An Isotopic Reconstruction of Diet and Origins in an 18th-Century Mass Burial Site at the Fortress of Louisbourg, Nova Scotia

by

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Abstract

The Fortress of Louisbourg, on the east coast of Cape Breton, played an important role in the 18th-century colonial history of North America. In 2006, a mass burial was discovered on nearby Rochefort Point. From the historical and archaeological evidence, it is believed the remains are of New England garrison members who died at the Fortress in the winter of 1745-46. To investigate this hypothesis, isotopic analysis was conducted on the individuals' skeletal remains and on faunal remains from the Fortress. While the dietary reconstruction revealed a great deal of isotopic variability, most individuals subsisted on C_3 based foods. The $^{87}Sr/^{86}Sr$ analysis was inconclusive, however, the lack of marine diets and non-French $\delta^{18}O$ values suggests the mass burial individuals were not Louisbourg residents. Furthermore, the $\delta^{18}O$ values suggest possible origins in New England which lends further support to the hypothesis that the mass burial individuals were members of the 1745 New England garrison.

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List of Symbols, Nomenclature or Abbreviations

~	Approximately
<	Less than
±	Plus-minus (symbol for standard deviation value)
®	Registered trademark
™	Trademark (unregistered)
‰	Per mil (parts per thousand)
µl	Microliter
σ	Standard deviation
δ	Delta
$\delta^{13}C$	Delta value of the ratio of ^{13}C to ^{12}C
$\delta^{13}C_{Carb}$	$\delta^{13}C$ value of carbonate
$\delta^{13}C_{Col}$	$\delta^{13}C$ value of collagen
$\delta^{13}C_{E-D}$	Enamel $\delta^{13}C$ value – dentine $\delta^{13}C$ value
$\delta^{15}N$	Delta value of the ratio of ^{15}N to ^{14}N
$\delta^{18}O$	Delta value of the ratio of ^{18}O to ^{16}O
$\delta^{18}O_{(VPDB)}$	$\delta^{18}O$ value relative to the VPDB scale
$\delta^{18}O_{(VSMOW)}$	$\delta^{18}O$ value relative to the VSMOW scale
$\delta^{18}O_{DW}$	$\delta^{18}O$ value of drinking water (relative to the VSMOW scale)
$\delta^{18}O_{DW(VSMOW)}$	$\delta^{18}O$ value of drinking water relative to the VSMOW scale
$\delta^{18}O_{E-D}$	Enamel $\delta^{18}O$ value – dentine $\delta^{18}O$ value
$\delta^{18}O_{E(VPDB)}$	$\delta^{18}O$ value of enamel relative to the VPDB scale
$\delta^{18}O_{E(VSMOW)}$	$\delta^{18}O$ value of enamel relative to the VSMOW scale
$\delta^{18}O_{PPT}$	$\delta^{18}O$ value of precipitation (relative to VSMOW)
$\Delta^{15}N$	Absolute $\delta^{15}N$ difference
$\Delta^{13}C$	Absolute $\delta^{13}C$ difference
^{12}C	Carbon-12 isotope (stable)
^{13}C	Carbon-13 isotope (stable)
^{14}C	Carbon-14 isotope (radioactive)
^{14}N	Nitrogen-14 isotope (stable)
^{15}N	Nitrogen-15 isotope (stable)
^{16}O	Oxygen-16 isotope (stable)
^{18}O	Oxygen-18 isotope (stable)
^{87}Rb	Rubidium-87 isotope (radioactive)
^{87}Sr	Strontium-87 isotope (radiogenic)
$^{87}Sr/^{86}Sr$	Ratio of ^{87}Sr to ^{86}Sr

$^{87}Sr/^{86}Sr_{E-D}$	Enamel $^{87}Sr/^{86}Sr$ value – dentine $^{87}Sr/^{86}Sr$ value
AIR	Atmospheric nitrogen (nitrogen scale)
C/N	Ratio of carbon to nitrogen
C_3	Plant type that uses the Calvin-Benson metabolic pathway
C_4	Plant type that uses the Hatch-Slack metabolic pathway
CAM	Crassulacean acid metabolism
CBUBL	Cape Breton University Bioarchaeology Laboratory
DI H_2O	Deionised water
df	Degrees of freedom
EA-IRMS	Elemental analyser – isotope ratio mass spectrometer
EA	Elemental analyser
HCl	Hydrochloric acid
HMP	High marine protein
HNO_3	Nitric acid
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
M	Molar
MΩ	Megaohm
MARC	Memorial Archaeology (laboratory sample number header)
MC-ICP-MS	Multi-Collector Inductively Coupled Plasma Mass Spectrometer
mg	Milligrams
ml	Milliliters
MNI	Minimum number of individuals
MUNBL	Memorial University Bioarchaeology Lab
mV	Millivolts
n	Sample size
N_2	Nitrogen gas
N_2-fixer	Nitrogen fixer
NH_4	Ammonium
NO_3	Nitrate
km	Kilometers
km^2	Square kilometers
p	p value
t	t value
VPDB	Vienna Pee Dee Belemnite (carbon and oxygen scale)
VSMOW	Vienna Standard Mean Oceanic Water (oxygen scale)
WMO	World Meteorological Organization
>	Greater than
LEHs	Linear enamel hypoplasias

Chapter 1

Introduction

The Fortress of Louisbourg National Historic Site of Canada is on Cape Breton Island, in the province of Nova Scotia. Apart from being a prime tourist attraction, the Fortress of Louisbourg's short and turbulent history has also received much attention from archaeologists and historians alike. Research on the fortress and its inhabitants has been aided by the copious amounts of primary documents concerning Louisbourg's past (e.g., civil records, commercial documents, official correspondence and journals [De Forest ed. 1932; Johnston 1996, 2001; MacLean 1995; Moore 1982) and by archaeological excavation which began in the 1940s and continues to date (O'Shea 1995). Through this work, researchers have created a detailed account of the Fortress's history. Previous research has focused on topics including economics (Varkey 2002), religion (Johnston 1996), family life (Donovan 1995), important events (Baker 1978), fortification construction (Fry 1995), and many others. However, there are parts of Louisbourg's past that were never documented and remain a mystery.

One such mystery concerns an archaeological site discovered after a destructive winter storm in 2006. A rescue excavation of a seemingly inconspicuous stone foundation revealed a mass burial containing 48 individuals (Duggan 2007, 2010; Parish 2006, 2007). Historical records in conjunction with archaeological evidence identified the stone foundation as a root cellar belonging to a home occupied from 1725 to 1745 by the Ste. Marie family (Duggan 2007, 2010). In 1745 the fortress was besieged by New England soldiers and the British Navy (Rawlyk 1999), and in preparation for battle, the Ste.

Marie's house was burned down by the French to clear a line of fire for the fortress's cannons (Duggan 2010).

After almost seven weeks of siege warfare, the French occupants of the fortress surrendered and returned to France (Baker 1978; Johnston 1996; McLennan 1918). To garrison the fortress, approximately (~) 2000 New England soldiers remained in Louisbourg until the following spring (Duggan 2010; McLennan 1918). Throughout this period, the garrison experienced substantial difficulties. They were unprepared for a long winter stay and suffered from camp diseases such as diphtheria and dysentery (Duggan 2007, 2010; McLennan 1918). As a result of these harsh conditions, between 900 and 1200 New England soldiers perished (Duggan 2007). From the historical and archaeological evidence it is believed that the New England soldiers used the Ste. Marie's root cellar as a place to inter the dead (Duggan 2010).

The goal of this thesis was to investigate the hypothesis that the human remains within the Ste. Marie's root cellar were New England soldiers who died in the winter of 1745-46. This was accomplished by performing isotopic analyses on the individuals' skeletal remains as a means of reconstructing their life histories.

For the past several decades archaeologists have used stable and radiogenic isotopes to reconstruct the diet and origins of past peoples. Carbon and nitrogen isotopic analysis allows archaeologists to differentiate between C_3 and C_4 plant based diets (Vogel and van der Merwe 1977), terrestrial and marine diets (Schoeninger et al. 1983), and determine the trophic level of a consumer (Richards et al. 2000), while analysis of oxygen and strontium isotopes, reflecting meteorologic and geologic conditions, allow researchers to

investigate questions relating to origins, residency, mobility, and migration (Bentley 2006; White et al. 2004a).

To examine the diet and origins of the Ste. Marie individuals, carbon and nitrogen isotopes were analysed from bone collagen, strontium isotopes from tooth enamel and dentine, and carbon and oxygen isotopes from the carbonate portion of enamel and dentine bioapatite. As part of this methodology, a large sample size of faunal bones and teeth was also analysed. These data contribute to a growing isotopic database of human and faunal materials from historical and colonial contexts.

The following is a brief description of the organisation of this thesis. Chapter 2 includes background information on the Fortress of Louisbourg such as the types of food present, the sources of the food, and the origins of the inhabitants. Also included is a brief discussion of the conflicts that occurred between the French and British leading up to the formation of Louisbourg and the events that took place during and after the 1745 siege. An account of the discovery of the Ste. Marie's root cellar site is given in Chapter 3. This includes an overview of the rescue excavation that followed, the hypothesis that was developed concerning the group's origins, and the research questions designed to test this hypothesis using isotopic analysis. The basic principles and uses of different isotopic analyses are given in Chapter 4. This includes a discussion of how and why isotopes are affected by biological, ecological, geographical, and physiological factors, and how these factors help archaeologists answer questions relating to diet and origins. Chapter 5 contains information on the faunal and human materials analysed including pertinent information from the osteological analysis of the mass burial remains. Also outlined, are the methodologies for sample preparation, the procedures for analysing isotopes, and the

methodologies for determining sample preservation. Chapter 6 reports the results of the faunal and the Ste. Marie individuals' isotopic analysis and sample preservation. Chapter 7 contains a reconstruction of the Ste. Marie individuals' and faunal specimens' diets and origins utilising the isotopic data from this study, published isotopic data, and environmental and historical information. Chapter 8 includes a summary of the study's findings and suggestions for future research.

Chapter 2

The Fortress of Louisbourg

2.1 Colonisation and Conflict

The Fortress of Louisbourg was an 18th-century French fortress located on the east coast of Isle Royale, current day Cape Breton Island (Figure 1). As a community and as a commercial and military center, the Fortress of Louisbourg was a diverse and successful settlement that experienced a swift and unfortunate end. Before European settlement, Cape Breton Island was populated by native groups, mainly the Mi'Kmaq of the Algonquin speakers (Johnston 2004; McNeill 1985). Shortly after European contact, fishermen frequented the island to take advantage of the teeming codfish and whale populations (Brown 1979; Vernon 1903). Fishing groups from France, Spain, Portugal, and England initially related with one another and local native groups on more or less friendly terms, however, in the 17th-century, relations between fishermen, merchants, and settlers from different nations appear to have gone through a period of unrest (Brown 1979; Downey 1965; Johnston 2004; Vernon 1903). The commercial potential of the island was becoming apparent, and numerous conflicts arose, particularly between the English and French (Balcom 1995; Downey 1965). Offshore, these conflicts concerned poaching and competition for fishing grounds, while onshore, settlement could be described as a veritable tug of war between Anglo and Franco, merchants and settlers, regardless of whether these nations were at peace or war (Downey 1965; Vernon 1903). Other Cape Breton settlements such as Ste. Anne and Ste. Pierre (Figure 1) were passed back and forth between French and English hands, or in some instances, between French

commercial rivals (Brown 1979; Johnston 2004; Vernon 1903). Due to numerous attacks and logistic struggles, both French bases at Ste. Anne and Ste. Pierre were abandoned, and no further attempt at settling Cape Breton was made until the 18th-century, however, discussions concerning its development continued among French officials (Johnston 2004; McLennan 1918; Varkey 2002; Vernon 1903).

Similar conflicts were also common in neighbouring regions (Brown 1979; Rawlyk 1999; Rowe 1980). On the mainland of current day Nova Scotia, Acadia's Port Royal exchanged hands between France and England on multiple occasions (Brown 1979; Graham 1958; Rawlyk 1999). Further north in Newfoundland, the English repeatedly attacked the French base at Plaisance (current day Placentia), while frequent attacks by the French on English settlements drastically reduced the English population and significantly damaged their fishing industry (Rowe 1980).

