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Eric J. Guiry

Stéphane Noël

Eric Tourigny

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

Eric J. Guiry, Stéphane Noël, and Eric Tourigny

Stable isotope–based paleodietary work is ideally suited for answering questions about a wide variety of human/animal relationships in historical archaeological contexts in northeastern North America and farther 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.

La reconstitution de l'alimentation passée grâce aux études isotopiques est plus qu'appropriée pour répondre à une variété de questions sur les relations homme-animal en archéologie historique dans le Nord-est américain, ainsi qu'ailleurs dans le monde. À ce jour, très peu d'études publiées se sont penchées sur l'élevage et le commerce des animaux d'un point de vue isotopique. Nous recommandons de porter une attention particulière sur les possibilités qu'offrent les isotopes stables en : 1) expliquant pourquoi la technique est bien adaptée pour répondre à des problèmes concernant les relations homme-animal rencontrés par les archéologues historiques, 2) présentant une revue de la littérature des travaux utilisant les isotopes stables pour mieux comprendre les relations homme-animal en contexte historique nord-américain, et 3) offrant une brève étude de cas sur l'historique de la diète d'un porc découvert sur le site archéologique de Ferryland, Terre-Neuve, Canada, basée sur les données d'isotopes de carbone et d'azote provenant du collagène prélevé en série sur les dents de l'animal.

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, Grimes, and Parish (2012), Goodman et al. (2004), Grimes (2013), Katzenberg (1991a, 1991b), Katzenberg, Saunders, and Abinyi (2000), Katzenberg and Pfeiffer (1995), Krigbaum et al. (2013), Owsley et al. (2006), Page (2007), Price et al. (2012), Raynor and Kennett (2008), Schroeder et al. (2009), Sparks et al. (2012), Ubelaker and Owsley (2003), Vanderpool (2011), Varney (2003), and 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 interactions between humans and animals in the past, e.g., Guiry (2012) and 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 lifeways 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 postmedieval 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 17th-century English site of Ferryland (CgAf-2), Newfoundland, Canada, demonstrating some of the potential information that can be gleaned from relatively simple

analyses of historical faunal remains. This case study focuses on a new suite of pilot data—see Guiry et al. (2012b) for previous work—from the serially sectioned tooth dentine collagen of a pig to reconstruct the dietary life history of an individual animal.

Stable-Isotope Theory and Methods

The stable-isotope composition of archaeologically preserved biological tissues (i.e., bone, teeth, and hair) can record the dietary history of the humans or animals to which they belonged 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 a 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 [$\delta^{13}\text{C}$]) from bone and tooth dentine collagen, the analytes in this study, are useful for distinguishing between diets based on C_3 vs. C_4 plants, which are isotopically lighter and heavier, respectively (Van der Merwe and Vogel 1978; O'Leary 1988). 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 $\delta^{13}\text{C}$ data, with the former producing values $\sim 7\text{‰}$ (‰ , or per-mil, refers to parts per thousand) heavier than the latter (Chisholm, Nelson, and Schwarcz 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 $\delta^{13}\text{C}$ 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, $\delta^{13}\text{C}$ values for terrestrial and marine diets at the site are expected to be around $-21.2\pm 1.0\text{‰}$ and $-15.6\pm 0.9\text{‰}$, respectively (Guiry et al. 2012b: 2,018–2,019).

Stable nitrogen-isotope values (^{14}N to ^{15}N [$\delta^{15}\text{N}$]) become elevated by 3 to 5‰ at each

step ascending a food chain (Ambrose and DeNiro 1986), for a 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 [Schurr 1998]). Finally, as freshwater and, particularly, marine ecosystems can have greatly extended food chains, $\delta^{15}\text{N}$ 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, $\delta^{15}\text{N}$ values for terrestrial and marine diets at the site are expected to be around $6.3\pm 1.2\text{‰}$ and $16.3\pm 1.8\text{‰}$, respectively (Guiry et al. 2012b: 2,018–2,019). While terrestrial-feeding omnivores or carnivores from Ferryland have not yet been analyzed, it is reasonable to assume that a pig at Ferryland raised on a purely terrestrial diet would have a $\delta^{15}\text{N}$ value elevated by up to 3 to 5‰ over terrestrial herbivores.

