techniques for identifying livestock husbandry and trade.

There are also a variety of relatively unique human-animal relations that occurred during the historical period that traditional faunal analyses have struggled to characterize adequately. Some of these historical relations and activities are particularly apt to be studied by means of stable isotope analyses. Extremely long range trade, for instance, between northeast North America, the Caribbean, and Europe, carried animals and animal products further from their place of origin than ever before (e.g. Pope 2004). The rise of industrial activities such as distilling, brewing, and fishing produced copious edible waste products encouraging inexpensive large scale livestock husbandry (e.g. Rixson 2000: 289; Wiseman 2000: 8). Increases in livestock production and demand related to these and other developments resulted in greater systematization of livestock production and distribution (e.g. Rixson 2000: 195). Each of these phenomena can influence the sources of food and water available to livestock and hence the way a variety of isotopic signatures are recorded in domesticates' tissues. For this reason, in many historical contexts, an understanding of the development of these phenomena could be approached from an isotopic perspective.

4. Previous Research

Given the potential for both our understanding of human-animal relations in historical contexts and for methodological development in stable isotope work, it is surprising to note that (to our knowledge) only two studies have been published to date that specifically focus on questions pertaining to historical fauna in North America, both of which have been aimed at identifying the presence of long distance meat trade based on the dietary specificities of regional animal husbandry practices.

In an early study, Klippel (2001) analyzed the stable carbon isotope compositions of seven cattle excavated from the 18th-century African slave living quarters associated with the sugar monoculture plantation at Brimstone Hill on St. Kitts in the West Indies. Based on bovid skeletal part frequencies he reasoned that some of the beef consumed in that context was brought to the site in a barrelled and salted form. He found $\delta^{13}C$ values suggesting that these cattle had maintained diets consisting of different amounts of C_4 plants, such as tropical grasses, and C_3

plants, such as most temperate grasses. Individuals with less negative $\delta^{13}C$ values, Klippel argues, probably consumed sugarcane tops locally on the island, whereas those with lower values reflect animals that grazed in a temperate area, most likely the eastern US. Based on this distinction a variety of insights were gained: it suggested that land-use for sugar production was so intense that land owners were importing salt meat for the slave population; that barrelled salt meat could contain bones which, at the time, was not widely assumed; and, that St. Kitts probably obtained some of their meat products from American sources. It should also be noted that Varney (2003:189-196) provided an excellent and complementary unpublished analysis of $\delta^{13}C$ and $\delta^{15}N$ values of a small group of faunal remains from three sites in Antigua.

Another study by Guiry and colleagues (2012b) analyzed the stable carbon and nitrogen isotope ratios of pig bone collagen from the 17th- to 19th-century French fishing station of *Champs Paya* (archaeologically known as the site of Dos de Cheval [EfAx-09]) and the 17th-century English fishing settlement of Ferryland (CgAf-02) in Newfoundland, Canada. They reasoned that, if pigs were raised at the remote fishing stations of Newfoundland, fish offal would likely have formed a large component of their dietary protein intake resulting in high $\delta^{13}C$ and $\delta^{15}N$ values. Meanwhile, pigs raised in Europe would probably have had diets focusing on terrestrial foods and therefore would have lower isotope values. Results from Ferryland show that over half of the specimens (n=11) analyzed derive from pigs with marine-oriented diets and probably came from locally raised livestock. Other pig specimens from Ferryland (n=6), as well as all pigs from Dos de Cheval (n=15), produced terrestrial isotope signatures. The authors interpreted these latter specimens as deriving from salt-pork, probably imported from Ireland, England, and/or France. As a test study, this work demonstrated the methodological possibility of determining the rough origin of pork products consumed at fisheries sites in the area. Furthermore, in addition to providing further counter evidence to the assumption that skeletal elements would not have been included in barrelled salt-meat (e.g. English 1990), the capacity to separate barrelled meat elements from locally butchered remains opens the way for new zooarchaeological analyses of Ferryland's pig remains. For instance, pairing pig skeletal part frequencies in deposits from different time periods and associated with social groups with stable isotope analyses could allow for a diachronic assessment of changing patterns in the consumption of imported *versus* locally raised pork products amongst different parts of the Ferryland community.

It is interesting to note a common thread binding this previous research. Each of these studies (Klippel 2001; Guiry et al. 2012b) has been aimed at identifying the presence of long distance meat trade but has relied on the use of stable carbon and nitrogen isotope evidence rather than other isotopic techniques that more directly record geographical signatures from migration and mobility events such as stable oxygen, sulfur, and radiogenic strontium isotope analyses (see below). Though stable carbon and nitrogen isotope analyses are normally reserved for dietary reconstructions and do not inherently record geographical information, it is possible, within the parameters of their respective historical and environmental contexts, to use these stable isotopes to make circumstantial inferences about long distance animal trade. In other words, the trend in the isotopic literature on human animal relations in historical North America has thus far has been a reliance on peculiarities relating to expected animal diets (anomalous within the context of local environmental and cultural contingencies) that can be exploited to identify instances of animal trade (i.e. cattle consuming C_3 plant in the C_4 dominated environment of a sugar cane plantation in the case of Klippel [2001] and pigs consuming significant amounts of terrestrial derived protein in the context of a cod fishery in the case of Guiry [et al 2012b]).

It is important to point out that there is a large body of isotope study focusing on domestic and wild fauna remains in other geographical and temporal contexts which may provide inspiration for isotope based research in North American historical contexts. For instance, stable carbon, nitrogen, and sulfur isotope analyses of cod bone collagen has been used to reconstruct the expansion of the historical European salt fish trade in the North Atlantic (Barrett et al. 2008, 2011, Orton et al 2011; Nehlich et al. 2013). Stable carbon and oxygen isotope analyses of tooth enamel apatite can be used to assess seasonality of birth and slaughter of livestock (e.g. Balasse et al. 2003; Frémondeau et al. 2012; Towers et al. 2011). Stable nitrogen isotope analyses on serial sections of tooth dentine collagen can be used to identify livestock weaning ages (e.g. Balasse and Tesset 2002). In some cases, stable nitrogen isotope analyses of modern and archaeological plants can be used to identify historical field manuring and fertilizing patterns (Bogaard et al. 2007; Commisso and Nelson 2006, 2007, 2008, 2010; Kanstrup et al. 2011; Szpak et al. 2012). Additional applications, relying on the use of stable carbon, nitrogen, sulfur, oxygen, and radiogenic strontium isotope analyses include the identification of strategies for omnivore feeding (e.g. Arge et al 2009; Hamilton et al. 2009;

Hamilton and Thomas 2012; Rawlings and Driver 2010; Richards et al. 2009; West 2007:166-175), herbivore foddering (e.g. Fisher and Thomas 2012; Madgwick et al. 2012; Peck-Janssen 2006:63-65) and grazing (e.g. Balasse et al. 2006; Britton et al. 2008; Hoekman-Sites and Giblin 2012; Mulville et al 2009; Richards et al 2006), animal mobility (e.g. Millard et al. 2011; Pearson et al. 2007; Viner et al. 2010; Zhao et al. 2012), and animal management more generally (Finucane et al. 2006; Jones et al. 2012; Lightfoot et al. 2009; Nelson et al. 2012; Oelze et al. 2011).