Franco-Anglo relations in the New World rose to a dangerous level during the War of the Spanish Succession (1701 – 1714) (Brown 1979; Graham 1958; Rowe 1980). This war was initially an Old World affair, however, it was not long before the North American colonies became involved (Graham 1958; Varkey 2002). In the New World theatre, this war was known as 'Queen Ann's War' and took the form of raids on settlements and towns, and privateering of ships, their cargo and crew, among other aggressions (Graham 1958; Hassler 1982; Leach 1986; Rowe 1980). Relations between the English and French were volatile throughout the New World, from Newfoundland to the West Indies, and inland to Canada (Brown 1979; Graham 1958; Hassler 1982; Leach 1986; Rowe 1980). Each side strived to protect their own territories and economies while attempting to dislodge their adversaries' position in the New World.

Queen Anne's War came to an end in 1713 with the signing of the Treaty of Utrecht (Brown 1979). The terms of this treaty ceded Acadia and Newfoundland to the British, but Cape Breton Island remained under French possession (Rowe 1980; McLennan 1918; Vernon 1903). The rest of France's territory in North America was restricted further inland and included three main areas: the Great Lakes, the St. Lawrence, and the Mississippi delta, with settlement restricted to the latter two areas (McNeill 1985). British territory extended along the coast of North America from Newfoundland to Florida (with the exception of Cape Breton) (Vernon 1903), however, British expansion westward was blocked by the Appalachian Mountain range, effectively preventing the British access to the French interior (McNeill 1985).

Thus, nearly the entire east coast of North America became British territory which made access into the French interior problematic. However, France still retained their last coastal territory, Cape Breton Island (Vernon 1903). Because of Cape Breton's coastal location and its placement at the mouth of the Gulf of St. Lawrence (Figure 1), the retention of this territory was believed essential for the safe transport of goods and people, in and out of the French interior (Graham 1958; McNeill 1985; Vernon 1903). Furthermore, the value of Cape Breton Island in relation to broader imperial affairs was becoming well known among French officials (McLennan 1918; McNeill 1985; Varkey 2002).

2.2 The Economic Value of Cape Breton Island

Cape Breton Island had many important features that made it an ideal port for France's commercial endeavours and a suitable base for the cod fishing industry. The following is

a summary of Cape Breton's beneficial features and why these features were valued by French officials.

2.2.1 A Port on Cape Breton Island

The transatlantic trade industry was important for France, as it created a great deal of profit (McLennan 1918; McNeill 1985; Varkey 2002). France's trade system consisted of a triangular network between France, North America, and the French West Indies, whereby France exported European goods, the West Indies exported sugar and rum, and North America exported fish and wheat (McNeill 1985; Varkey 2002). With the decrease in French territory after the Treaty of Utrecht, Cape Breton Island became a strategic location from which Canadian and coastal materials could be exported, and French and West Indian materials, imported (Balcom 1995; McNeill 1985; Vernon 1903).

In addition, the geographic location of Cape Breton was a favourable one in terms of its position along Atlantic trade routes (McNeill 1985). Trade winds in the Atlantic move in a clockwise fashion with the westerly winds crossing the Atlantic at a close latitude with Cape Breton Island. Therefore, ships planning to return to Europe from the West Indies or New England would sail with the trade winds in a northerly direction as far as Cape Breton before crossing the Atlantic via the westerly trade winds (McNeill 1985). Also, since contemporaneous navigational instruments could determine latitude only (and not longitude), it was common practice when making a journey across the Atlantic to sail along the coast to the same latitude as your destination before crossing (Balcom 1995). Cape Breton Island was roughly on the same latitude as France, making crossing between these regions less complicated (Balcom 1995).

Furthermore, because of Cape Breton's placement at the mouth of the Gulf of St. Lawrence, a port on the island would be an ideal place to transfer goods from the large seafaring ships, to the smaller vessels more appropriate for sailing in the gulf and down the St. Lawrence River (Balcom 1995; McNeill 1985). A settlement on Cape Breton could also offer a safe anchor where ships could dock, materials could be stored, and the crew could rest (Clark 1980). All the above factors illustrate how a port on Cape Breton Island could be easily integrated into imperial-colonial trade, and indeed how such a settlement could greatly contribute to this system.

2.2.2 Fishing off the Baccalaos

The loss of Newfoundland to Britain in 1713 created a crisis in French colonial affairs (McLennan 1918). Plaisance was the base of the fishing industry in Newfoundland, but after the transfer of Newfoundland to British sovereignty, French officials were greatly concerned with the continuation of the cod fishing industry (Balcom 1995; Johnston 1995a; McLennan 1918). French fishermen were given allowance to fish off of Newfoundland's western shores, however, under the terms of the Treaty of Utrecht, French fishermen and settlers were not allowed to overwinter or have permanent living structures on Newfoundland soil (Varkey 2002; Rowe 1980). The French had found great value in the resident fishery, and therefore, a new territory was sought for the establishment of a permanent fishing outpost from which the Plaisance population could operate (McLennan 1918; Varkey 2002). To this end, French officials turned to their last coastal territory, Cape Breton Island (McNeill 1985; Varkey 2002).

Cape Breton Island was an ideal place for a resident fishery, as it held prosperous fishing grounds teeming with cod (McNeill 1985). Several hundred kilometers off the east coast is a continental shelf named Banquereau Bank (McNeill 1985). This bank was an ideal environment for fish to feed and mate, and as such, cod aggregated on Banquereau Bank in large numbers (McNeill 1985). Indeed, the early Basque and Breton fishermen found the waters off of Cape Breton, Newfoundland, and mainland Nova Scotia to be so plentiful with cod they gave the area the name 'Baccalaos' (the Basque word for cod) (Brown 1979; Vernon 1903).

Maintaining the cod fishing industry was of vital importance to France since it granted significant returns which surpassed even that of the fur trade (Johnston 1995a; McLennan 1918; Varkey 2002). The great value of the fishing industry was due to a number of factors: cod was easily and reliably caught in large amounts, could be dried and preserved with salt or brine for extended periods, could be readily traded for other food, products, and materials, and was a cheap high-protein mineral-rich staple food in both Old World and New World markets (Balcom 1995; Downey 1965; McNeill 1985; Moore 1995; Varkey 2002).

Considering Cape Breton's ideal conditions for cod fishing, the island's valuable offshore resources easily surpassed its onshore resources (McNeill 1985). The soil was not very supportive of agriculture (with a few exceptions, e.g., Mira, Ste. Anne, and Ste. Pierre) (Donovan 1995; McNeill 1985; Vernon 1903). Much of the island's hardwood was in the interior, and most of the accessible wood was stunted pine and spruce (McNeill 1985). Although coal was utilised by early Cape Breton settlers, the rich coal seams were

not exploited in any significant manor until the mid-19th-century (Martell 1980; McNeill 1985).

It was initially thought that a stronghold on Cape Breton Island could act as a barrier against an invading force (Vernon 1903). In truth Cape Breton was not intended as being a first line of defense for the interior settlements, nor was it ever outfitted to perform such duties (Fry 1995; McNeill 1985; Varkey 2002). Priority among these matters was given to the fishing and trading industry (Johnston 1995a). Concerning naval affairs, however, the fishing industry was often considered a 'nursery for seamen' (Bollan 1746; Downey 1965; McLennan 1918; Varkey 2002). This factor was not an insignificant one considering the French fisheries in North America in the early 18th-century included 400 – 800 ships and employed 16,000 – 30,000 men, any number of which could be called to take up arms in times of war (Downey 1965; Varkey 2002). This factor was indeed one of the many threats William Shirley, Governor of Massachusetts, heralded as motivation for the 1745 capture of Louisbourg (Downey 1965). For the above reasons, maintaining the fishing industry was of vital importance not only for colonial matters but also imperial affairs.

2.3 The Fortress of Louisbourg

Having realised the value, and perhaps also the vulnerability of their last coastal territory, the island was given the grand name 'Isle Royale', and an imposing fortress was devised for its capital (McLennan 1918). The harbour formerly known as English harbour (or Havre à l'Anglois) was chosen as the site for the town later to be christened 'Louisbourg' (Johnston 1995a; McLennan 1918). The first settlers arrived in 1713, and construction of

the fortifications began in 1720 (Johnston 1995a). Historical writings concerning Isle Royal's Fortress of Louisbourg are varied and copious. Since the basis of this thesis is focused on determining the diet and origins of the Ste. Marie mass burial individuals, the following contextual summary is focused on the inhabitant's food, drink, and origins.

2.3.1 Food and Drink

Apart from small scale agriculture in the Mira area and on Boularderie Island, agriculture on Isle Royale was relatively non-existent in comparison to Acadia or other French and British colonies (Clark 1980). Louisbourg households had their own backyard vegetable gardens and supplemented their diet with occasional hunting and freshwater fishing (Downey 1965; Lane Jonah and Véchambre 2012; McNeill 1985; O'Neill 1995), however, a Louisbourg inhabitant's diet, especially during winter months, was based on locally baked bread and locally caught cod (Downey 1965; McNeill 1985; Lane Jonah and Véchambre 2012).

In the early 18th-century the fishery was the most profitable industry for New France (Johnston 1995a; Varkey 2002). In the first five years after the establishment of Louisbourg, the colony had produced a total of 156,500 quintals of cod (a quintal = 100 pounds) (McNeill 1985; Varkey 2002). Leading up to the 1740s, the annual catch was as high as 150,000 quintals per year and worth over three million livres back in France (Downey 1965; McNeill 1985; Moore 1995). Since codfish was a reliable and nutritious food, which could be easily preserved and stored, it was a staple food at the Fortress of Louisbourg (Balcom 1995; Downey 1965; McNeill 1985).

Following the fishery, the most important industry for the Fortress of Louisbourg was trade, both inter-colonial and inter-continental (McNeill 1985; Moore 1995). Louisbourg harbour saw over 150 trade ships each year carrying food items, building materials, and other goods (Downey 1965). Since Louisbourg's economy was based on fishing and lacked any significant agricultural production, the Fortress relied on the importation of almost all of the town's food supply (Clark 1980; McLennan 1918; Moore 1995). Much of the imported goods received by Louisbourg were through trade with France (Moore 1995; Varkey 2002). Food items imported from the Old World included salt, grain, flour, wine, brandy, and salted meat (Varkey 2002). Louisbourg received flour and dried vegetables from Canada (Moore 1995; Varkey 2002) and sugar, coffee molasses, and rum from the French West Indies (Clark 1980; Varkey 2002; Vernon 1903).

Although trade with foreign entities was discouraged by imperial policy, these activities still occurred at the Fortress of Louisbourg (Chard 1995; Varkey 2002). Anglo and Franco merchants weaved through loopholes in their respective trade regulations and effectively intertwined two competing imperial economies (Clark 1980; Varkey 2002). Because of this, Louisbourg trade included to a large extent numerous Acadian and New England goods (Clark 1980; Rawlyk 1999). Imported foodstuffs from Acadia included fish, flour, bread, oats, wheat, peas, and meat (Clark 1980; Moore 1995). Acadia also shipped livestock to Louisbourg: ~600 – 700 cattle and ~2000 sheep annually (Clark 1980; Moore 1995; Rawlyk 1999). Goods imported from New England included, livestock (e.g., cattle, oxen, and sheep), meat (e.g., pork and poultry), eggs, butter, cheese, flour, corn, wheat, rice, produce (e.g., potatoes, onions, apples, and pears), and cider

(Chard 1995; Clark 1980; McLennan 1918). Overall, whether through licit or illicit means the Fortress of Louisbourg imported a variety of food items from various regions within the transatlantic trade system.