Bone and tooth dentine collagen preserves dietary signatures reflecting the nature and timing of incorporation of dietary constituents used in their construction. As a protein, collagen stable-isotope values disproportionately 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 generally grows 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 (Ballasse et al. 2012; Fuller, Richards, and Mays 2003; Eerkens, Berget, and Bartelink 2011). 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.

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 nondietary 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—compare Reitz and Wing (2008). The integration of techniques from the archaeological sciences, such as analyses of ancient DNA and other biomolecular approaches, have significantly widened the breadth and scope of questions that can be addressed through the analyses of archaeological faunal records (Buckley et al. 2010; Kefi 2011)—see also the next section.

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 the next section). For this reason, the accumulated faunal collections from historical sites in North America represent an unrealized wealth of potential information 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 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 foodstuffs, 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, Cipolla, and Landon (2007), and 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 interpopulation 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, Saunders, and Abinyi 2000: 2). For instance, the highly specific information about the transport of meat products (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, among northeast North America, the Caribbean, and Europe

carried animals and animal products farther from their place of origin than ever before (Pope 2004). The rise of industrial activities such as distilling, brewing, and fishing produced copious edible waste products encouraging inexpensive large-scale livestock husbandry (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 (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.

Previous Research

Given the potential for both the 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 barrelled and salted form. He found $\delta^{13}\text{C}$ 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 $\delta^{13}\text{C}$ values, Klippel argued, 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 U.S. Based on this distinction, a variety

of insights were gained: it suggested that land use for sugar production was so intense that landowners 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 its meat products from American sources. It should also be noted that Varney (2003: 189–196) provided an excellent and complementary analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of a small group of faunal remains from three sites in Antigua.

Another study by Guiry and colleagues 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 (Guiry et al. 2012b). 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 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Meanwhile, pigs raised in Europe probably would have had diets focusing on terrestrial foods and therefore would have lower isotope values. Results from Ferryland show that over half 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 fishery sites in the area. Furthermore, in addition to providing further counterevidence to the assumption that skeletal elements would not have been included in barrelled salt meat (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 vs. locally raised pork products among different parts of the Ferryland community.

A common thread binds much of this previous research. Each of these studies (Klippel 2001; Guiry et al. 2012b) has been aimed at identifying the presence of a 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 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 plants in the C_4 -dominated environment of a sugarcane 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]).

Importantly, a large body of isotope studies focusing on domestic and wild fauna remains in other geographical and temporal contexts provides inspiration for isotope-based research in North American historical contexts. For instance, stable carbon-, nitrogen-, and sulfur-isotope analyses of cod bone collagen have 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, Barrett, and Richards 2013). Stable carbon- and oxygen-isotope analyses of tooth enamel apatite can be used to assess seasonality of birth and slaughter of livestock (Balasse et al. 2003; Towers et al. 2011; Frémondeau et al. 2012). Stable nitrogen-

isotope analyses on serial sections of tooth dentine collagen can be used to identify livestock weaning ages (Balasse and Tessel 2002). In some cases, stable nitrogen-isotope analyses of modern and archaeological plants can be used to identify historical field manuring and fertilizing patterns (Commisso and Nelson 2006, 2007, 2008, 2010; Bogaard et al. 2007; 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 (West 2007: 166–175; Arge, Church, and Brewington 2009; Hamilton, Hedges, and Robinson 2009; Richards et al. 2009; Rawlings and Driver 2010; Hamilton and Thomas 2012), herbivore foddering (Peck-Janssen 2006: 63–65; Fisher and Thomas 2012; Madgwick, Mulville, and Stevens 2012) and grazing (Balasse, Tresset, and Ambrose 2006; Richards, Fuller, and Molleson 2006; Britton, Müldner, and Bell 2008; Mulville et al. 2009; Hoekman-Sites and Giblin 2012), animal mobility (Pearson et al. 2007; Viner et al. 2010; Millard et al. 2011; Zhao et al. 2012), and animal management more generally (Finucane, Agurto, and Isbell 2006; Lightfoot et al. 2009; Oelze et al. 2011; Jones et al. 2012; Nelson et al. 2012).