Many of these studies reflect changing attitudes towards stable isotope based analyses of faunal remains. Most early stable isotope studies analyzed faunal remains as part of the standard practice of reconstructing the environmental baseline of a region in order to more accurately interpret associated human stable isotope data (e.g. Katzenberg 1989). In this context, many of these more recent studies (e.g. Mulville et al. 2009:51) stem from increasing recognition that stable isotope information from animals, and particularly from husbanded domesticates, is valuable in and of itself – a fact that may not have been fully realized in recent stable isotope based studies of North American historical archaeological contexts (e.g. Goodman et al. 2009; Owsley et al. 2006; Wescott et al. 2010).

5. Case Study

To further demonstrate the potential diversity of insights that can be gleaned from stable isotope work on historical faunal remains in northeast North America, we conducted a pilot study to reconstruct the dietary life history of a single pig husbanded at Ferryland. We analysed collagen extracted from serial dentine sections from the third and second molars from the left mandible of a pig (no. 2848) previously found (Guiry et al. 2012b:2016; MARC ID no. 312) to have had a relatively marine-oriented diet based on mandibular bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of -17.8 ‰ and 13.6 ‰, respectively. In particular, we were interested in exploring the feasibility of identifying changing feeding strategies among pig keepers at Ferryland. For instance, when were pigs weaned and what foods were they weaned onto? Was this individual fed fish throughout its entire life, or was fish used for pig feed only when it was most abundantly available during summers?

5.1 Historical Context

One of the earliest permanent English settlements in Newfoundland, the community of Ferryland (Figure 1) was founded in 1621 by Sir George Calvert (later, the first Lord Baltimore). It later served as the home of the island's first Governor, David Kirke and prospered until its destruction in the late 17th century. Unlike planters in other regions of colonial North America, Newfoundland planters did not own land and grow crops; they owned boats for fishing and could hire employees to work in this industry (Pope 2004). The settlement's main economic activity was the cod fishery, including the capture, cleaning and salting of the fish prior to export to burgeoning European markets (Gaulton and Tuck 2003; Tuck and Gaulton 2013).

The pig specimen analysed here was collected from a deposit associated with a cellar located within a stone walled building adjacent to the Mansion House, currently interpreted as its kitchen outbuilding (Barry Gaulton, personal communication, 2013). Archaeological excavations and historical documents indicate that the Mansion House complex was constructed by Ferryland's initial settlers sometime between 1623 and 1625. Historical documents make reference to the construction of a large kitchen structure upon the first year of settlement in Ferryland in 1621. The entire Mansion House complex, which is composed of multiple buildings and a courtyard, was destroyed during the French attack on Ferryland on September 21st, 1697, thus providing a solid *terminus ante quem* date for the deposit. The deposit includes a mix of materials from the cellar and the collapse of the cellar room on top of it. It measured more than eight feet in depth and there is no exact provenience associated with the pig mandible to indicate where it was found within this deposit. The dating of the deposit cannot be narrowed down more precisely than a 71 to 73 year time span.

Documentary and folklore information on pig husbandry in historical Newfoundland are detailed by Guiry and colleagues (2012b:2013-2014). A long tradition of feeding of fish offal to pigs raised at fisheries and fishing towns is attested to by 18th and 20th century accounts from travelers and fishermen. In concurrence with Tourigny's (2009:171-172) interpretation of the historical and archaeological data, these accounts also suggest that pigs were usually kept in pens near fishing stages to facilitate greater efficiency in pig feeding as well as to prevent foraging pigs from wreaking havoc upon fish salting and drying operations.

5.2 Specimen Background

Based on osteological analyses this individual is inferred to have been slaughtered at 18 to 20 months of age (Tourigny 2009:136), corresponding to the peak of its growth period.

Available information suggests residents of Ferryland may have found it difficult to produce quantities of fodder adequate for sustaining large herds overwinter. This is evidenced by historical letters, and census documents which indicate that large cattle herd sizes were never attained at Ferryland. This is also supported by zooarchaeological evidence indicating that the majority of cattle and pigs were slaughtered in the late fall/winter, at the peak of their growth periods (Hodgetts 2006; Tourigny 2009). Keeping with this pattern, we make the assumption that the individual represented by the specimen in question was slaughtered at a similar time of the year and therefore born sometime in the spring, 18-20 months earlier (it should be noted that, based on observations of modern improved pig breeds, a second annual birth could theoretically have been possible). For a review of the timing of pig tooth eruption as it pertains to the stable isotope analysis of pig dental tissues see Frémondeau and colleagues (2012:2026; also see Hillson 2005). Neither tooth exhibited any morphological abnormalities. The M2 was fully formed and in wear stage TWS=b (Grant 1982) (Figure 2). Pig second molars are known to begin formation during the first or second month of life (May or June of first year) and are completed during the seventh or eighth month (November of December of first year) (Hillson 2005: 234). The M3 was visible in the crypt (but below head of bone) and, having completed about half of its root growth, was not yet fully formed. Third molars begin forming in the third or fourth months of life (July or August of first year) and are highly variable in their times of completion, usually finishing formation between the twelfth and eighteenth month of life (Hillson 2005: 234; Frémondeau et al. 2012:2026). For this particular individual, the latter appears to have been the case and, in this context, the dentine collagen from the much slower growing M3 should provide a coarser record for dietary intake during the individual's latter life right up until slaughter.

It is important to note that the particular pig specimen analyzed here does not exhibit evidence of roasting or charring. While heating events such as boiling cannot be excluded entirely, the stable isotopic composition of this specimen is not expected to have undergone the pronounced alterations that can accompany prolonged cooking with intense heat (DeNiro et al. 1985).

5.3 Methods

Collagen extraction procedures differed only slightly from those previously published (e.g. Ballasse et al. 2002; Eerkens et al. 2011; Fuller et al. 2003). Pig second and third lower molars from a single individual were cut in half along their growth axis following a buccal-labial transect using a diamond surfaced dental cut wheel. One half of each was set aside for posterity. Removal of the enamel portion of pig molars was not possible due to the highly irregular surface of the crown. Halved molars were sectioned perpendicular to the growth axis of the tooth at two to three mm intervals. The M2 and M3 produced 13 and 6 samples, respectively. Collagen was extracted from each dentine section using established methods as described by Richards and Hedges (1999) and modified as seen in research by Honch et al. (2006) and Müldner et al. (2011). Sections were placed in 0.5M hydrochloric acid until adhering enamel and dentine apatite was demineralized. Collagen pseudomorphs were then gelatinized in water adjusted to a pH of 3 on a heating block set to 70ºC for 48 hours. Gelatins were then purified using 5μm Ezee® filters, frozen for 24 hours, and lyophilized for 48 hours. Isotopic ratios were measured in the Max Plank Institute, Department of Human Evolution using an elemental analyzer coupled to a Thermo Delta V continuous flow isotope-ratio mass spectrometer. Replicate measurement errors for a known standard (methionine, *n*=6) were below ±0.1 ‰ for both $\delta^{13}C$ and $\delta^{15}N$. Collagen integrity was assessed using percent carbon and nitrogen concentrations as well as carbon to nitrogen ratios (C:N). All dentine collagen samples produced viable carbon and nitrogen concentrations above 18% and 6%, respectively, and C:N values between 2.9 and 3.6 (Ambrose 1990; DeNiro, 1985; Van Klinken, 1999). Collagen yields were not obtained but based on a yield of 13.7% from a bone sample from the associated mandible (Guiry et al. 2012b:2016; MARC ID no. 312) we expect that collagen extractions from dentine would produce acceptable yields.