The food supply at the Fortress of Louisbourg was a reoccurring concern, especially during the winter months (McLennan 1918). Approximately half of Louisbourg's soldiers had relocated during the winter of 1718 to avoid starvation (McLennan 1918; McNeill 1985), and in the winter of 1743-44, on the verge of famine, the town's officials contemplated shipping the entire population of Louisbourg back to France (Downey 1965). During the winter months, Louisbourg residents relied on those food items that did not spoil (e.g., flour, salt fish, hogs lard, and biscuit), and as a result of this low vitamin diet, Louisbourg residents regularly suffered from scurvy (McLennan 1918; McNeill 1985).

2.3.2 The Louisbourg Inhabitants

The first inhabitants of Louisbourg were the settlers and fishermen expelled from their home in Plaisance in 1713 (McLennan 1918). Joining them were a small number of Canadians and those Acadians not wishing to remain as neutral French in British owned Acadia (Donovan 1995; McLennan 1918). Eventually, the population of Louisbourg grew to include a garrison of French, Swiss, and German soldiers, royal and civil officials, servants, merchants, tradesmen, fishermen, shore-workers, sailors, proprietors, innkeepers, artisans, labourers, and many others (Johnston 1995b, 1995c, 2001). Of those individuals involved in trade and fishing, some were permanent inhabitants, while others were transient workers (Johnston 1995c, 2001; McLennan 1918).

Of the resident population, considering the fort's military status and its involvement in the fishing industry, adult males greatly outnumbered females, at times 8 – 10:1 (Johnston 1995b). Even without the soldier population, the ratio of adult males to females was never below 3:1 (Johnston 1996). In the early years of Louisbourg's settlement, the percentage of children within the town was within the 20% range and eventually grew to as high as 45% (Johnston 2001; McNeill 1985). Population characteristics, such as birth place, spoken language, and religion, were occasionally recorded in census documents, however, concerns have been raised concerning the consistency, reliability, and scope of these records (see Johnston 1995b and 2001 for more information). As a result, this information must be taken as an approximate description of Louisbourg's population characteristics. Other documents, such as parish records, are also helpful for examining birth place, baptisms, marriages, and deaths, but it should be noted that this information only covered those parishioners of the Roman Catholic faith and excluded Irish Catholic and Protestant residents who made up a small but not insignificant portion of the Louisbourg population (Johnston 1995b, 2001).

Considering these limitations, some rough, yet valuable inferences regarding the Louisbourg population can be drawn. Louisbourg inhabitants originated from various areas in France, particularly western France (Johnston 1995b, 2001; McNeill 1985). A smaller percentage of Louisbourg inhabitants had a place of birth in New France and an even smaller percentage from foreign countries (Johnston 1995b, 2001). For example, in 1734, 21.2% of inhabitants were from New France and 6.2% were from foreign countries (Johnston 1995b, 2001). However, the above statistics include only those males or females who were heads of households and not those inhabitants who were non-heads of

households including wives, children, fishermen, soldiers and servants (Johnston 1995b). Since non-heads of households were a significant portion of Louisbourg's total population, accurately determining the origins of all Louisbourg inhabitants is a difficult task (Johnston 1995b, 1995c).

From various other sources, information on brides, fishermen, soldiers, servants, and slaves has been compiled. Of those brides whose origins were recorded in parish records, most were from New France (e.g., 83.63% between 1722 and 1745, and 59.23% between 1749 and 1758) (Johnston 2001). Most of Louisbourg's fishermen were from France (mainly Basque country, Normandy, and Brittany), and some were from Plaisance or other areas of New France or foreign countries (Johnston 1995b, 1995c). Almost all of Louisbourg's soldiers were recruited from France with only a few determined by historians as having non-French origins (e.g., Irish, Swiss, and Acadian) (Johnston 1995b, 1995c). Louisbourg also became host to a group of Swiss and German soldiers belonging to the Karrer Regiment which made up one-quarter of the total garrison population by 1741 (Johnston 1995b, 2001). The total garrison population ranged anywhere from one-quarter to one-half of the total Louisbourg population (Johnston 1995b). Native peoples did not reside in the fortress apart from the few who lived as servants or slaves (Johnston 1995b, 1996, 2001). The Black residents, who are believed to be from Africa or the Antilles, were mostly slaves, and few were free individuals (Donovan 1995; Johnston 1995b, 2001). Overall, the Fortress of Louisbourg was not limited to people of French origins but had a varied minority population including Aboriginal, non-French European, African and colonial-born individuals.

2.4 The Siege of 1745

By the 1740s, the New England colonies had become uneasy at the growth of Louisbourg (Baker 1978, Graham 1958, Rawlyk 1999). Much concern was given to the growth of French trade in the Atlantic, their alliance with the Natives, and the ever growing fear of attack, but paramount among these concerns was privateering and the prosperity of the French fishing industry (Baker 1978; Graham 1958; Leach 1986). The long standing competition for fishing rights between France and England had continued into the early 18th-century, and by the 1740s France's fishing industry in the Atlantic was vastly larger than Britain's (Bollan 1746; McNeill 1985). Massachusetts lawyer and London Colonial Agent William Bollan in comparing the French and English Fishing industries stated that the French fishery… "amounted (within a Trifle) to a *Million, Sterling: Our's* not to one Third of that Sum. They employed 27 500 Men: We, at most, 14 or 1500. They, 564 Sail of Ships: We about 300, great and small." (Bollan 1746:91). Thoughts of overthrowing the Fortress of Louisbourg began circulating among British and New England officials (Baker 1978; McLennan 1918). These deliberations would eventually find a working platform when war between British and French colonies was declared in the spring of 1744.

Previous to the declaration of war, the town of Louisbourg was in trouble (Downey 1965; Rawlyk 1999). Fishermen and merchants steered clear of the area around Louisbourg to avoid becoming caught in the middle, or be the target of violent outbreaks (Rawlyk 1999). As a result, Louisbourg's food supply was running dangerously low (Downey 1965; Rawlyk 1999). This problem led Louisbourg officials to organise an attack on Canso, a small British settlement at the northeastern tip of mainland Nova

Scotia, south of Isle Royale (Rawlyk 1999). In the eyes of Louisbourg officials, attacking Canso would open up trade routes between Louisbourg and Nova Scotia (providing the former with provisions for the town's ailing food supply) and lay the groundwork for the capture of the much desired Nova Scotia and the return of the Acadians to French sovereignty (Rawlyk 1999). The seizure of Canso and Acadia would also deliver a significant blow to the British fisheries which in turn would open up more fishing territory for the French (Rawlyk 1999).

Once war was declared against Britain, Louisbourg sent an expedition to capture Canso in May of 1744 (Rawlyk 1999). The fort was quickly capitulated and burned to the ground with its inhabitants deported or taken prisoner (Baker 1978; Rawlyk 1999). This victory spurred the Louisbourg governor, Du Quesnel, to go one step further and attack Annapolis Royal, the British place name for the former French settlement of Port-Royal (Rawlyk 1999). A joint French-Native offensive was employed, but the attack was eventually withdrawn (McLennan 1918; Rawlyk 1999). In addition, throughout the summer of 1744, privateers out of Louisbourg routinely prayed on New England trade ships which significantly disrupted the trade industry and irritated New England merchants (Baker 1978; Hitsman and Bond 1980; Rawlyk 1999). New England privateers responded by attacking French fishing and merchant vessels (Rawlyk 1999).

In the eyes of New England and British officials, the actions of the French in the early months of King George's War displayed a swift and resolute aggression and revealed a disorganised military and an unreliable navy (Baker 1978; Rawlyk 1999). Furthermore, prisoners taken from Canso in the spring of 1744, once released, revealed valuable information about the dilapidated condition of Louisbourg's defenses (Baker

1978; Hassler 1982; Leach 1986). This information, coupled with past concerns, fueled discussions among New England officials regarding offensive and defensive measures (Graham 1958; Rawlyk 1999). Massachusetts Governor, William Shirley, formulated a proposal for the eradication of the French presence on Isle Royale (Baker 1978; Rawlyk 1999). Shirley's proposal eventually gained support in the New England and British governments, and by 1745 plans were underway for the capture of the Fortress of Louisbourg (Baker 1978; Hassler 1982; Leach 1986; Rawlyk 1999).

A joint expedition was formulated using New England land troops (led by merchant and militia colonel, William Pepperell) supported by the British Navy (led by British Commodore, Peter Warren) (Baker 1978; Hassler 1982; Rawlyk 1999). The enlisted soldiers were from three New England colonies: 456 men from New Hampshire, 516 from Connecticut, and 3,300 from Massachusetts (which included current day Maine) (Baker 1978; Rawlyk 1999). The soldiers were accompanied by 34 cannons, 115 ships, and four British warships (Hassler 1982). The men enlisted for the Louisbourg expedition were not trained soldiers but a hodgepodge of tradesmen: fishermen, deckhands, longshoremen, farmers, mechanics, and merchants (Baker 1978; Clark 1980; Hassler 1982). What these men lacked in training and military weapons and accoutrements, they made up for with youthful energy (Rawlyk 1999). Most of the soldiers were in their twenties, but overall, their ages ranged from 16 – 60 (Baker 1978; Rawlyk 1999).

A blockade was formed in the spring of 1745 to isolate the Fortress from aid and supplies (Rawlyk 1999). The governor of Louisbourg, Du Chambon, was either naive or unaware of any pending danger (McLennan 1918; Rawlyk 1999). This changed when a French vessel maneuvered its way through the blockade and carried intelligence to

Louisbourg officials that a vast British naval presence was gathered off the coast (Rawlyk 1999). Upon hearing this news, all exterior inhabitants were called to take shelter behind the fortress walls, and a total of 590 regular soldiers and ~900 civilians were called into action (Rawlyk 1999).

With Warren's ships effectively blockading Louisbourg harbour, Pepperell's troops made landfall approximately four miles southwest of Louisbourg on May 11th and slowly advanced personnel, provisions, and artillery closer to the Fortress's western fortifications (Leach 1986; McLennan 1918). A measure of success was quickly achieved when the New England soldiers occupied the abandoned Royal Battery and outfitted her cannons to fire against the Fortress (McLennan 1918; Rawlyk 1999). From this position, the captured lighthouse battery, and from numerous other makeshift fascine batteries to the west of Louisbourg, the New England artillery rendered significant damage to the Fortress's fortifications (Baker 1978; Rawlyk 1999).

As the siege continued, the state of Louisbourg slowly declined with no signs of relief (Baker 1978). Eventually, Du Chambon, with low provisions, exhausted inhabitants, and a ruined fortress, began negotiations for the capitulation of Louisbourg (Hassler 1982; McLennan 1918; Rawlyk 1999). Agreeable terms were reached on June 27th, and Louisbourg's Troops marched out with the honours of war the next day (Baker 1978). Louisbourg was turned over to its captors, and the town's occupants were deported back to France (Johnston 1996; McLennan 1918).

To prevent the French from retaking the Fortress, a New England garrison of ~2000 soldiers occupied Louisbourg until the following spring (Duggan 2007, 2010; McLennan 1918; Wood 1920). While many studies of Louisbourg's history quickly glance over this

small period of history, there are many that give short accounts of those events that occurred between the capture of Louisbourg and the beginning of British occupation in the spring of 1746 (e.g., Downey [1965], Duggan [2010], Johnston [1996], Leach [1986], McLennan [1918], Rawlyk [1999], and Wood [1920]). Throughout the winter months, the New England garrison suffered greatly. The soldiers were unprepared for their stay and had an inadequate supply of food and proper clothes (Leach 1986). Lacking in military discipline, the garrison had not prepared sufficient shelters, and once the winter cold descended on the ruined town, a lack of fuel caused them to dismantle parts of their shelters for firewood (Knowles 1746; Leach 1986). To further avoid the cold, it was reported that the soldiers "did their filth" indoors (Knowles 1746).

As a result of these harsh conditions, the soldiers suffered from numerous illnesses resulting in epidemic-like casualties (Downey 1965; Johnston 1996; Wood 1920). To make matters worse, those who died were not properly disposed of but in some instances buried below the floorboards of the same houses the soldiers inhabited (Knowles 1746), likely contributing to the spread of illness. By the end of the garrison's occupation of Louisbourg, around 1000 (of the original 2000) New England soldiers perished (Duggan 2010). Many of the deceased were carried out of town through the Maurepas Gate and buried on Rochefort Point (Johnston 1996; Wood 1920), however, exactly where or how these individuals were laid to rest is unknown.