Many of these studies reflect changing attitudes toward 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 to more accurately interpret associated human stable-isotope data (Katzenberg 1989). In this context, many of these more recent studies (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.

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 analyzed collagen extracted

from serial dentine sections from the second and third molars of the left mandible of a pig (No. 2848) previously found (Guiry et al. 2012b: 2,016) (MARC ID No. 312) to have had a relatively marine-oriented diet based on mandibular bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ 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 onto what foods were they weaned? Was this individual fed fish throughout its entire life, or was fish used for pig feed only during summers when it was most abundantly available?

Historical Context

One of the earliest permanent English settlements in Newfoundland, the community of Ferryland (FIG. 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 analyzed here was collected from a deposit associated with a cellar within a stone-walled building adjacent to the Mansion House, currently interpreted as its kitchen outbuilding (Barry Gaulton 2013, pers. comm.). 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 21

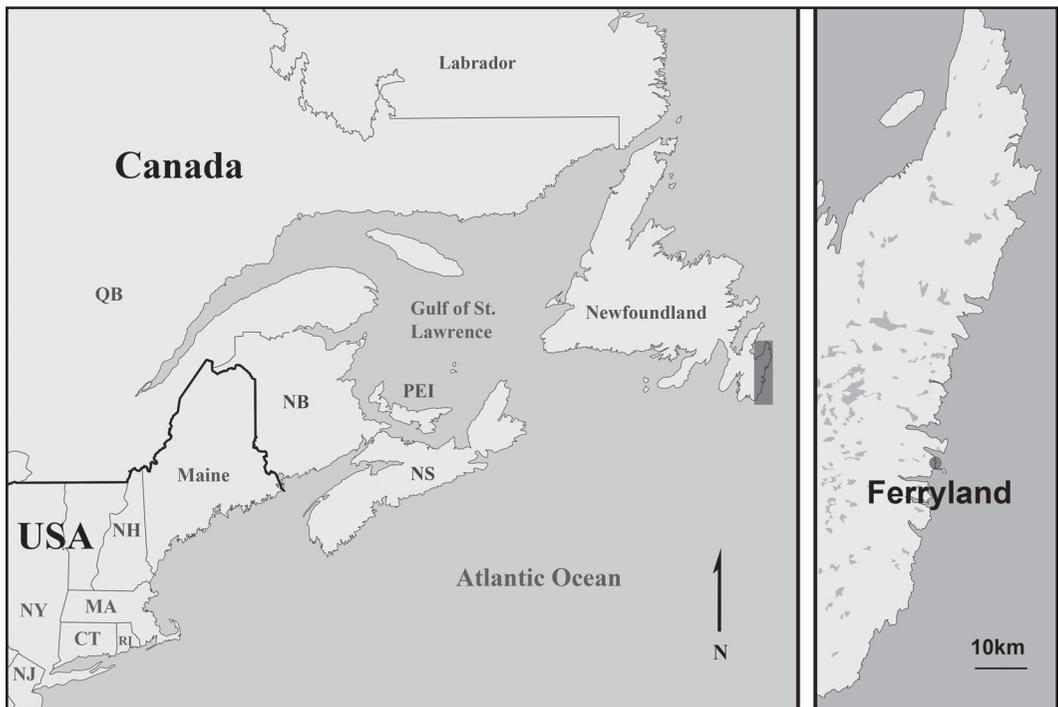


Figure 1. Map detailing study area. (Map by Eric Guiry, 2013.)

September 1696, 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 8 ft. 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 73 year time span.

Documentary and folklore information on pig husbandry in historical Newfoundland is detailed by Guiry et al. (2012b: 2,013–2,014). A long tradition of feeding 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.