5.4 Results and Discussion

Stable carbon and nitrogen isotope data are presented in Table 1 and Figures 3 and 4. Both teeth show a dietary shift with an overall range in $\delta^{13}C$ and $\delta^{15}N$ of ~3 ‰ and 5 ‰, respectively. M2 sections 1 and 2 (from the tooth crown) appear to reflect milk feeding from a sow with a predominantly terrestrial diet with minor contributions of marine derived foods. Decreasing $\delta^{15}N$ values in sections 3 and 4 of the same tooth are consistent with a shift from milk to predominantly terrestrial foods with a stable isotope composition like that of the sow from which the piglet was milk-fed. A sharp increase in $\delta^{15}N$, and to a lesser extent $\delta^{13}C$, values in M2 section 5, and continuing through section 13, indicate a relatively rapid and sustained dietary regime change to predominantly marine foods, probably cod offal. Consistent with what is known about the timing of growth of pig molars (Hillson 2005: 234), the latter M2 sections appear to match up with stable isotope data from earliest forming sections of the M3. The latter M3 sections, corresponding to the final year of the pig's life, track an increasing reliance on marine derived protein.

Assessment of these preliminary results provide some interesting insights into the husbandry of this particular pig as well as the sow that milk-fed it. To the resolution that two to three mm serial sections of dentine from these teeth can track relatively fine scale dietary shifts, we can see that during the time of milk feeding the sow maintained a predominantly terrestrial diet and the piglet was also weaned onto an isotopically similar diet. Though the dietary values attributed to the sow and milk-fed piglet's diets are relatively terrestrial in the contexts of other pigs raised at Ferryland, they still contain more marine derived dietary protein than would be expected from pigs or pork products imported to Ferryland based on Guiry's (et al. 2012b:2020) survey of available European pig stable isotope data. For this reason, while relatively terrestrial, the stable isotope values thought to reflect the sow's milk feeding are interpreted as deriving from an animal raised at Ferryland. This suggests that there may have been differential husbandry practices for pigs kept for breeding and those kept for meat at Ferryland. In this scenario, the data suggests that the piglet was kept under the same conditions until it developed enough to transfer into a secondary animal husbandry regime involving fattening on fish offal.

These pilot study findings on the dietary life history of a single pig, demonstrate how stable isotope analyses can open new questions to historical archaeologists. For instance, as the latter stage of fish consumption spans both summer and winter seasons, could it be that exploitation of marine resources occurred on a year round basis at Ferryland - to the extent that it could produce sufficient offal to keep growing pigs well-fed throughout the winter? Alternatively, albeit an olfactory quagmire, could it be that Ferryland residents stored enough fish offal from the summer fishery to feed pigs throughout the winter? How variable were pig husbandry practices among colonists who raised these animals? Did planters and other colonists of different social or economic status raise pigs differently? And, if so, were others raised with specific purposes in mind? Archaeological and historical documentation have already suggested that the number of pigs being raised at the colony was more than would be needed for self-sufficiency of permanent settlers (Hodgetts 2006: 129). In this scenario, had Ferryland become a local exporter or supplier of animal products for other fishing operations? Use of stable isotope analyses to understand the life histories of animals excavated at Ferryland and historical sites elsewhere in Newfoundland and the North Atlantic may be able to answer these and a diversity of other questions about historical lifeways.

Ongoing stable isotope research on the pig remains of Ferryland is seeking to address these questions. Future efforts will mainly be focused on the $\delta^{13}C$ and $\delta^{15}N$ analyses of dentine collagen from pig teeth. In particular, as recommended by Delphine Frémondeau (personal communication 2013), we are assessing the possibility of analyzing the collagen of serial dentine sections from the ever-growing canines of male pigs which, despite their sex specific origins, can provide a longer and more uniform record of pig diet.

6. Conclusion

Faunal remains from historical contexts in North America represent a vast and largely untapped resource for the mutual advancement of stable isotope applications and understandings of historical human-animal interactions at a critical time when such relations began to take on novel forms (e.g. long distance trade of meat products and the standardization and industrialization of animal husbandry practices). In recent years, isotopic analyses have become more wide-spread and inexpensive, making the technique accessible and affordable for smaller archaeological projects with well-formulated research questions. While there are two studies that have taken such work as their focus, there exists a rapidly growing stable isotope literature on human-animal relations from other regions of the world that demonstrates the productivity of zooarchaeological bone chemistry and which might be looked to for inspiration (see Section 4).

To demonstrate the relative ease with which stable isotope work can be used to complement and engage with other lines of archaeological inquiry, we have provided a preliminary case study that documents otherwise unavailable high resolution evidence for animal husbandry at the historical site of Ferryland.

In closing, we would like to offer a few practical suggestions about how historical zooarchaeologists and stable isotope analysts can integrate their efforts. In our experience, a key way to accomplish this is to build stable isotope analyses into the research design of zooarchaeological projects and historical excavations. For instance, excavators and faunal analysts alike could remain cognizant of the stable isotope analysts' focus on practical aspects of minimum number of individuals (MNI) counts. By analyzing specimens used to construct MNI counts, stable isotope analysts are able to ensure that they are not producing overlapping data. From the excavator's point of view, this means collecting and documenting faunal materials in a way that minimizes the loss of any contextual associations. From the faunal analyst's perspective, it is important that MNI counts be based on as many lines of reasoning as possible, not just by context, element, siding, age, and sex but also, where possible, by other morphological indicators such as pathology, wear patterns, and congenital abnormalities. Another factor germane to sample selection for stable isotope analysis is the special attention that can be given to skeletal elements that bear teeth. As considered in Section 5, due to their differing tissue compositions and developmental histories, teeth and associated bone can have a valuable capacity to answer diachronic questions about the life histories of animals that open up the possibility of a range of additional questions.

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List of Figure Captions

Figure 1. Map detailing study area.