Chapter 3

The Ste. Marie Mass Burial

In the winter of 2006, a massive winter storm hit the east coast of Cape Breton and damaged numerous archaeological features at the Fortress of Louisbourg (Duggan 2010). One area that was substantially damaged was Rochefort Point, a small piece of land which extends from the Fortress's eastern walls toward the entrance of Louisbourg harbour (Duggan 2010). Several sections of the point's bank had ripped away revealing important archaeological features (Duggan 2010). One such feature, exposed on the north bank of the point ~185 meters (m) outside the Fortress walls (Figure 2), appeared upon initial inspection to be a dry laid stone foundation of unknown function (Figure 3) (Duggan 2010; Parish 2006).

In the summer of 2006, small exploratory units were excavated as part of a field school led by Rebecca Duggan, site archaeologist and Jean-Pierre Chrétien, from the Canadian Museum of Civilisation (Duggan 2010). This excavation uncovered the corners of the foundation and revealed that the structure was ~4 x 5 m in size (Duggan 2010). A comparison of the feature's location to 18th-century maps of the fortress allowed the archaeologists to conclude that the foundation was a root cellar associated with a house owned by the Ste. Marie family (Figure 4) (Duggan 2010).

Within the root cellar were an abundance of 18th-century artifacts (Duggan 2010). This was expected since the house was occupied between 1725 and 1745 (Duggan 2007). However, rather unexpected was the discovery of human remains situated within the root cellar ~1 m below the surface (Duggan 2010). At the end of the two-week project, further

excavation was put on hold so a field crew could conduct further historical research (Duggan 2010). With a field crew assembled (which included Dr. Joseph Parish, physical anthropologist and assistant professor at Cape Breton University), excavation resumed in the fall of 2006 (Duggan 2010). In the initial stages of the project, it was believed only a small number of individuals were interred in the area. However, as excavation continued, the minimum number of individuals (MNI) quickly rose, and by the end of the excavation (in the fall of 2007) a mass burial of 48 individuals was uncovered (Figure 5) (Duggan 2010; Parish 2006, 2007).

Most of the individuals within the Ste. Marie mass burial were anatomically articulated, lying on their back, with their hands over their pelvis (Parish 2006, 2007). The manner in which they were placed is unique. The skeletal remains were in two layers, with the bottom layer oriented east to west and the top layer oriented north to south (Duggan 2010; Parish 2006, 2007). Adjacent individuals were mainly laid out opposite one another in terms of their head to toe orientation. For example, individual A was laid out head to toe (north to south), with adjacent individual B laid out toe to head (north to south) (Duggan 2010; Parish 2006, 2007) A detailed description of the skeletal remains can be found in Chapter 5.1.

The burial fill within the root cellar consisted mostly of brick and stone rubble, beach gravel, and fossiliferous limestone slabs, the latter two likely acquired from the nearby beach and limestone kiln, respectively (Duggan 2010). No personal belongings or grave goods were found with the remains, and the only artifacts associated with the burial layer were copper alloy shroud pins, indicating that the deceased were likely buried without clothes and wrapped in shrouds (Duggan 2010).

3.1 The New England Garrison Hypothesis

Historical records and archaeological evidence identified the root cellar as belonging to a house occupied by the Ste. Marie family (Duggan 2007, 2010), but why was the Ste. Marie's root cellar used for a mass burial? As mentioned in Chapter 1, The Ste. Marie house was burned down in preparation for the 1745 siege (Duggan 2010). After Louisbourg's capture and over the winter months, the New England garrison sustained epidemic-like casualties (Duggan 2007, 2010; McLennan 1918; Rawlyk 1999). It is believed that the New England garrison used the burned out foundation of the Ste. Marie's root cellar as a place to inter the dead (Duggan 2010).

Evidence from the site supports this hypothesis. The use of a root cellar for interment indicates that digging a hole in the ground was not preferred or feasible, and the fill layer within the root cellar (consisting of loose, available materials) suggests that soil for fill was not readily available (Duggan 2010; Parish 2006, 2007). These factors suggest that burial took place when the ground was frozen which could range from mid-December to early April for eastern Cape Breton Island (Duggan 2010; Parish 2006, 2007).

Since there was no burial fill between the two layers of remains, it is believed that the individuals all died within a very short period of time (Parish 2006, 2007). Thus, the high number of deceased from the New England winter occupation may be the origins of the Ste. Marie group. A high mortality rate within a short period of time could be the result of an epidemic. Louisbourg was host to two small pox epidemics, one in 1732 and one in 1755 (Hoad 1976; Johnston 1996; McLennan 1918; McNeill 1985) and the former epidemic did indeed result in the use of a mass burial on a harbour front property across

from the fortress (Johnston 1996). However, the most telling evidence from the Ste. Marie site is the presence of a burn layer and a rubble layer of brick, stone, and mortar believed to be related to the destruction of the house before the 1745 siege (Duggan 2007, 2010; Parish 2007). The placement of the individuals above the rubble and burn layers indicates the deceased were interred within the root cellar shortly after this event (Duggan 2007, 2010; Parish 2007). Considering the short time frame for interment after the introduction of the burn layer, and considering historical records of the New England occupation give testimony to the use of Rochefort Point as a burial ground (Johnston 1996; Wood 1920), it is believed that the Ste. Marie remains are that of the deceased New England garrison members who died at the Fortress in the winter of 1745-46 (Duggan 2007, 2010; Parish 2007).

3.2 Research Objectives

There are a few facts pertaining to the Ste. Marie site that appear to conflict with the New England garrison hypothesis. Osteological analysis of the remains indicated that some individuals were likely not soldiers: three were female and three were children (Parish 2006, 2007). Furthermore, there was no mention of the use of a mass grave to bury the deceased New England garrison members. Thus, the main objective of this research is to contribute to a deeper understanding of the life histories of the Ste. Marie individuals and to empirically investigate the New England garrison hypothesis. The specific questions outlined are:

1. What was the diet of the Ste. Marie individuals? Did they have a diet consisting of marine food items, terrestrial food items, or a combination of both? Did they eat C_3 or C_4 plants?
2. From where did they originate? Did they originate from New England, France, or elsewhere?
3. Are there any correlations between the individuals' isotopic values and the information obtained from the osteological analysis (e.g., age, sex, dental health, and pathological conditions)?
4. Based on the isotopic results, is it possible the Ste. Marie individuals are deceased New England garrison members?

To examine the life histories of the Ste. Marie individuals, the well-established technique of stable (carbon, nitrogen, and oxygen) and radiogenic (strontium) isotope analysis was used to reconstruct the individuals' diet and origins (see Chapter 4). This information was used in conjunction with information obtained from the osteological analysis of the Ste. Marie remains. This analysis was conducted by Dr. Joseph Parish at the Cape Breton University Bioarchaeology Laboratory (CBUBL) and included a basic assessment of age, sex, dental health, and pathologies (see Chapter 5.1).

Chapter 4

Reconstructing Diet and Origins: An Introduction to Isotope Analysis

Elemental isotopes are present in the environment and passed through the food chain to humans (Bentley 2006; Budd et al. 2004; DeNiro 1987). By making comparisons between the isotopic values of different foods or environments, and human bone and dental tissues, it is possible to uncover certain aspects of an individual's life history. For example, the types of food ingested (Raynor et al. 2008; Schwarcz et al. 1985; Walker and DeNiro 1986), the trophic level of the consumer (Bocherens et al. 1995; Minagawa and Wada 1984), origins, residency, mobility, and migration (Evans et al. 2006; Müller et al. 2003; Price et al. 2004), as well as societal and cultural aspects related to food and origins such as age, status, sex, marriage patterns, body modification, occupation, weaning age, and slavery (Bentley et al. 2005; Kusaka et al. 2011; Price et al. 2006; Prowse et al. 2005; Reitsema and Vercellotti 2012; Richards et al. 2002). The following outlines the principles of carbon, nitrogen, oxygen, and strontium isotopic analysis and the techniques used to reconstruct diet and origins.

4.1 What are Isotopes?

Isotopes are atoms of the same element but with different atomic masses (Hoefs 2004). The atomic mass of an element is the sum of the protons and neutrons within the nucleus (Hoefs 2004; Sulzman 2007). Isotopes of the same element will always have the same number of protons but will vary in the number of neutrons (DeNiro 1987; Sulzman 2007). For example, the most common isotope of carbon (C) has an atomic mass of 12 (denoted

as ^{12}C) since it has six protons and six neutrons within its nucleus (6 + 6 = 12). Another isotope of carbon is ^{13}C which has six protons and seven neutrons (6 + 7 = 13). The small atomic mass variations of different isotopes may seem inconsequential, however, within biological and ecological systems these small differences have notable and valuable impacts for archaeological research.

^{12}C and ^{13}C are *stable* isotopes, meaning they are energetically stable, and their abundance remains constant over time, while ^{14}C is a *radioactive* isotope, meaning it is unstable and undergoes radioactive decay (Hoefs 2004; Sulzman 2007). Nitrogen isotopes ^{14}N and ^{15}N, and oxygen isotopes ^{18}O and ^{16}O, are also stable (Gat et al. 2001; Parwel et al. 1956). A *radiogenic* isotope is produced by the radioactive decay of another isotope (Beard and Johnston 2000). Pertinent to this research, ^{87}Sr is a radiogenic isotope of strontium which is produced when rubidium (Rb) isotope ^{87}Rb decays due to radioactive activity (Beard and Johnston 2000).

Isotopic amounts are measured using *isotopic ratios* expressed in *delta (δ) notation* in units of *per mil* (‰), whereby an *isotopic ratio* is the abundance of one isotope compared to another isotope of the same element (e.g., $^{13}C/^{12}C$), *delta notation* is an isotopic ratio expressed relative to a standard (denoted as $\delta^{13}C$ using carbon as an example), and *per mil* indicates the number of parts per thousand (Hoefs 2004; Katzenberg 2008; Sulzman 2007). The function used to calculate the delta value of an isotopic ratio is shown below (using carbon as an example).

$$\delta^{13}C = \frac{^{13}C/^{12}C \text{ sample} - ^{13}C/^{12}C \text{ standard}}{^{13}C/^{12}C \text{ standard}} \times 1000$$

A standard is a material that has a known isotopic ratio. Researchers measure their unknowns relative to a standard, which allows for the calibration of isotopic results, as well as lab to lab comparisons (Katzenberg 2008; Mariotti et al. 1981). The isotopic values of standards fall on isotopic scales. The scale for carbon is Vienna Pee Dee Belemnite (VPDB). VPDB is a calcite containing cretaceous fossil called Belemnite (*Belemnitella americana*) from the Pee Dee formation in South Carolina (Craig 1953; Katzenberg 2008). The scale for nitrogen is AIR which is essentially the nitrogen isotopic ratio present in the atmosphere (Hoering 1955; Sulzman 1997). A positive delta value indicates a sample is isotopically heavier than the standard, and a negative value means the sample is isotopically lighter than the standard (Sulzman 2007). Furthermore, a delta value of +34‰ (for example) indicates that a sample is 3.4% higher than the scale against which the sample was compared (Mariotti et al. 1981).

4.2 Carbon and Nitrogen Isotopes: Reconstructing Diet

Two elements commonly used to reconstruct the diet of past peoples are carbon and nitrogen. The most common type of material archaeologists analyse for carbon and nitrogen isotopes is bone collagen, however, the carbonate fraction of bone and dental tissues are also analysed for carbon isotopes (Harrison and Katzenberg 2003; van der Merwe et al. 2003). This study examines carbon and nitrogen isotopes within bone collagen and carbon isotopes within tooth dentine and enamel bioapatite carbonate. The following sub-chapters summarise the processes by which carbon and nitrogen isotopes are passed from the environment through the food chain to humans and the types of information retrievable from carbon and nitrogen isotopic analysis.