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 over winter. Historical letters and census documents indicate that large cattle-herd sizes were never attained at Ferryland. Zooarchaeological evidence indicating that the majority of cattle and pigs were slaughtered in the late fall/winter, at the peak of their growth periods also supports the practice of culling herds prior to the winter months (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

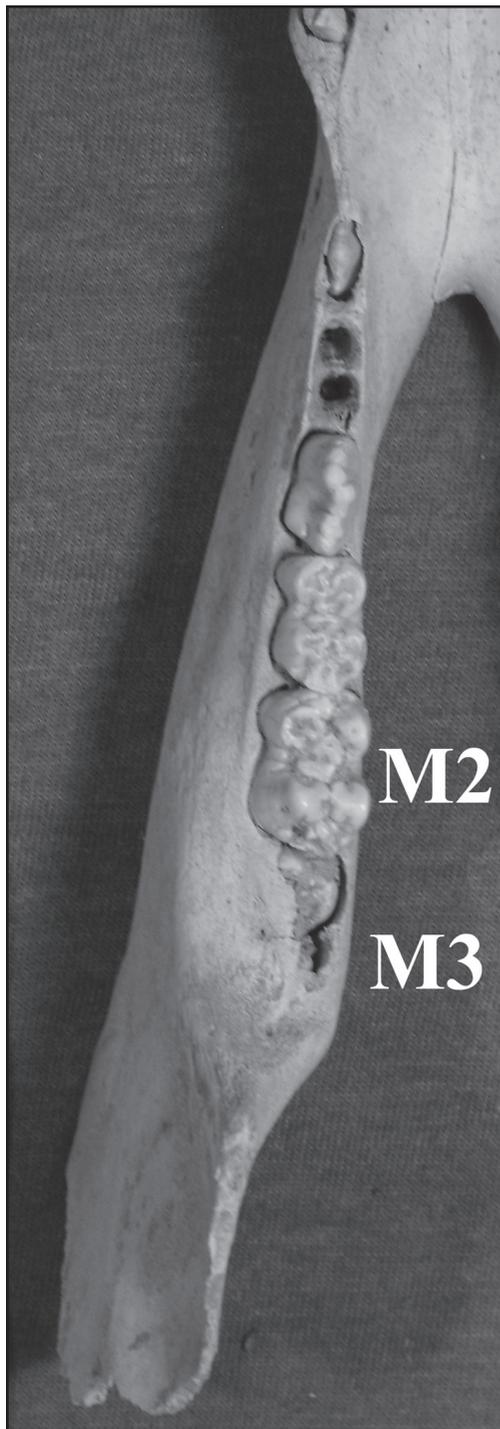


Figure 2. Image of Ferryland pig mandible specimen 2848 showing complete eruption of M2 (in wear) and M3 visible in crypt. (Photo by Eric Guiry, 2013.)

tooth eruption as it pertains to the stable-isotope analysis of pig dental tissues, see Frémondeau et al. (2012: 2,026) and also Hillson (2005). Neither tooth exhibited any morphological abnormalities. The M2 was fully formed and in wear stage TWS=b (Grant 1982) (FIG. 2). Pig second molars are known to begin formation during the first or second month of life (May or June of the first year) and are completed during the seventh or eighth month (November or December of the first year) (Hillson 2005: 234). The M3 was visible in the crypt (but below the 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 the first year) and are highly variable in their times of completion. They usually finish formation between the 12th and 18th months of life (Hillson 2005: 234; Frémondeau et al. 2012: 2,026). 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, Schoeninger, and Hastorf 1985).

Methods

Collagen-extraction procedures differed only slightly from those previously published (Ballasse et al. 2012; Fuller, Richards, and Mays 2003; Eerkens, Berget, and Bartelink 2011). 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 the 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 2–3 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, Chenery, and Eckardt (2011). Sections were placed in 0.5M hydrochloric acid until adhering enamel and dentine apatite were demineralized. Collagen pseudomorphs were then gelatinized in water adjusted to a pH of 3 on a heating block set to 70°C for 48 hours. Gelatins were then purified using 5µm Ezee filters, frozen for 24 hours, and lyophilized for 48 hours. Isotopic ratios were measured at the Max Planck 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 δ¹³C and δ¹⁵N. 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 (DeNiro 1985; Ambrose 1990; 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: 2,016) (MARC ID No. 312) we expect that collagen extractions from dentine would produce acceptable yields.