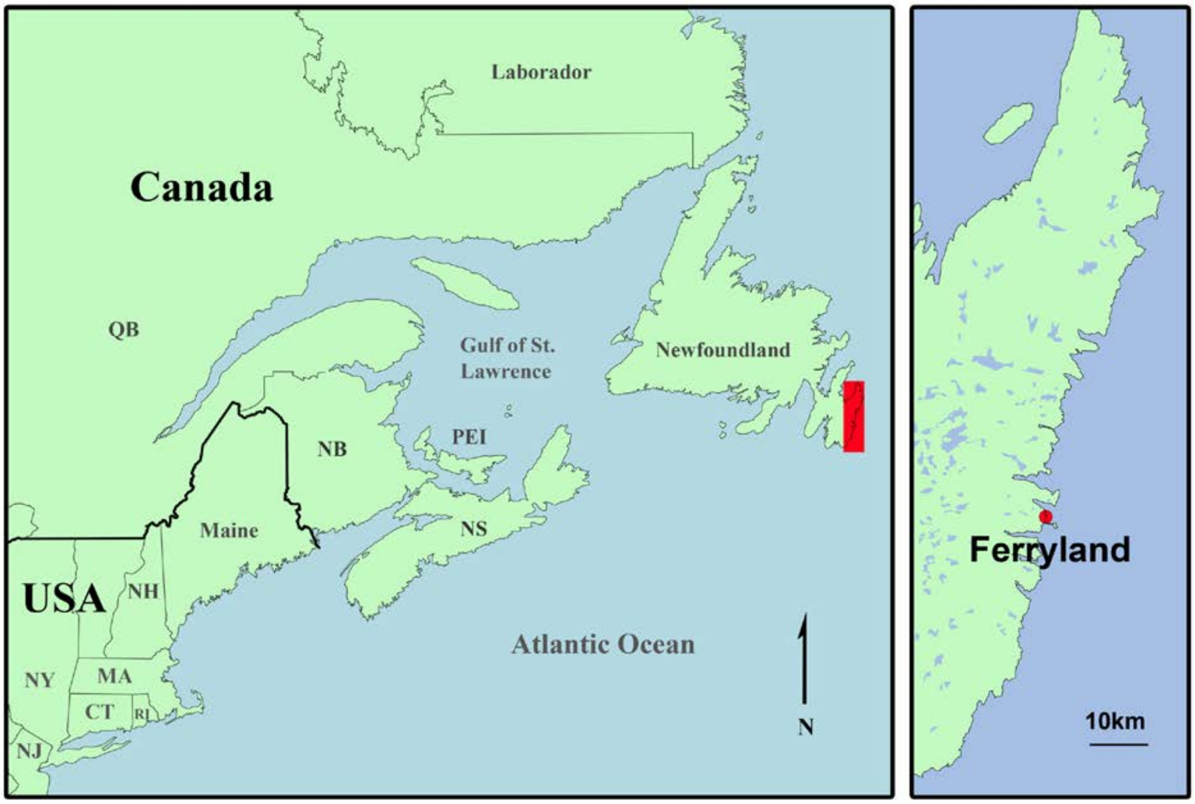


Figure 2. Image of Ferryland pig mandible specimen 2848 showing complete eruption of M2 (in wear) and M3 visible in crypt.

Figure 3. Stable carbon and nitrogen isotope data from serial sections of M2 tooth dentine. Age increases from left to right.

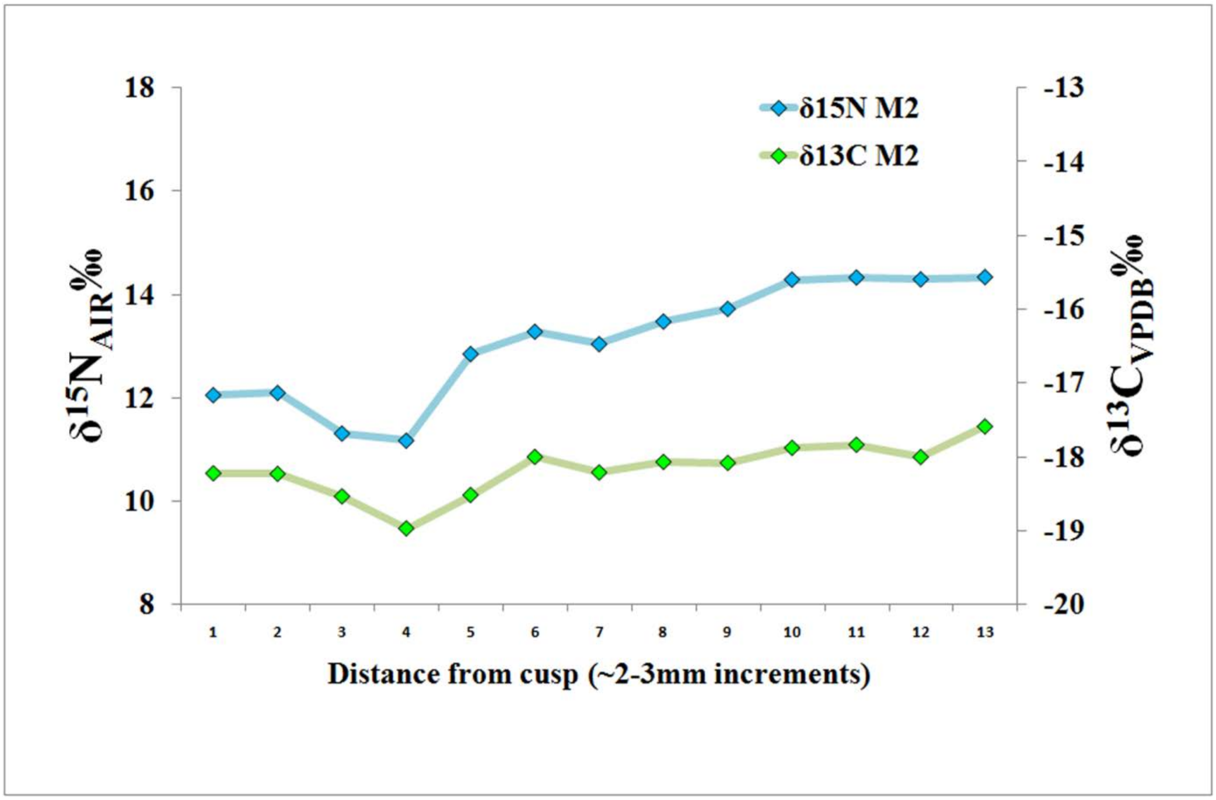
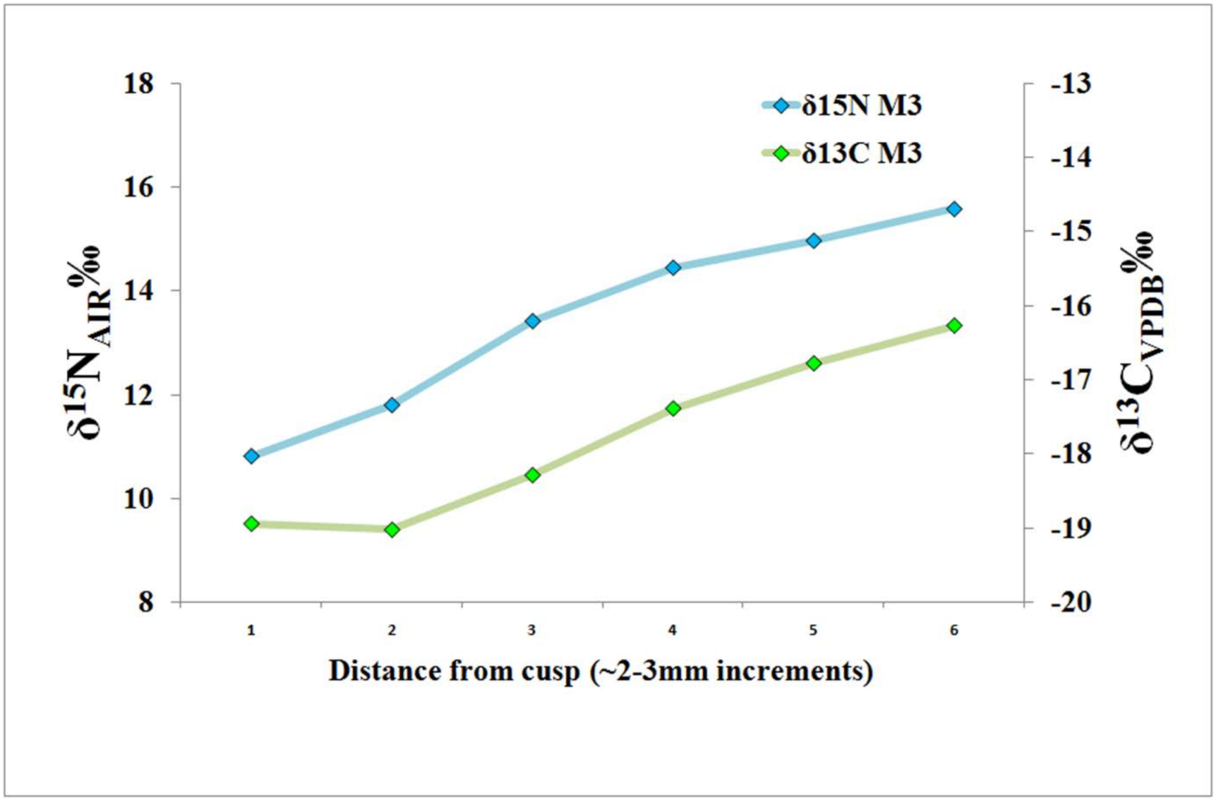


Figure 4. Stable carbon and nitrogen isotope data from serial sections of M3 tooth dentine. Age increases from left to right.