4.2.1 Carbon from the Environment to Plants

Isotopes ^{13}C and ^{12}C are available in the atmosphere in the form of carbon dioxide (CO_2) which becomes incorporated into the cellular structure of plant tissue during the process of photosynthesis (Farquhar et al. 1989; Katzenberg 2008). Plants preferentially fix more of the lighter isotope (^{12}C) than the heavier isotope (^{13}C) (Craig 1954; O'Neir and Gulbransen 1939; Smith and Epstein 1971), and as a result, the $\delta^{13}C$ values of most plant tissues will be less than the atmospheric $\delta^{13}C$ values (which has a pre-industrial value of -6.5‰ [Marino and McElroy 1991]) (Bender 1971).

There are three main types of photosynthetic pathways with which terrestrial plants fix carbon dioxide. Terrestrial plants that fix carbon into a three-carbon molecule via the Calvin-Benson photosynthesis pathway are called C_3 plants (Calvin and Benson 1948; van der Merwe 1982). Plants that fix carbon into a four-carbon molecule via the Hatch-Slack photosynthesis pathway are called C_4 plants (Hatch and Slack 1966, 1970; van der Merwe 1982). C_3 plants, which predominate in temperate environments, include grasses (e.g., oats, rice, wheat, and barley), beans, trees, and most shrubs, fruits, and vegetables, while C_4 plants, which typically grow in hot dry conditions, include tropical grasses such as maize, sorghum, millet, and sugar cane (Ambrose and Norr 1993; Bender 1968; DeNiro 1987; van der Merwe 1982). Comparatively, C_3 plants have a lower $\delta^{13}C$ value than C_4 plants because C_3 plants have a greater discrimination against the heavier ^{13}C isotope (Katzenberg 2008; Waller and Lewis 1979). The $\delta^{13}C$ values of C_3 plants typically range from -35 – -20‰ and average -27‰, and C_4 plants typically have values between -20 and -6‰ and average -13‰ (Bender 1971; Smith and Epstein 1971; van der Merwe 1982). Photosynthesis by marine plants can be similar to either the Calvin-Benson or the

Hatch-Slack pathway (Reinfelder et al. 2000; Xu et al. 2012) and have $\delta^{13}C$ values that overlap with C_3 and C_4 terrestrial plants (DeNiro 1977; Schoeninger and DeNiro 1984; Smith 1972; Smith and Epstein 1971).

Terrestrial plants that fix carbon dioxide via Crassulacean acid metabolism are called CAM plants and include cacti, agave, pineapple, and other succulents (Ambrose and Norr 1993; Osmond et al. 1973). Depending on the growth conditions, CAM plant photosynthesis can be similar to C_3 plants or to C_4 plants, and as a result, the $\delta^{13}C$ values of CAM plants overlap with C_3 and C_4 values (Osmond et al. 1973). Since these types of plants do not grow locally and are not listed on historical foodstuff import records from the Fortress of Louisbourg (see Chapter 2.3.1), CAM plants were not considered in this study. In summation, there are three types of isotopic information concerning plant carbon isotopes considered in this study: C_3 terrestrial plants, C_4 terrestrial plants, and marine plants.

4.2.2 Nitrogen from the Environment to Plants

Terrestrial plants acquire nitrogen from the atmosphere in the form of nitrogen gas (N_2) and/or from soil in the form of nitrate (NO_3) or ammonium (NH_4) (DeNiro 1987; Evans and Barber 1977). Nitrogen isotopes ^{14}N and ^{15}N are present in the air with an overall delta value ($\delta^{15}N$) value of 0‰ (Parwel et al. 1956), while nitrogen isotopes in the soil vary according to geologic material, topography, and various other environmental factors (Cheng et al. 1964; Garten 1993; Wada et al. 1975). Those plants that acquire nitrogen through both atmospheric and soil sources are called nitrogen fixers (N_2-fixers) and include some species of shrubs, trees, ferns, lichens, mosses, and legumes such as peas,

beans, clover, and alfalfa (DeNiro 1987; Evans and Barber 1977; Virginia and Delwiche 1982). Non-N_2-fixers rely on soil nitrogen only (NO_3 and NH_4) (Evans and Barber 1977). Since atmospheric nitrogen has lower $\delta^{15}N$ values than most soil nitrogen (Cheng et al. 1964; Parwel et al. 1956), legumes and other N_2-fixers have $\delta^{15}N$ values that are typically isotopically lighter than non-N_2-fixers (Virginia and Delwiche 1982; Wada et al. 1975). Furthermore, the incorporation of seawater-bound nitrogen by marine plants produces $\delta^{15}N$ values that are typically higher than that of terrestrial plants (Miyake and Wada 1967; Schoeninger and DeNiro 1984; Waser et al. 1998). This difference allows for the discrimination between marine plants from C_3 and C_4 plants when $\delta^{13}C$ and $\delta^{15}N$ values are analysed in conjunction with one another (Figure 6).

4.2.3 Carbon and Nitrogen from Plants to Animals and Humans

When plant tissue is eaten by herbivores and omnivores the carbon and nitrogen isotopic values of these plants are passed into the animals' skeletal tissue (DeNiro and Epstein 1978, 1981). Since C_3 vs. C_4 plants and marine vs. terrestrial plants have more or less distinct isotopic ranges (Schoeninger and DeNiro 1984; van der Merwe 1982), animals eating relatively homogeneous diets of C_3 vs. C_4 and marine vs. terrestrial plants will likewise have more or less distinct $\delta^{13}C$ and $\delta^{15}N$ values (Honch et al. 2012; Schoeninger et al. 1983).

In this study, the types of skeletal tissue analysed for diet reconstruction include bone collagen, which was analysed for carbon and nitrogen, and the carbonate portion of enamel and dentine bioapatite, which was analysed for carbon content. When reconstructing diet, it is important to understand the biological processes by which these

tissues are formed.

Bone Collagen Carbon and Nitrogen Isotopes: Bones are composed of 24% organic material, of which, the protein collagen constitutes 90% (Grant and Prockup 1972; International Commission on Radiological Protection [ICRP] 1975). Collagen is often the material of choice for isotopic analysis for a number of reasons. First, collagen is resistant to degradation (Katzenberg 2008; Nelson et al. 1986; Yoder 2010). Second, any degradation that has occurred can be detected by a number of means (see Chapter 5.3.2). Third, collagen contains both carbon and nitrogen at ~35% and 11 – 16%, respectively (van Klinken 1999) which allows for the analysis of both carbon and nitrogen isotopes within the same sample.

Due to a process called bone remodeling, animal bones are constantly turning over (Hadjidakis and Androulakis 2006). Old bone tissue is absorbed by the body and new bone tissue is formed (Hadjidakis and Androulakis 2006). When collagen is forming within new bone tissue, it utilises pre-existing protein from the animal's diet, and as a result, the isotopic information retrieved from bone collagen reflects the protein portion of the consumer's diet (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993).

Furthermore, if one were to analyse the isotopic ratio of carbon and nitrogen along a single food chain (plant-herbivore-carnivore), the delta values will be progressively shifted (DeNiro 1977; DeNiro and Epstein 1978, 1981; Minagawa and Wada 1984; Schoeninger and DeNiro 1984). This phenomenon is possible because isotopes of the same element *differ* in the number of neutrons but will always have the *same* number of

electrons (Hoefs 2004; Sulzman 2007). The *difference* in the number of neutrons between isotopes means they will have different masses (resulting in different reaction rates and bond strengths) which will cause isotopes of the same element to behave *physically different* (Bigeleisen 1949; Hoefs 2004). The *similarity* in the number of electrons between isotopes means that they will be able to form the same types of chemical bonds which will allow isotopes of the same element to behave *chemically similar* (Hoefs 2004; Sulzman 2007). For example, isotope ^{12}C can form the same chemical compounds as isotope ^{13}C, but since ^{12}C is isotopically lighter than ^{13}C, ^{12}C will more readily form chemical reactions because of its faster reaction rate (Bigeleisen 1949). Within the biochemical system of animals, the heavier ^{13}C and ^{15}N isotopes will be preferred over the lighter ^{12}C and ^{14}N isotopes (DeNiro and Epstein 1981; Katzenberg 2008; Michener and Kaufman 2007). As a result, the consumer will have slightly higher carbon and nitrogen delta values compared to the consumer's diet (DeNiro 1977; DeNiro and Epstein 1978, 1981; Minagawa and Wada 1984; Schoeninger and DeNiro 1984). Since the heavier isotope is preferred in this instance, the consumer's cellular tissue can be referred to as *isotopically heavier* than the consumer's diet which in turn can be referred to as *isotopically lighter* by comparison.

The above process is called fractionation, and if one were to graph the isotopic values of a simple food chain (Figure 7), the $\delta^{13}C$ and $\delta^{15}N$ values of consecutive diet components will increase in a stepwise fashion (e.g., carnivores will have higher delta values than the omnivores which will have higher delta values than the herbivores) (Minagawa and Wada 1984; Miyake and Wada 1967; Schoeninger and DeNiro 1984). These isotopic shifts, called fractionation factors, have a value of ~1‰ for $\delta^{13}C$ and ~3‰

for $\delta^{15}N$ (DeNiro 1977; DeNiro and Epstein 1978, 1981; Minagawa and Wada 1984; Schoeninger and DeNiro 1984).

Dental Tissue Bioapatite Carbon Isotopes: Bioapatite comprises 75% and 58% (dry weight) of enamel and dentine, respectively (Bowes and Murray 1935). Carbon isotopes within the bioapatite portion of enamel and dentine can be measured from the carbonate molecule (CO_3) which occasionally occupies the hydroxyl (OH) and phosphate (PO) position within bioapatite's chemical formula: $Ca_{10}(PO_4)_6(OH)_2$ (LeGeros et al. 1969). Foreign carbonate is able to absorb into the surface of structural carbonate crystals (Krueger 1991), and therefore, any surface carbonate is systematically removed prior to analysis by purification procedures (see Chapter 5.3.3).

As discussed previously, carbon from bone collagen is acquired from the consumer's protein intake (Ambrose and Norr 1993; Tieszen and Fagre 1993), but carbon from bioapatite sources is acquired from bicarbonate in the blood (Lee-Thorp et al. 1989; Poyart et al. 1975) which originates from ingested macronutrients: carbohydrates, lipids, and proteins (Ambrose and Norr 1993; Krueger and Sullivan 1984; Tieszen and Fagre 1993). As a result, isotope analysis of bioapatite carbon reflects contributions from an animal's *total* diet (Ambrose and Norr 1993; Tieszen and Fagre 1993). Since collagen isotopic data only reflect information about the protein portion of a consumer's diet, collagen isotopic results can be biased towards diets that are rich in protein (e.g., meat), while very low protein food (e.g., plant material) may be relatively imperceptible (Ambrose and Norr 1993; Krueger and Sullivan 1984). By analysing carbon isotopes from both collagen and bioapatite, it is possible to contrast and compare protein vs. total

diet contributions (Ambrose and Norr 1993; Harrison and Katzenberg 2003; Jim et al. 2004).

As a result of the isotopic variability of different environments and plants, and of the chemical, biological, and physiological processes of tissue development within a consumer's body, isotopic analysis of body tissues can reveal interesting information concerning a consumer's diet (C_3 vs. C_4, marine vs. terrestrial, N_2-fixers vs. non-N_2-fixers) and trophic position (herbivore, omnivore, and carnivore).

A common approach for reconstructing an individual's diet is to first analyse the isotopic values of potential food sources available within the environment relating to the context in question (Ambrose 1991; Codron et al. 2007; Tykot et al. 2009). Depending on where an individual's isotopic values fall relative to data from potential food items, it is possible to make inferences concerning an individual's dietary source(s).

4.3 Oxygen Isotopes: Reconstructing Origins

Oxygen isotopes in bone and dental tissues allow researchers to examine questions relating to origin, residency, and the geographical movement of people. This study involves the analysis of oxygen isotopes in bioapatite carbonate in tooth dentine and enamel.