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 δ¹³C and δ¹⁵N of ~3‰ and 5‰, respectively. M2 sections 1 and 2 (from the tooth crown) appear to reflect milk feeding from a sow on a predominantly terrestrial diet with minor contributions of marine-derived foods. Decreasing δ¹⁵N 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 δ¹⁵N, and to a lesser extent δ¹³C, values in M2 section 5, and continuing through section 13, indicate a relatively rapid and sustained dietary regime change to

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 $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of -17.8‰ and 13.6‰ , respectively (C:N = 3.3; C% = 42.7, N% = 15.1; % collagen yield = 13.7). (Table by Eric Guiry, 2013.)

Lab no.	Tooth	Section	$\delta^{13}\text{C}_{\text{VPDB}}\text{‰}$	$\delta^{15}\text{N}_{\text{AIR}}\text{‰}$	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

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 the 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 provides some interesting insights into the husbandry of this particular pig, as well as the sow that milk fed it. To the resolution that 2–3 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 the Guiry et al. (2012b: 2,020) 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 at Ferryland for pigs kept for breeding and those kept for meat. 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 raise new questions

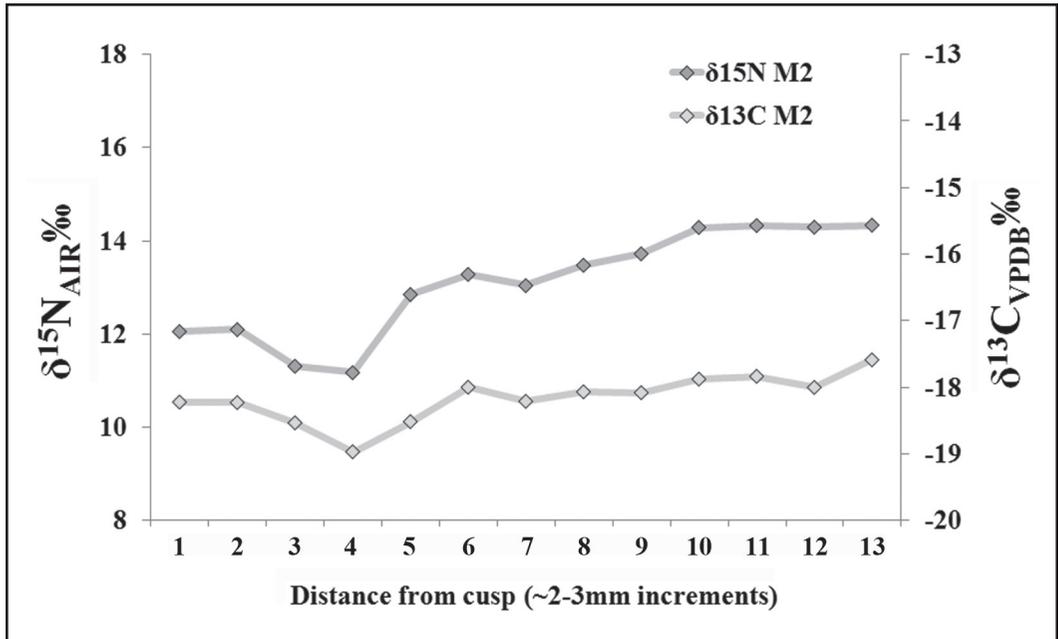


Figure 3. Stable carbon- and nitrogen-isotope data from serial sections of M2 tooth dentine. Age increases from left to right. (Figure by Eric Guiry, 2013.)

for 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 statuses 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 the 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 seeks to address these questions. Future efforts will focus mainly on the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analyses of dentine collagen from pig teeth. In particular, as recommended by Delphine Frémondeau (2013, pers. comm.), 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.