Tables

Table 1. Stable carbon and nitrogen isotope and associated dentine collagen integrity data from Ferryland pig mandible (no. 2848) M2 and M3. Analyses of collagen from associated manibular bone showed $\delta^{13}C$ and $\delta^{15}N$ values of -17.8‰ and 13.6‰, respectively (C:N = 3.3; C% = 42.7, N% = 15.1; % collagen yield = 13.7).

Lab No.	Tooth	Section	$\delta^{13}C_{VPDB}$‰	$\delta^{15}N_{AIR}$‰	C %	N %	C:N
S-UBC-775	M2	1 Crown	-18.2	12.1	42.9	15.7	3.2
S-UBC-775	M2	2	-18.2	12.1	42.6	15.6	3.2
S-UBC-774	M2	3	-18.5	11.3	42.9	15.8	3.2
S-UBC-773	M2	4	-19.0	11.2	44.3	16.4	3.1
S-UBC-772	M2	5	-18.5	12.9	44.1	16.4	3.1
S-UBC-771	M2	6	-18.0	13.3	43.7	16.3	3.1
S-UBC-770	M2	7	-18.2	13.0	43.5	16.2	3.1
S-UBC-769	M2	8	-18.1	13.5	44.0	16.2	3.2
S-UBC-768	M2	9	-18.1	13.7	42.6	15.7	3.2
S-UBC-767	M2	10	-17.9	14.3	42.4	15.4	3.2
S-UBC-766	M2	11	-17.8	14.3	41.9	15.1	3.2
S-UBC-765	M2	12	-18.0	14.3	42.1	14.7	3.3
S-UBC-764	M2	13 Root tip	-17.6	14.3	39.1	13.9	3.3
S-UBC-781	M3	1 Crown	-18.9	10.8	41.9	15.3	3.2
S-UBC-780	M3	2	-19.0	11.8	43.7	16.1	3.2
S-UBC-779	M3	3	-18.3	13.4	45.1	16.7	3.2
S-UBC-778	M3	4	-17.4	14.4	44.1	16.2	3.2
S-UBC-777	M3	5	-16.8	15.0	44.2	16.1	3.2
S-UBC-776	M3	6 Root tip	-16.3	15.6	41.7	15.2	3.2

Bibliography

Ambrose, Stanley H

1990 Preparation and Characterization of Bone and Tooth Collagen for Isotopic Analysis. *Journal of Archaeological Science* 17:431-451.

Ambrose, Stanley H., and Michael J. DeNiro

1986 Reconstruction of African Human Diet Using Bone Collagen Carbon and Nitrogen Isotope Ratios. *Nature* 319: 321-324.

Ambrose, Stanley H., and Lynette Norr

1993 Experimental Evidence for the Relationship of the Carbon Isotope Ratios of Whole Diet and Dietary Protein to Those of Collagen and Carbonate. In *Prehistoric Bone: Archaeology at the Molecular Level*, ed. by Joseph B. Lambert and Gisela Grupe, 1-37. Springer-Verlag, Berlin.

Arge, Símun V., Mike J. Church, and Seth D. Brewington

2009 Pigs in the Faroe Islands: An Ancient Facet of the Islands' Paleoeconomy. *Journal of the North Atlantic* 2: 19-39.

Bain, Allison, and Marie-Annick Prévost

2010 Environmental archaeology and landscape transformation at the seventeenth-century Ferryland site, Newfoundland. Historical Archaeology 44(3):21-35

Balasse, Marie, Loïc Boury, Joël Ughetto-Monfrin, and Anne Tresset

2012 Stable Isotope Insights (d18O, d13C) Into Cattle and Sheep Husbandry at Bercy (Paris, France, 4th Millennium BC): Birth Seasonality and Winter Leaf Foddering. *Environmental Archaeology* 17: 29-44.

Balasse, Marie, Andrew B. Smith, Stanley H. Ambrose, and Steven R. Leigh

2003 Determining Sheep Birth Seasonality by Analysis of Tooth Enamel Oxygen Isotope Ratios: The Late Stone Age Site of Kasteelberd (South Africa). *Journal of Archaeological Science* 30: 205-215.

Balasse, Marie, and Anne Tresset

2002 Early Weaning of Neolithic Domestic Cattle (Bercy, France) Revealed by Intra-Tooth Variation in Nitrogen Isotope Ratios. *Journal of Archaeological Science* 29: 853-859.

Balasse, Marie, Anne Tresset, and Stanley H. Ambrose

2006 Stable Isotope Evidence ($\delta^{13}C$, $\delta^{18}O$) for Winter Feeding on Seaweed by Neolithic Sheep of Scotland. *Journal of Zoology* 270: 170-176.

Barrett, James H, Cluny Johnstone, Jenifer Harland, Wim Van Neer, Anton Ervynck, Daniel Makowiecki, Dirk Heinrich, Anne K. Hufthammer,Inge B. Enghoff, and others

2008 Detecting the medieval cod trade: a new method and first results. *Journal of Archaeological Science* 35:850-861.

Barrett, James H, David Orton, Cluny Johnstone, Jennifer Harland, Wim Van Neer, Anton Ervynck, Callum Roberts, Alison Locker, Colin Amundsen C, Inge B. Enghoff, and others.

2011 Interpreting the expansion of sea fishing in medieval Europe using stable isotope analysis of archaeological cod bones. *Journal of Archaeological Science* 38:1516-1524.

Bogaard, Amy, Tim H.E. Heaton, Paul Poulton, and Ines Merbach

2007 The Impact of Manuring on Nitrogen Isotope Ratios in Cereals: Archaeological Implications for Reconstruction of Diet and Crop Management Practices. *Journal of Archaeological Science* 34: 335-343.

Britton, Kate., Gundula Müldner, and Martin Bell
2008 Stable Isotope Evidence for Salt-Marsh Grazing in the Bronze Age Severn Estuary, UK: Implications for Palaeodietary Analysis at Coastal Sites. *Journal of Archaeological Science* 35: 2111-2118.

Buckley, Mike, Sarah, W. Kansa, Sarah Howard, Stuart Campbell, Jane Thomas-Oates, and Mathew Colins
2010 Distinguishing between archaeological sheep and goat bones using a single collagen . peptide. *Journal Archaeological Science* 37:13-20

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

Commisso, Rob E. and D. Erle Nelson
2006 Modern Plant δ^{15}N Values Reflect Ancient Human Activity. *Journal of Archaeological Science* 33: 1167-1176.

Carter, Cindy, P., Ashley Seidell, Donald P. Craig, D. Edmond Boudreaux, Krista L. Burleigh, Jason L. Gardner, Stacey A. Young, and Marie E. Danforth
2004 A bioarchaeological analysis of the French Colonial burials at the Moran Gallery, Biloxi, MS. *Mississippi Archaeology* 39: 39-68.

Commisso, Rob E. and D. Erle Nelson
2007 Patterns of Plant δ^{15}N Values on a Greenland Norse farm. *Journal of Archaeological Science* 34: 440-450.

Commisso, Rob E. and D. Erle Nelson
2008 Correlation Between Modern Plant δ^{15}N Values and Activity Areas of Medieval Norse Farms. *Journal of Archaeological Science* 35: 492-504.