4.3.1 Oxygen in the Environment

Oxygen isotopic analysis involves stable isotopes ^{16}O and ^{18}O. Similar to stable isotopes of carbon and nitrogen, oxygen isotope ratios are expressed in delta notation ($\delta^{18}O$) in

units of per mil (‰) relative to the scales VPDB or VSMOW (Vienna Standard Mean Ocean Water) (Craig 1961).

Oxygen isotopes are available in abundance in the atmosphere, in precipitation, and in groundwater. The main source of atmospheric oxygen is from ocean water (Gat et al. 2001). As water evaporates from the ocean, there is a preferential loss of the lighter isotope ^{16}O which creates atmospheric vapor with a lower $\delta^{18}O$ value than oceanic oxygen (Bleeker et al. 1966). With a decrease in temperature within a cloud system, atmospheric vapor condenses, and in the transition there is a preferential loss of the heavier ^{18}O isotope (Bleeker et al. 1966; Dansgaard 1964; Gat et al. 2001). The $\delta^{18}O$ value of precipitation is highest in oceanic equatorial regions, but as atmospheric vapor moves inland and to higher altitudes and latitudes (with colder temperatures and varying humidity and precipitation amounts), the $\delta^{18}O$ value of precipitation continues to decrease as cloud vapor becomes progressively depleted in ^{18}O (Bleeker et al. 1966; Dansgaard 1953, 1954, 1964; Gat 1996). Considering the relationship between temperature and oxygen isotope fractionation, seasonal variations of precipitation $\delta^{18}O$ values have also been observed (Dansgaard 1964; Price et al. 2008).

The $\delta^{18}O$ value of groundwater is often found to be similar to the $\delta^{18}O$ value of local precipitation (Aggarwal et al. 2004), while river water is typically reflective of the $\delta^{18}O$ values of precipitation and run-off from the river's catchment area (Dutton et al. 2005). Since a catchment area describes an upstream location higher in elevation (with lower $\delta^{18}O$ values) the $\delta^{18}O$ value of a river is often isotopically lighter than the $\delta^{18}O$ value of local precipitation (Dutton et al. 2005). $\delta^{18}O$ values in non-oceanic large bodies of water, such as lakes and aquifers, are formed from various sources (e.g., precipitation,

tributary water, and groundwater) and are subject to various fractionation effects such as evaporation and drainage (Dansgaard 1954; Dinçer 1968; Epstein and Mayeda 1953).

Considering the various climatic and geographic factors that affect oxygen isotopes, $\delta^{18}O$ values around the world are extremely varied. The Global Network for Isotopes in Precipitation in co-operation with the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO) began documenting meteoric and isotopic conditions by analysing and mapping meteoric $\delta^{18}O$ values from hundreds of stations around the world (Gat et al. 2001; Price et al. 2008). This research is ongoing and has resulted in a detailed database of $\delta^{18}O$ values which has been utilised in this thesis and can be accessed via the IAEA/WMO website (IAEA/WMO 2013).

4.3.2 Oxygen from the Environment to Plants, Animals, and Humans

Oxygen is incorporated into plant tissue largely from meteoric water percolating within the soil (Ritchie 1998; Tang and Feng 2001). Animals ingest oxygen isotopes from drinking water, food-bound water, and to a lesser degree atmospheric O_2 (Kohn 1996; Longinelli 1984). The oxygen isotopes are then incorporated into the bioapatite portion of skeletal tissues (Land et al. 1980). As a result, the isotopic values of skeletal tissue bioapatite are largely a reflection of local meteoric water (Longinelli 1984).

The type of skeletal tissue analysed (bone or enamel) has an impact on the type of information received by isotopic analysis. Since enamel forms during childhood and does not regenerate, its isotopic values will reflect the juvenile stages of that individual's life (Hillson 1996; Sealey et al. 1995). In contrast, bone tissue regenerates throughout an

individual's development, and as a result, the isotopic information therein represents an averaging of isotopes ingested in the more recent stages of an individual's life (Hadjidakis and Androulakis 2006; Sealey et al. 1995). In terms of oxygen isotopes, this study focuses on the analysis of dental tissues only.

There are two types of molecules within dental tissue bioapatite that can be analysed for $\delta^{18}O$ content: phosphate (PO_4) and carbonate (CO_3) (Daux et al. 2008; Harrison and Katzenberg 2003). The chemical formula for bioapatite is $Ca_{10}(PO_4)_6(OH)_2$ (ICRP 1975). Within this formula, carbonate molecules are able to occupy the hydroxyl position (OH) and the phosphate position (PO) (LeGeros et al. 1969). The correlation between phosphate and carbonate molecule $\delta^{18}O$ values has been determined to be high (e.g., Bryant et al. (1996) reports a correlation of r^2=0.986 with an offset of 8.7‰, and Iacumin et al. (1996) reports r^2=0.98 with an offset of 9.2‰), thus, either molecule can be used as a reliable indicator of a consumer's water intake (Bryant et al. 1996). While it is believed that the phosphate molecule is more resistant to digenesis than carbonate, based on the superior strength of the P-O chemical bond over the C-O bond, this appears to be true for bone and dentine only (Martin et al. 2008; Sponheimer and Lee-Thorp 1999). Conversely, carbonate content in enamel bioapatite have been found to be largely unaffected by digenetic processes (Chenery et al. 2012; Koch et al. 1997). For more information on this, please see Chapter 4.5.

In practice, the superior strength of the P-O bond in bioapatite makes the analysis of phosphate more difficult and lengthy than the analysis of carbonate (Sponheimer and Lee-Thorp 1999). Furthermore, by analysing the carbonate molecule, researchers are able

to analyse oxygen and carbon isotopes simultaneously. For these reasons, bioapatite carbonate was the molecule of choice for the analysis of $\delta^{18}O$ values in this study. As discussed in Chapter 4.2.3, the examination of carbon atoms within bioapatite carbonate allows researchers to examine a consumer's total diet.

By analysing bioapatite $\delta^{18}O$ values within dental tissues and comparing these with local groundwater and precipitation $\delta^{18}O$ values, it is possible to examine questions relating to geographic origins, residency, mobility, and migration. For example, If an individual's enamel $\delta^{18}O$ value differs from local $\delta^{18}O$ values, it is likely they did not grow up in the local environment (Dupras and Schwarcz 2001; Evans et al. 2006). Conversely, if an individual's enamel $\delta^{18}O$ value matches local $\delta^{18}O$ values, than it is likely that they grew up in the local environment or in an environment with similar $\delta^{18}O$ values (Budd et al. 2004; Knudson et al. 2012). Also, by utilising oxygen isotopic data from other regions, it is possible to speculate on the origins of a non-local individual (Schroeder et al. 2009).

4.4 Strontium Isotopes: Reconstructing Origins

Similar to oxygen analysis, strontium analysis allows researchers to examine an individual's origins, residency, and geographic movement. This study involves the analysis of strontium isotopes from tooth enamel and dentine. Where oxygen isotopes reflect local meteoric water, strontium isotopes generally reflect the local geology of an individual's food source.

4.4.1 Strontium in the Environment

Strontium isotopes are present in calcium (Ca) bearing minerals such as apatite, calcite, gypsum, plagioclase feldspar, and many others (Bentley 2006; Capo et al. 1998). Within geologic materials, strontium isotope ^{87}Sr is produced by the radioactive decay of rubidium isotope ^{87}Rb (half-life 48.8 x 10^9) which is able to replace potassium in potassium feldspar, mica, clay, and many other minerals (Bentley 2006; Capo et al. 1998). As a rock ages, more and more ^{87}Rb decays, thus increasing the rock's ^{87}Sr concentration (Capo et al. 1998). The overall amount of ^{87}Sr will also be influenced by the rock's original strontium and rubidium concentrations (Budd et al. 2004; Dasch 1969).

Strontium is represented as a ratio of two isotopes: ^{87}Sr and ^{86}Sr. If one were to use the abundance of ^{87}Sr only, such a value would not account for variations in total strontium concentration which could drastically skew the results (Beard and Johnston 2000). To remove this bias and account for overall strontium abundance, ^{87}Sr is compared to ^{86}Sr, a stable isotope whose abundance does not change over time (Beard and Johnston 2000). By using the ratio $^{87}Sr/^{86}Sr$, any bias created by total strontium variation is removed, and the value produced is representative of the decay of ^{87}Rb into ^{87}Sr (reflecting the age of the rock) and of the relative rubidium and strontium composition only (Beard and Johnston 2000; Bentley 2006). The overall strontium concentration of skeletal materials is represented as a weight percentage in parts per million, meaning the number of parts of strontium, per million parts of skeletal material (Schoeninger 1985).

Considering the long half-life of Rb (48.8 x 10^9 years) and the different types of geologic materials with variable Rb and Sr compositions, $^{87}Sr/^{86}Sr$ values are quite variable across the Earth (Beard and Johnston 2000) and can even be quite diverse across

smaller regions (Sillen et al. 1998). In general, rocks with a high $^{87}Sr/^{86}Sr$ value (more than ~0.710) will be those that are very old with a high Rb/Sr ratio (e.g., continental crust granite), and rocks with a low $^{87}Sr/^{86}Sr$ value (less than ~0.704) will be younger with a low Rb/Sr ratio (e.g., oceanic basalt) (reviewed in Bentley 2006; Capo et al. 1998). As bedrock erodes, the soils produced will have a $^{87}Sr/^{86}Sr$ value that reflects the type of bedrock, the various erosion rates of different mineral types therein, the age of the bedrock, and the strontium and rubidium concentrations within these materials (Bentley 2006; Price et al. 2002).

Strontium is also available from other sources. Atmospheric strontium is deposited and absorbed on the surface of plant leaves (Graustein and Armstrong 1983). In some instances, water sources, such as precipitation, ground, river, and ocean water, can be significant contributors and transporters of strontium isotopes (Aubert et al. 2002; Négrel et al. 2004; Palmer and Edmond 1992; Whipkey et al. 2000; Xu and Han 2009). The $^{87}Sr/^{86}Sr$ ratio of river water ranges from 0.7045 – 0.943 worldwide (Veizer 1989) and 0.70460 – 0.73844 in Canada's major rivers (Wadleigh et al. 1985). Modern ocean water has a constant $^{87}Sr/^{86}Sr$ ratio of 0.70923 (DePaolo and Ingram 1985) since the residence time of oceanic strontium far exceeds the mixing time of the ocean (5 million years vs. ~1000 years) (Hess et al. 1986). Furthermore, in modern contexts strontium can be introduced to the area from fertilizers and pollution which can significantly alter the natural $^{87}Sr/^{86}Sr$ value of an environment (Böhlke and Horan 2000; Hurst et al. 1991; Jiang 2011). Overall, strontium isotopes are available from a variety of natural and anthropogenic sources.

4.4.2 Strontium from the Environment to Plants, Animals, and Humans

Strontium from the environment is taken up by plants, and when these plants are eaten by animals, the strontium is passed along the food chain (Comar et al. 1957). Atmospheric and water sources commonly contribute less strontium to plant materials than geologic materials (Beard and Johnston 2000; Capo et al. 1998; Price et al. 2002), but depending on the environment, atmospheric and water sources may become more significant contributors (Graustein and Armstrong 1983; Miller et al. 1993; Whipkey et al. 2000).

Strontium from an animal's diet is incorporated into the animal's skeletal tissue because of its chemical similarity to calcium, a common component of bioapatite found in bone and dental tissues (MacDonald et al. 1951a, 1951b; Parker and Toots 1970). Unlike carbon and nitrogen isotopes, strontium isotopic values do not fractionate as they are passed through the food chain (Blum et al. 2000). If any mass-based fractionation did occur, this would be corrected during analysis by the normalisation of the ratio of non-radiogenic isotopes $^{86}Sr/^{88}Sr$ to a set value of 0.1194 (Capo et al. 1998). Thus, a consumer's $^{87}Sr/^{86}Sr$ value will be similar to the $^{87}Sr/^{86}Sr$ value of its diet, and ultimately, their local environment (Blum et al. 2000).