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,

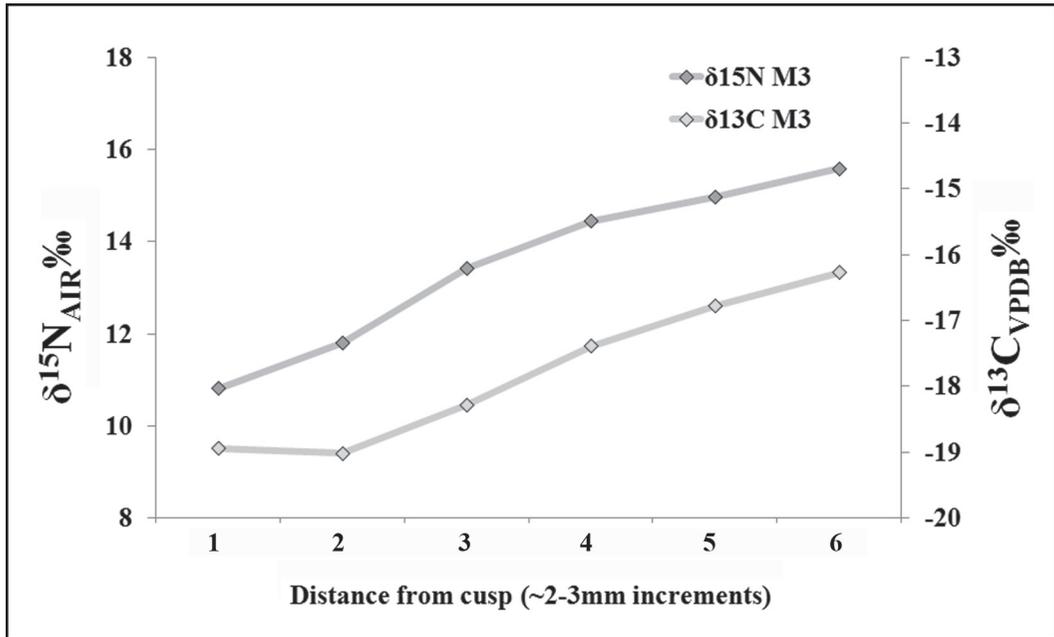


Figure 4. Stable carbon- and nitrogen-isotope data from serial sections of M3 tooth dentine. Age increases from left to right. (Figure by Eric Guiry, 2013.)

isotopic analyses have become more widespread and inexpensive, making the technique accessible and affordable for smaller archaeological projects with well-formulated research questions. While two studies have taken such work as their primary focus, a rapidly growing stable-isotope literature on human/animal relations from other regions of the world demonstrates the productivity of zooarchaeological bone chemistry and might be looked to for inspiration. 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 join their efforts. In our experience, a key way to accomplish this integration 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 above, 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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Author Information

Eric Guiry is a doctoral student at the University of British Columbia in Vancouver. He completed an MA in archaeology (2012) at Memorial University of Newfoundland and an Honors Bachelor of Science in Anthropology (2009) at Lakehead University. Integrating stable isotope, paleoethnobotanical and zooarchaeological techniques, his research interests focus on reconstructing past animal and human diets and mobility in historical and pre-contact periods.

Eric J. Guiry
Department of Anthropology
University of British Columbia
Vancouver, BC V6T 1Z1

Stéphane Noël is a doctoral candidate at Université Laval in Quebec City. He earned his MA from Memorial University of Newfoundland, where he worked on faunal collections from seasonal French cod fishing stations. Intersecting historical archaeology and zooarchaeology, his research interests revolve around the archaeology of French America, foodways, identity formation, rural colonial landscapes, the fisheries and archaeological science in general.

Stéphane Noël
Laboratoires d'archéologie
Département des sciences historiques
Université Laval, Québec, QC G1V 0A6

Eric Tourigny is currently a PhD candidate at the University of Leicester with interests in zooarchaeology, foodways, and paleopathology in the historical period of North America. Eric is particularly interested in British and Loyalist settlements in 19th-century southern Ontario and in early English settlements in Newfoundland.

Eric Tourigny
School of Archaeology and Ancient History
University of Leicester
Leicester, LE1 7RH
United Kingdom