Commisso, Rob E. and D. Erle Nelson
2010 Stable Nitrogen Isotopic Examination of Norse Sites in the Western Settlement of Greenland. *Journal of Archaeological Science* 37: 1322-1240.

DeNiro, Michael J.
1985 Postmortem Preservation and Alteration of In Vivo Bone Collagen Isotope Ratios in Relation to Paleodietary Reconstructions. *Nature* 317: 806-809.

DeNiro, Michael J., Margaret .J. Schoeninger, and Christine A. Hastorf
1985 Effects of heating on the stable carbon and nitrogen isotope ratios of bone collagen. *Journal of Archaeological Science* 12:1-7.

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(11): 3101-3111.

Ellerbrok, Brittany A., Vaughan Grimes, and Joseph. Parish
2012 Reconstruction of Diet and Demography of Human Remains From an Eighteenth-Century Mass Burial Site at the Fortress of Louisbourg, Nova Scotia. Paper presented at the 2012 Council for Northeast Historical Archaeology, St. John’s, NL, Canada, 4-7 October.

English, Anthony J.
1990 Salted Meats From the Wreck of the William Salthouse: Archaeological Analysis of Nineteenth Century Butchering Patterns. *Australian Journal of Historical Archaeology* 8: 63-69.

Finucane, Brian, Patricia M. Agurto, and William H. Isbell
2006 Human and Animal Diet at Conchopata, Peru: Stable Isotope Evidence for Maize Agriculture and Animal Management Practices During the Middle Horizon. *Journal of Archaeological Science* 33: 1766-1776.

Fisher, Abigail, and Richard Thomas
2012 Isotopic and Zooarchaeological Investigation of Later Medieval and Post-Medieval Cattle Husbandry at Dudley Castle, West Midlands. *Environmental Archaeology* 17: 151-167.

Frémondeau, Delphine, Thomas Cucchi, François Casabianca, Joël Ughetto-Monfrin, Marie-Pierre Horard-Herbin, and Marie Balasse
2012 Seasonality of Birth and Diet of Pigs From Stable Isotope Analyses of Tooth Enamel (δ18O, δ 13C): A Modern Reference Data Set from Corsica, France. *Journal of Archaeological Science* 39: 2023-2035.

Fuller, Ben T., Michael P. Richards, and Simon A. Mays.
2003 Stable Carbon and Nitrogen Isotope Variations in Tooth Dentine Serial Sections From Wharram Percy. *Journal of Archaeological Science* 30(12): 1673-1684

Gaulton, Barry, and James A. Tuck
2003 The Archaeology of Ferryland, Newfoundland Until 1696. *Avalon Chronicles* 8 :187-224.

Goodman, Alan H., Jenifer Jones, John Reid, Mark E. Mack, Michael L. Blakey, Dulasiri Amarasiriwardena, Portia Burton, and David Coleman
2009 Isotopic and Elemental Chemistry of Teeth: Implications for Places of Birth, Forced Migration Patterns, Nutritional Status, and Pollution. In *Skeletal Biology of the New York African Burial Ground*, ed. by Michael L. Blakey and Lesley M. Rankin-Hill, 95–118. The New York African Burial Ground: Unearthing the African Presence in Colonial New York, Volume 1, Part 1. Howard University, Washington, D.C.

Grimes, Vaughan
2013 The Basque of "Butus': Life at a 16th Century Whaling Enterprise in the New World. Paper presented at the 2013 UK Archaeological Science Conference, Cardiff, April 11-14th.

Grant, Annie
1982 The Use of Tooth Wear as a Guide to the Age of Domestic Animals. In *Ageing and Sexing Animal Bones from Archaeological Sites*, ed. by Bob Wilson, Caroline Grigson and Sebastian Payne, 91-108. British Archaeological Reports, British Series 109. BAR, Oxford.

Guiry, Eric J.
2012 Dog as Analogs in Human Stable Isotope Based Paleodietary Reconstructions: A Review and Consideration for Future Use. *Journal of Archaeological Method and Theory* 19: 351-376.

Guiry, Eric J., Vaughan Grimes, Colin Smith, Stéphane Noël, and Eric Tourigny
2012a Integrating Bone chemistry and Faunal Analyses in Historical Archaeology: A Review and Case Study from Newfoundland. Paper presented at the 2012 Council for Northeast Historical Archaeology, St. John's, NL, Canada, 4-7 October.

Guiry, Eric J., Stéphane Noël, Eric Tourigny, and Vaughan Grimes
2012b A Stable Isotope Method for Identifying Transatlantic Origin of Pig (*Sus scrofa*)

Remains at French and English Fishing Stations in Newfoundland. *Journal of Archaeological Science* 39: 2012-2022.

Hamilton, Julie, and Richard Thomas
2012 Pannage, Pulses and Pigs: Isotopic and Zooarchaeological Evidence for Changing Pig Management Practices in Later Medieval England. *Medieval Archaeology* 56: 234-258.

Hamilton, Julie, Robert E.M. Hedges, and Mark Robinson
2009 Rooting for Pig Fruit: Pig Feeding in the Neolithic and Iron Age Britain Compared. *Antiquity* 83: 998-1011.

Heaton, Tim H.E., and John C. Vogel
1986 Climatic Influences on the Isotopic Composition of Bone Nitrogen. *Nature* 322: 822-823.

Hedges, Robert E.M., and Linda M. Reynard
2007 Nitrogen Isotopes and the Trophic Level of Humans in Archaeology. *Journal of Archaeological Science* 34: 1240-1251.

Hillson, Simon
2005 *Teeth* (Second Edition). Cambridge Manuals in Archaeology. Cambridge University Press, Cambridge, UK.

Hoekman-Sites, Hanneke, A. and Julia I. Giblin
2012 Prehistoric Animal Use on the Great Hungarian Plain: A Synthesis of Isotope and Residue Analyses from the Neolithic and Copper Age. *Journal of Anthropological Archaeology* 31: 515-527.

Hodgetts, Lisa M.
2006 Feast or Famine? Seventeenth-Century English Colonial Diet at Ferryland, Newfoundland. *Historical Archaeology* 40(4): 125-138.

Honch, Noah V., Tom F.G. Higham., John Chapman, Bisserka Gaydarska, and Robert E.M. Hedges
2006 A Paleodietary Investigation of Carbon (13C/12C) and Nitrogen (15N/14N) in Human and Faunal Bones from Copper Age Cemeteries of Varna I and Duankulak, Bulgaria. *Journal of Archaeological Science* 33: 1493-1504.

Jones, Jennifer R., Jacqui A. Mulville, Rona A.R. McGill, and Richard.P. Evershed
2012 Palaeoenvironmental Modelling of δ^{13}C and δ^{15}N Values in the North Atlantic Islands: Understanding Past Marine Resource Use. *Rapid Communication in Mass Spectrometry* 26: 2399-2406.

Katzenberg, M. Anne
1989 Stable Isotope Analysis of Archaeological Faunal Remains from Southern Ontario. *Journal of Archaeological Science* 16: 319-329.

Katzenberg, M. Anne
1991a Analysis of Stable Isotopes of Carbon and Nitrogen. In *Snake Hill: An Investigation of a Military Cemetery from the War of 1812,* ed. by Susan Pfeiffer and Ronald F. Williamson, 247-255. Dundurn Press, Toronto.

Katzenberg, M. Anne
1991b Stable Isotope Analysis of Remains From the Harvie Family. In *The Links that Bind: The Harvie Family Nineteenth Century Burying Ground*, ed. by Shelley R. Saunders and Richard A. Lazenby, 65-70. Occasional Papers in Northeast Archaeology No.5. Copetown Press, Dundas, ON.