This study only involves the analysis of tooth enamel for the purpose of studying strontium isotopes. Since enamel does not turnover once fully developed (Hillson 1996), enamel $^{87}Sr/^{86}Sr$ values will reflect the individual's geographic location during childhood (Sealey et al. 1995). By analysing bioapatite strontium isotopes within dental tissues and comparing these with local strontium values, it is possible to examine questions relating to origins, residency, mobility, and migration. For example, if an individual's enamel $^{87}Sr/^{86}Sr$ values match local $^{87}Sr/^{86}Sr$ values, then it is likely that they grew up in the local

area (or in an area with a similar $^{87}Sr/^{86}Sr$ value) (Conlee et al. 2009; Price et al. 2004). Conversely, if an individual's enamel $^{87}Sr/^{86}Sr$ values are different from local $^{87}Sr/^{86}Sr$ values, then it is likely that they did not grow up in the local environment (Kusaka et al. 2011). In theory, a consumer can be traced back to the geologic environment where they grew up, by comparing the consumer's dental $^{87}Sr/^{86}Sr$ value to the $^{87}Sr/^{86}Sr$ values of a given environment (Oulhote et al. 2010). In practice, determining a consumer's origin becomes complicated by the fact that numerous areas around the world have similar $^{87}Sr/^{86}Sr$ values. However, by utilising strontium isotopic research conducted in areas around the world, it is possible to speculate on the origins of a consumer (Müller et al. 2003; Schroeder et al. 2009).

For such comparisons to be made, it is necessary to know the $^{87}Sr/^{86}Sr$ values of the environment in question. Since strontium atoms originate from a number of sources (e.g., geologic, water, atmospheric, and anthropogenic) with differing strontium values and pass through a number of pathways (e.g., weathering and mixing) before uptake and incorporation into skeletal tissues, a good approach for strontium analysis as a means for determining origins is to first determine the $^{87}Sr/^{86}Sr$ ratio that is biologically available (Laffoon et al. 2012; Price et al. 2002; Sillen et al. 1998). A common method for determining the biologically available strontium of an area is to analyse the strontium content of local organisms, ideally from the same location and temporal period as the consumer(s) in question (Price et al. 2002). The $^{87}Sr/^{86}Sr$ values present in local flora and fauna, representing the biologically available strontium of an environment, can then act as a baseline against which the human isotopic values can be compared (Bentley et al. 2004; Price et al. 2002).

4.5 Bone vs. Dental Tissues: Isotopic 'Visibility' and Diagenesis

The interpretation of isotopic values must consider the time ranges that are detectable or 'visible' within different skeletal materials caused by the differential formation periods of bone vs. dental tissue. There are also numerous concerns regarding the susceptibility of bone and dentine bioapatite to diagenetic alteration, as opposed to the relative impervious nature of enamel bioapatite. The following discussion concerns the causes and consequences of these issues.

While enamel remains unchanged from initial formation, and the isotopic values therein reflect the consumer's isotopic intake during their juvenile years, bone tissue regenerates throughout an individual's life, and as a result, the isotopic values of bone reflect a consumer's isotopic intake during more recent years (Hadjidakis and Androulakis 2006; Hillson 1996; Lee-Thorp 2002). By using the 'temporal visibility' differences of bone vs. enamel, it is possible to comment on the geographic movement of an individual by comparing the older isotopic values (within enamel), with the more recent isotopic values (within bone) (Müller et al. 2003; Price et al. 2004; White et al. 2004b). A difference between the strontium or oxygen values of enamel vs. bone suggests that an individual migrated between two geologic or meteoric areas with differing isotopic values between childhood and adulthood, while a similarity of these values suggests that the individual remained in the same location since birth (but does not rule out the possibility that the individual moved between isotopically similar geologic and meteoric areas during their life) (Beard and Johnston 2000; White et al. 2004b). If an individual was fairly mobile during life, or ingested food and water originating from different regions their skeletal tissue will convey a mixing of various strontium and

oxygen values (Bentley 2006; Longinelli 1984).

There are major issues concerning the susceptibility of bone bioapatite to digenesis. Enamel is very resistant to diagenesis because of its high density, large crystal size, low porosity, and low organic component, and as a result, the isotopic values within enamel are highly biogenic (Hoppe et al., 2003; Koch et al. 1997; Kohn and Cerling 2002; Kohn et al. 1999; Lee-Thorp and van der Merwe 1991; Lee-Thorp 2002; Wang & Cerling 1994). Conversely, because of the high porosity, high organic component, and small crystal size of the inorganic portion of bone and dentine, these materials may undergo dissolution (causing loss of original isotopes) or mineral absorption or recrystallisation (resulting in the incorporation of foreign isotopes) causing the isotopes within bone and dentine to be highly diagenetic in origin (Hoppe et al. 2003; Koch et al. 1997; Kohn and Cerling 2002; Kohn et al. 1999; Lee-Thorp and van der Merwe 1991; Lee-Thorp 2002; Nelson et al.1986; Wang and Cerling 1994). For these reasons, this study excludes the use of bone bioapatite for isotopic examinations of an individual's diet and origins.

This study includes the analysis of the collagen component of bones. Collagen is relatively more impervious to diagenesis than bone bioapatite, but collagen deterioration is possible and depends on a number of factors such as time, temperature, and microbial action (Collins et al. 2002). Methods to detect diagenesis within bone collagen samples have been developed by DeNiro (1985) and van Klinken (1999), and involve examining carbon to nitrogen (C/N) atomic ratios and collagen yields, respectively (see Chapter 5.3.2).

The isotopic visibility differences between bone and dental tissue are still an issue in this study (since the materials analysed in this study include bone collagen and dental

bioapatite). These differences were considered when contrasting and comparing the isotopic values of each material in making inferences regarding a specimen's or individual's diet and origins.

For humans, all permanent teeth (excluding the third molar) are estimated to erupt at different stages between the ages of ~6 and ~13 (ICRP 1975). Approximate years of tooth development are shown in Table 1. Depending on the tooth analysed, the isotopic values will reflect the isotopic intake during development of the enamel. Bone tissue turnover varies depending on the bone in question, the bone material (e.g., cortical vs. trabecular), and the age and health of the individual (Bryant and Loutit 1964; Jowsey 1960; Jowsey et al. 1965; Klepinger 1984; Sealey et al. 1995). Bone turnover rates are high for young individuals and generally decrease as an individual ages (Jowsey 1960; Jowsey et al. 1965). The mean percent turnover rates per year of whole adult bones and the number of years required for 100% turnover are shown in Table 2. Depending on the bone analysed, the isotopic values will roughly represent the most recent years of an individual's life as calculated from the turnover rate of each bone type. For example, isotopic values from whole ribs will represent the individual's isotopic intake during the last 21.3 years of that adult's life.

The above values pertain to whole bone. However, the estimated percentage turnover for adult cortical and trabecular bone is reported as 2.5 – 4% and 10% per year, respectively (ICRP 1973; Klepinger 1984; Manolagas 2000). Since the skeleton is formed largely of cortical tissue by weight (Hadjidakis and Androulakis 2006; ICRP 1975), the above values are closer to the turnover rates of cortical bone (2.5 – 4%), as opposed to trabecular bone (10%). More specifically, bones that are largely cortical tissue (e.g.,

femur and tibia shaft) have lower % annual turnover rates (1.8, 1.1, and 2.0, respectively) and therefore take several decades to remodel (55.6, 90.9, and 50.0 years, respectively), while bones that contain less cortical bone and comparatively more trabecular bone (e.g., vertebra, rib and iliac crest) have higher % annual turnover rates (8.3, 4.7, and 6.5, respectively) and therefore remodel within a couple decades (12.0, 21.3, and 15.4 years, respectively) (Bryant and Loutit 1961 in ICRP 1975; Bryant and Loutit 1964; Hadjidakis and Androulakis 2006; Jowsey et al. 1965; Spiers 1966). These values pertain to bulk bone material (i.e., both cortical and trabecular bone). More suitable for this study is the estimated turnover rate of an adult's cortical bone which is estimated to between ~2.5 and 4% per year (ICRP 1973; Manolagas 2000). As a result, the $\delta^{13}C$ and $\delta^{15}N$ values of cortical bone collagen will represent the average carbon and nitrogen intake from the last ~25 – 40 years of an adult's life. Overall, inferences concerning diet and origins must consider the diagenetic susceptibility of the skeletal tissues examined (bone vs. enamel) and the time ranges represented by the materials analysed (e.g., bone vs. teeth, and bone element and type).

Chapter 5

Materials and Methods

5.1 Ste. Marie Individuals

Each set of remains is identified using the Parks Canada provenience system. Using individual 55L28F34 as an example: 55L is the site number, wherein 55 represents a section of Rochefort Point and L represents the Fortress of Louisbourg. The number 28 represents the 28th operation within that location, F is the sub-operation or unit, and 34 is the lot number (the 34th lot within sub-op F). In this case, 55L28F34 represents a single set of human remains. Some individuals' remains extended across two sub-ops, and as a result, were given a double provenience (e.g., 55L28E8/55L28F22). An adult and sub-adult were given the same sub-op and lot (D7) but are differentiated from one another by the letters 'A' and 'B' where A is the adult and B is the sub-adult. Since all individuals begin with the letters/numbers 55L28, each individual will henceforth be referred to by their sub-op letter(s) and lot number(s) only (e.g., F34, E8/F22, D7A/F8, and D7B).

It should also be noted that during the osteological analysis of individual A17, small foot bones were found which did not belong to this individual's skeleton or to the neighbouring skeletons. As a result, A17 was given a MNI of two but had not yet been divided into A17A and A17B at the time of this study. All data for this study are associated with the full skeleton (possibly later to be re-designated as '55L28A17A') and not the small foot bones (possibly later to be reassigned as '55L28A17B'). No skeletal materials were analysed from individual A17B.

Once excavated, the human remains were sent to the CBUBL for osteological analysis. Analysis was performed by Dr. Joseph Parish, using standard data collection record forms developed by Buikstra and Ubelaker (1994). The remains were brushed clean of any loose matrix and given a basic assessment of age and sex, as well as a brief overview of dental health and visible pathological conditions. Age designations were based on such studies by İsçan (1985), İsçan et al. (1984a, 1984b), Brooks and Suchey (1990), Suchey and Katz (1986), Todd (1921a, 1921b), Lovejoy et al. (1985), and Meindl and Lovejoy (1989). Sex designations were based on, but not limited to, studies by Scheuer and Elkington (1993), Buikstra and Ubelaker (1994), and Phenice (1969). Other characteristics, including dental health, pathologies, congenital traits, and ethnicity, were based off studies by Mayhall (2000), Buikstra and Ubelaker (1994), Dahlberg (1956), Hershey (1979), Ortner (2003), Saunders (1978), and Barnes (1994).

The Ste. Marie root cellar burial included a total of 48 individuals: 45 adults and three sub-adults. A total of three individuals were identified as female, 25 were identified as male, and another 20 could not be identified according to sex (Parish 2006, 2007). Also uncovered from the Ste. Marie site (and included in this study) was an additional single individual (H3) located exterior to the root cellar on the northeast corner. It is believed that this burial was re-interred from a previous resting place, a common occurrence at the Fortress of Louisbourg (Johnston 1996, 2001; Parish 2007). The dates when this individual died or was re-interred, are unknown (Parish 2007). This grave included the disarticulated remains of an adult male which brings the total number of individuals retrieved from the site up to 49 (with 26 males and 46 adults).

The osteological analysis (Parish 2006, 2007) has resulted in age designations for 33 of the Ste. Marie individuals. One individual was over 50, 10 individuals were in their 30s or 40s, 22 individuals were in their 20s or younger, and of these, three were sub-adults (i.e., less than 15 years old) (Table 3). The dental health of all individuals recovered at the Ste. Marie site was worse than expected, with numerous carious lesions common on both the young and old, possibly indicating a sweeter than normal diet for this time and place in history. The most common pathological conditions observed were porotic hyperostosis and periostitis, which are bone conditions caused by a lack of essential nutrients, such as iron and vitamin C, likely caused by a poor diet or metabolic disorder. Population affinity based on osteological analysis was inconclusive due to the damaged state of the cranial and facial bones. Also noted were numerous cases of muscular strain in the arms and shoulders suggesting a physically demanding lifestyle, as well as pipe smoker wear on many individuals' teeth indicating a regular habit of pipe smoking.