Katzenberg, M. Anne
2008 Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In *Biological Anthropology of the Human Skeleton*, ed. by M. Anne Katzenberg and Shelley R. Saunders, 387-410. Wiley-Liss, New York.
Katzenberg, M.Anne, and Susan Pfeiffer
1995 Nitrogen Isotope Evidence for Weaning Age in a Nineteenth Century Canadian Skeletal Sample. In *Bodies of Evidence: Reconstructing History Through Skeletal Analyses*, ed. by Anne L. Grauer, 221-236. John Wiley and Sons, New York.
Katzenberg, M. Anne, and Shelley R. Saunders, and Sylvia Abinyi
2000 Bone Chemistry, Food, and History: A Case Study From 19th Century Upper Canada. *In Biogeochemical Approaches to Paleodietary Analysis*, ed. by Stanley H. Ambrose, 1-19. Kluwer Academic: New York.
Kanstrup, Marie, Ingrid K. Thomsen, Astrid J. Andersen, Amy Bogaard, and Bent T. Christensen
2011 Abundance of ^{13}C and ^{15}N in Emmer, Spelt and Naked Barley Grown on Differently Manured Soils: Towards a Method for Identifying Past Manuring Practice. *Rapid Communications in Mass Spectrometry* 25: 2879–2887.
Kefi, Rym
2011 Ancient DNA Investigations: A Review on Their Significance in Different Research Fields. *International Journal of Modern Anthropology* 4: 61-76.
Klippel, Walter E.
2001 Sugar Monoculture, Bovid Skeletal Part Frequencies, and Stable Carbon Isotopes: Interpreting Enslaved African Diet at Brimstone Hill, St Kitts, West Indies. *Journal of Archaeological Science* 28: 1191-1198.
Krigbaum, John, George Kamenov, Benjamin Valentine, and Gary Anderson.
2013 Multiple Isotope and Trace Element Proxies to Infer Life History of Mid-19th Century Human Skeletal Remains From New Haven, Connecticut. Paper presented at the 78th Annual Meeting of the Society for American Archaeology, Honolulu, April 3-7th.
Landon, David B.
2005 Zooarchaeology and Historical Archaeology: Progress and Prospects. *Journal of Archaeological Method and Theory* 12: 1-36.
Landon, David B.
2009 An Update on Zooarchaeology and Historical Archaeology: Progress and Prospects. In *International Handbook of Historical Archaeology*, ed. Teresa Majewski, and David Gaimster, 77-104. Springer, New York.
Lightfoot, Emma, Tamsin O'Connell, Rhiannon E. Stevens, Julie Hamilton, Gill Hey, and Robert E.M. Hedges
2009 An Investigation Into Diet at the Site of Yarnton, Oxfordshire, Using Stable Carbon and Nitrogen Isotopes. *Oxford Journal of Archaeology* 28: 301-322.
Lysaght, Averil M.
1971 *Joseph Banks in Newfoundland and Labrador, 1766. His Diary, Manuscripts and Collections*. University of California Press, Berkeley and Los Angeles.
Madgwick, Richard, Jacqui Mulville, and Rhiannon E. Stevens
2012 Diversity in Foddering Strategy and Herd Management in Late Bronze Age Britain: An Isotopic Investigation of Pigs and Other Fauna From Two Midden Sites. *Environmental Archaeology* 17: 126-140.

Makarewicz, Cheryl, and Noreen Tuross
2006 Foddering by Mongolian Pastoralists is Recorded in the Stable Carbon ($\delta^{13}C$) and Nitrogen ($\delta^{15}N$) Isotopes of Caprine Dentinal Collagen. *Journal of Archaeological Science* 33: 862-870.

Millard, Andrew R., Nayeli G. Jimenez-Cano, Ophelie Lebrasseur, and Yurika Sakai
2011 Isotopic Investigation of Animal Husbandry in the Welsh and English Periods at Dryslwyn Castle, Carmarthenshire, Wales. *International Journal of Osteoarchaeology* DOI: 10.1002/oa.1292.

Müldner, Guldela, Carolyn Chenery, Hella Eckardt
2011 The 'Headless Romans': Multi-Isotope Investigations of an Unusual Burial Ground from Roman Britain. *Journal of Archaeological Science* 38: 280-290.

Mulville, Jacqui., Richard Madgwick, Rhiannon Stevens, Tamsin O'Connell, Oliver Craig, Adrienne Powell, Niall Sharples, and Mike Parker Pearson
2009 Isotopic Analysis of Faunal Material From South Uist, Western Isles, Scotland. *Journal of the North Atlantic* 2: 51-59.

Nehlich, Olaf, James H. Barrett, Michael P. Richards
2013 Spatial variability in sulphur isotope values of archaeological and modern cod (*Gadus morhua*). *Rapid Communications in Mass Spectrometry* 27:2255-2262.

Nelson, D. Eele, Jan Heinemeier, Jeppe Møhl, and Jette Arneborg
2012 Isotopic Analyses of the Domestic Animals of Norse Greenland. *Journal of the North Atlantic* 3: 77-92.

Noël, Stéphane
2010 Fishermen's Foodways on the Petit Nord: Faunal Analysis of a Seasonal Fishing Station at the Dos de Cheval Site (EfAx-09), Newfoundland. M.A. Thesis, Memorial University, St John's, NL.

Oelze, Vicky M., Angelina Siebert, Nicole Nicklisch, Harald Meller, Veit Dresely, and Kurt W. Alt
2011 Early Neolithic Diet and Animal Husbandry: Stable Isotope Evidence From Three Linearbandkeramik (LBK) Sites in Central Germany. *Journal of Archaeological Science* 38: 270-279.

O'Leary, Marion, H.
1988 Carbon Isotopes in Photosynthesis. *Bioscience* 38:328-336.

Orton, David C, Daniel Makowiecki, Tessa de Roo, Cluny Johnstone, Jennifer Harland, Lief Jonsson, Dirk Heinrich, Inge B. Enghoff, Lembi Lõugas, Win Van Neer, and others
2011 Stable Isotope Evidence for Late Medieval (14th–15th C) Origins of the Eastern Baltic Cod (*Gadus morhua*) Fishery. *PLoS One* 6:e27568.

Owsley, Douglas W., Karin S. Bruwelheide, Larry W. Cartmell, Laurie E. Burgess, Shelly J. Foote, Skye M. Chang, and Nick Fielder
2006 The Man in the Iron Coffin: An Interdisciplinary Effort to Name the Past. *Historical Archaeology* 40: 89-108.

Page, Miranda D.
2007 Dietary Reconstruction Through Stable Isotope Analysis at the Moran French Colonial Cemetery on the Mississippi Gulf Coast. M.A. Thesis, University of Southern Mississippi, Hattiesburg.

Pearson, Jessica A., Hijlke Buitenhuis, Robert E.M. Hedges, Louise Martin, Nerissa Russell, and Katheryn C. Twiss

2007 New Light on Early Caprine Herding Strategies From Isotope Analysis: A Case Study From Neolithic Anatolia. *Journal of Archaeological Science* 34: 2170–2179.

Peck-Janssen, Shannon M.
2006 Animal Husbandry at Tell el Hesi (Israel): Results for Zooarchaeological and Isotopic Analysis. M.A. Thesis, University of South Florida, Tampa.

Pope, Peter E.
2004 *Fish into Wine*, *the Newfoundland Plantation in the Seventeenth Century*. University of North Carolina Press, Chapel Hill.

Price, T. Douglas James H. Burton, Andrea Cucina, Pillar Zabala, Robert Frei, Robert H. Tykot, and Vera Tiesler
2012 Isotopic Studies of Human Skeletal Remains from a Sixteenth to Seventeenth Century AD Churchyard in Campeche, Mexico: Diet, Place of Origin, and Age. *Current Anthropology* 54: 396-433.

Rawlings, Tiffany A., and Jonathan C. Driver
2010 Paleodiet of Domestic Turkey, Shields Pueblo (5MT3807), Colorado: Isotopic Analysis and its Implications for Care of a Household Domesticate. *Journal of Archaeological Science* 37: 2433-2441.

Raynor, Laura A., and Douglas J. Kennett
2008 Dietary Variability Among a Sample of United States Soldiers During the War of 1812. *Historical Archaeology* 42: 76-87.

Reitz, Elizabeth J., and Elizabeth S. Wing
2008 *Zooarchaeology*. 2nd Ed. Cambridge University Press, Cambridge.

Richards, Michael P., Ben T. Fuller, and Theya I. Molleson
2006 Stable Isotope Palaeodietary Study of Humans and Fauna From the Multi-Period (Iron Age, Viking and Late Medieval) Site of Newark Bay, Orkney. *Journal of Archaeological Science* 33: 122-131.

Richards, Michael P., Robert E.M. Hedges
1999 Stable Isotope Evidence for Similarities in the Types of Marine Foods Used by Late Mesolithic Humans at Sites Along the Atlantic Coast of Europe. *Journal of Archaeological Science* 26: 717-722.

Richards, Michael P., Eric W. West, Barry Rolett, and Keith Dobney
2009 Isotopic Analysis of Human and Animal Diets From the Hanamiai Archaeological Site (French Polynesia). *Archaeology in Oceania* 44: 29-37.

Rixson, Derrick
2000 *The History of Meat Trading*, Nottingham University Press, Nottingham.

Schoeninger, Margaret .J., Michael J. DeNiro, and Henrik Tauber
1983 Stable Nitrogen Isotope Ratios Reflect Marine and Terrestrial Components of Prehistoric Human Diet. *Science* 220: 1381-1383.

Schroeder, Hannes, Tamsin C. O'Connell, Jane A. Evans, Kristina A. Shuler, and Robert E.M. Hedges
2009 Trans-Atlantic Slavery: Isotopic Evidence for Forced Migration to Barbados. *American Journal of Physical Anthropology* 139: 547-557.

Schurr, Mark R.
1998 Using Stable Nitrogen-Isotopes to Study Weaning Behavior in Past Populations. *World Archaeology* 30: 327-342.

Sparks, Hillary, Tamara L. Varney, Patrice Courtaud, Thomas Romon, and David Watters

2012 Reconstructing the Diet of the Enslaved From Two Archaeological Sites (Guadeloupe and Montserrat). *Caribbean Connections* 2(1).

Sportman, Sarah, Craig Cipolla, David Landon
2007 Zooarchaeological Evidence for Animal Husbandry and Foodways at Sylvester Manor. *Northeast Historical Archaeology* 36: 127-142.

Szpak Paul, Jean-François Millaire, Christine D. White, and Fred J. Longstaffe
2012 Influence of Seabird Guano and Camelid Dung Fertilization on the Nitrogen Isotopic Composition of Field-Grown Maize (*Zea mays*). *Journal of Archaeological Science* 39:3721-3740.

Staniforth, Mark
2000 Wreck of the William Salthouse, 1841: Early Trade Between Canada and Australia. *Urban History Review* 18: 19-32.

Tieszen, Larry, and Tim Fagre
1993 Effect of Diet Quality and Composition on the Isotopic Composition of Respired CO_2, Collagen, Bioapatite and Soft Tissues. In *Prehistoric Bone: Archaeology at the Molecular Level*, ed. by Joseph B. Lambert and Gisela Grupe, 121-155. Springer-Verlag, Berlin.

Tourigny, Eric
2009 What Ladies and Gentlemen Ate for Dinner: The Analysis of Faunal Materials Recovered From a Seventeenth Century High Status Household at Ferryland, Newfoundland. M.A. Thesis, Memorial University, St John's, NL.

Towers, Jacqueline, Mandy Jay, Ingrid Mainland, Olaf Nehlich, and Janet Montgomery
2011 A Calf for All Seasons? The Potential of Stable Isotope Analysis to Investigate Prehistoric Husbandry Practices. *Journal of Archaeological Science* 38: 1858-1868.

Tuck, James A., and Barry Gaulton
2013 Lord Baltimore's Mansion: The evolution of a 17^{th}-century manor. *In A Glorious Empire: Archaeology and the Tudor-Stuart Atlantic World*, ed. by Eric Klingelhofer, 41-52. Oxbow, Oxford.

Ubelaker, Douglas H., and Douglas W. Owsley
2003 Isotopic Evidence for Diet in the Seventeenth-Century Colonial Chesapeake. *American Antiquity* 68: 129-139.

Vanderklift, Matthew A., and Sergin Ponsard
2003 Sources of Variation in Consumer-Diet $\delta^{15}N$ Enrichment: A Meta-Analysis. *Oecologia* 136: 169-182.

Van der Merwe, Nikolaas J., and Johann C. Vogel
1978 ^{13}C Content and Human Bone Collagen as a Measure of Prehistoric Diet in Woodland North America. *Nature* 276: 815- 816.

Vanderpool, Emily
2011 Bioarchaeological Investigations of Community and Identity at the Avondale Burial Place (McArthur Cemetery), Bibb County, Georgia. M.A. Thesis, Georgia State University, Atlanta.

Van Klinken, Gert J.
1999 Bone Collagen Quality Indicators for Paleodietary and Radiocarbon Measurements. *Journal of Archaeological Science* 26: 687-695.

Varney, Tamara L.
2003 Reconstructing Diet and Tracing Life Histories in Colonial Populations of the Northeastern Caribbean Using Stable Carbon and Nitrogen Isotopes. Ph.D. Dissertation, University of Calgary, Calgary.

Viner, Sarah, Jane Evans, Umberto Albarella, and Mike Parker Pearson
2010 Cattle Mobility in Prehistoric Britain: Strontium Isotope Analysis of Cattle Teeth From Durrington Walls (Wiltshire, Britain). *Journal of Archaeological Science* 37: 2812-2820.

Wescott, Daniel J., Kelly Brinsko, Marina Faerman, Stephanie D. Golda, Jeff Nichols, Mark Spigelman, Bob Stewart, Margaret Streeter, Robert H. Tykot, and Ljuba Zamstein
2010 A Fisk Patent Metallic Burial Case From Western Missouri: An Interdisciplinary and Comprehensive Effort to Reconstruct the History of an Early Settler of Lexington, Missouri. *Archaeological and Anthropological Science* 2: 283-303.

West, Eric W.
2007 An Archaeological Investigation of Pig Husbandry on Tahuata Island, Marquesas, French Polynesia. Ph.D. Dissertation, University of Hawaii, Manoa.

White, Christine D.
2004 Stable Isotopes and the Human-Animal Interface in Maya Biosocial and Environmental Systems. *Archaeofauna* 13: 183-198.

Wiseman, Julian
2000 *The Pig: A British History*. Duckbacks, London.

Zhao ChunYan, Jie Yang, J. Jing Yuan, ZhiPeng Li, Hong Xu, HaiTao Zhao, and GuoLiang Chen
2012 Strontium Isotope Analysis of Archaeological Fauna at the Erlitou Site. *Science China Earth Science* 55: 1255-1259.