Parish's (2006, 2007) osteological analysis also included possible cause of death. H3 (male, 18 – 25 years old), found outside the northeast wall of the root cellar, showed blunt force trauma to the right cranium from a single pronged instrument less than one centimeter in diameter. Sub-adults D7B and F32 (three to four and ~12 years at time of death, respectively), showed incomplete fusion of the cervical and thoracic vertebrae, respectively, a congenital disorder or genetic defect which may have contributed to their young deaths. D12, a male adult 18 – 20 years old at time of death, likely died due to complications related to the below-knee amputation of his right leg. Another male individual, E8/F22 (over 35 years old), showed possible cause of death indicators

consistent with death by hanging. These indicators include complete and incomplete greenstick fractures to the C1 – C3 with a wear pattern on the mandible possibly related to agitation by the noose's rope. Other injuries reported include two (possibly three) puncture wounds, possibly from a pronged fork, to the right cranium of E7, one of the oldest males with an age at time of death of 50 – 55 years. A18, a female adult, had an iron fragment (possibly from a pike or bee-de-corbin) impaled in a cranial fragment located near the front of her skull. For the other individuals, cause of death could not be determined via osteological analysis.

Concerning the materials and elements analysed in this study, long bones and ribs were preferred over other bone elements. Each individual was sampled for bone collagen twice to observe the variability of isotopic values within the same bone or within different bones from the same individual. For the dentition, molars (excluding third molars) were the preferred choice over premolars, canines, or incisors. If possible, enamel and dentine samples were taken from the same tooth, but this was not always feasible. Due to taphonomic forces, not all individuals from the Ste. Marie site had a full skeleton available for isotopic analysis, and not all the materials recovered were suitable for analysis. Wave action from the storm had removed the superior portion (including the teeth) of some individuals, while extreme bone decomposition rendered isotopic analysis of bone impossible for other individuals. As a result, the bone and tooth elements chosen to represent each individual for isotopic analysis depended on the availability and state of preservation of the preferred elements within each set of remains. The total number of individuals sampled was 44. Twenty-nine individuals were sampled for both bone and

dental tissues, 11 were sampled for bone only, and four individuals for dental tissues only.

5.2 Faunal Specimens

A total of 58 faunal specimens excavated from the Ste. Marie site were analysed in this study. The faunal identification was performed by Dr. Joseph Parish of Cape Breton University. A further 51 faunal specimens were selected from faunal identification studies performed by Steve Cumbaa and Anne Rick at the Zooarchaeological Identification Centre at the Canadian Museum of Nature. Almost all of these specimens came from archaeological excavations within Blocks 3 and 4 which are located across from the quay wall on the north end of the town. Block 3 held Louisbourg's first cemetery, a bakery, a guardhouse, an inn, a tavern, a pool hall, a large storehouse, a public square, and residential homes including a surgeon's home (Harris 1982). Within Block 4 were a number of business establishments, including a bakery, butchery, and an inn, as well as many residential homes, some owned by prominent merchant families (Cumbaa 1976).

The total number of faunal specimens sampled from the Ste. Marie site and the town site was 109. Mandible or maxilla elements containing teeth were preferred so inferences involving diet and origins could be drawn concerning a single individual. In some cases this was not possible. The number of individual specimens sampled for both bone collagen and dental tissues was 17. The total number of specimens sampled for bone collagen only was 74, and the total number of specimens sampled for dental tissue only was 18.

The types of faunal species selected were chosen to represent the types of food that would have been available to a Louisbourg resident. Codfish was the main protein source, followed by cow and sheep (Cumbaa 1976; Lane Jonah and Véchambre 2012). Other domestic animals sampled include pigs, goats, horses, chickens, turkeys, and domestic geese. Some animals may have been born and raised locally, while others may have been raised and butchered elsewhere and imported to Louisbourg as meat. Some animals may have been raised elsewhere and imported as livestock which were then living in Louisbourg for an unknown duration. Since hunting wild animals was common at Louisbourg (Lane Jonah and Véchambre 2012; McNeill 1985), a variety of wild fauna were also sampled. Wild specimens include snowshoe hares, red squirrels, beavers, red foxes, lynx, deer, moose, caribou, ducks, spruce grouse, and an unidentified avian species. It was also documented that Louisbourg inhabitants resorted to pets and rodents when food supply was low (Lane Jonah and Véchambre 2012), and cat bones excavated from the Fortress showed evidence of butchering and burning (Cumbaa 1976). Therefore, mice, rats, doves (possibly robins), and cats were also sampled.

Faunal remains excavated from soil layers dating to French-only occupation were preferred over remains from layers that included New England or British occupation (e.g., the New England and British occupation between 1745 and 1749, and the British occupation of the Fortress after 1758). This was done to exclude those animals/foods brought in by non-French occupants of the Fortress. This restriction was accomplished for pigs, cows, and sheep, but could not be achieved for other domestic animals, such as goats, horses, and domestic geese.

Since it is believed that French vs. New England or British occupation of the Fortress would have no substantial influence on the isotopic ratios of wild fauna, and since the selection of wild animal remains within the collection available for this study was more limiting, faunal remains from New England or British occupation layers were not excluded from this study. Wild faunal remains have a date association between 1713 and 1974, but most fall within a more constrained temporal range beginning with the initial occupation of the Fortress in 1713, to the 1780s.

The isotopic values of the faunal specimens in this study also acted as an indicator of local meteoric and geologic conditions and aided in the determination of local vs. non-local status of the Ste. Marie individuals. Considering the potential for many domestic specimens to be imported (either as livestock or pickled meat, and thus harbouring foreign isotopes), the faunal specimens used to identify the local oxygen and strontium isotopic ranges were those wild specimens that typically have small home ranges and do not migrate (Price et al. 2002).

5.3 Isotope Analysis Methodology

Faunal bone and enamel samples were taken by the author at the Memorial University of Newfoundland Bioarchaeology Laboratory (MUNBL) or by Michael O'Dea, a student assistant under the direction of Dr. Joseph Parish at the CBUBL. Human bone, enamel, and dentine samples were taken by Dr. Joseph Parish and student assistant Stephen MacIsaac at the CBUBL. All samples were documented and assigned separate MARC (Memorial Archaeology) sample numbers.

Standard procedures for both laboratories included photographing all bones and teeth prior to sampling (using a digital camera with a scale present) and sampling cortical bone from pre-broken ends to minimise damage. Bone and teeth samples collected at the MUNBL were cleaned of any macroscopic surface contaminants using air abrasion or mechanical abrasion. Mechanical abrasion and cutting were performed using a Grobet USA® Micromotor drill. Before and after sampling, all drill burrs and discs were cleaned by ultrasonication in deionised water (DI H_2O) (17.5 megaohms [MΩ]) for five minutes. Samples collected at the CBUBL were cleaned by mechanical abrasion and cut using a Dremel® Microdrill. Drill bits were cleaned between sampling with isopropyl rubbing alcohol.

5.3.1 Carbon and Nitrogen Analysis of Bone Collagen

The collagen extraction procedure used in this study was based on those established by Longin (1971), Brown et al. (1988), and Semal and Orban (1995), and is an accepted procedure within the field of isotope analysis. Collagen extraction was performed at the MUNBL and included three main steps: demineralisation (removing the mineral phase of the bone), gelatinisation (heating the bone thereby bringing the collagen into solution), and lyophilisation (removing the water from the pure collagen). These steps were performed as follows:

Demineralisation: Two hundred milligrams (mg) of cortical bone were sampled for collagen extraction. Each bone sample was demineralised in ~10 milliliters (ml) of 0.5 molar (M) hydrochloric acid (HCl) chilled to 4ºC. The acid was regularly changed until

the bone turned soft or flexible. This took as little as one day for some samples, or as many as 60 days for others, depending on the size, density, and state of preservation of the bone. Once demineralisation was complete the acid solution was removed, and the demineralised bone was rinsed three times with DI H_2O (17.5 MΩ).

Gelatinisation: The demineralised bone was then suspended in DI H_2O acidified to a pH of three using 0.5M HCl and placed on a heating block for 48 hours at a temperature of ~70ºC. This process gelatinises the bone and brings the collagen fibrils into the solution. The collagen solution was then separated from the bone material using an Elkay Ezee-filter™ Separator.

Lyophilisation: Each collagen solution was frozen for a minimum of 24 hours and lyophilised in a VirTis LyoTroll™ freeze dryer for 48 hours. The resulting pure collagen was typically a white, light beige, or peach color with a fluffy or slightly flaky texture.

Approximately 1 mg of collagen from each sample was weighed and compressed into a 7 x 7 ultrathin tin capsule and analysed on a Carlo Erba NA1500 Series II Elemental Analyser (EA) at the Memorial University of Newfoundland Stable Isotope Laboratory, under the direction of Lab Co-ordinator Allison Pye. Within the EA, each sample was combusted, and the resulting gas divided into separate beams based on isotopic mass. These beams were introduced into a ThermoElectron DeltaVPlus Gas Source Isotope Ratio Mass Spectrometer which measured the intensity of each beam signal. The carbon and nitrogen isotopic values were calculated using lab standards that

were calibrated using international reference scales: VPDB for carbon and AIR for nitrogen. Table 4 reports the analytical error of the collagen analysis.

5.3.2 Collagen Quality Control

A great concern for collagen analysis involves the degradation and contamination of collagen's isotopic content. Two methods were used to assess the diagenesis of collagen samples in this study. One method was the calculation of each sample's collagen yield (van Klinken 1999). The typical collagen yield from a piece of modern bone is around 22% (Collins et al. 2002). A yield below 1% indicates that the collagen had degraded in the post-mortem environment (van Klinken 1999). The equation to calculate collagen yield is as follows:

$$\% \text{ Collagen Yield} = \frac{\text{Collagen Mass (mg)}}{\text{Bone Sample Mass (mg)}} \times 100$$

Another method used to assess collagen diagenesis was the calculation of each sample's C/N atomic ratio (DeNiro 1985). The mean C/N atomic ratio for modern bone collagen is 3.2 (Ambrose 1990). An acceptable ratio between carbon and nitrogen atoms within archaeological collagen is between 2.9 and 3.6 (DeNiro 1985). If the C/N atomic ratio of a sample falls outside this range it is possible that the carbon and nitrogen isotopes may have been diagenetically altered (DeNiro 1985). Thus, if a sample had a % yield below 1.0% or a C/N atomic ratio below 2.6 or above 3.6, the sample's carbon and

nitrogen delta values were regarded as unreliable (DeNiro 1985; van Klinken 1999) and were omitted from the study.

5.3.3 Carbonate Analysis of Enamel and Dentine Bioapatite

Approximately 5 mg of powdered enamel and dentine were sampled for carbonate analysis. When possible, the powdered sample was taken along the length of the tooth from cementoenamel junction to the occlusal edge so the entire development of the tooth's enamel could be included in the analysis.

The enamel and dentine powder samples were put through a series of pre-treatment steps modified from the methods of Lee-Thorp et al. (1989). The following methodology is an accepted and tested procedure within the field of isotope analysis for the extraction of bioapatite carbonate within dental tissues.

Each sample was brought to solution in ~1.8 ml sodium hypochlorite (NaOCl, ~1.7% volume per volume [v/v]) to oxidise any organic materials. After 30 minutes with frequent agitation, the samples were centrifuged and rinsed with DI H_2O (17.5 MΩ) three times. The DI H_2O was removed, and ~1.8 ml of 0.1M acetic acid (CH_3COOH) was added for a total of 10 minutes to dissolve any absorbed carbonate. The samples were again centrifuged and rinsed with DI H_2O three times and covered with perforated parafilm and left to air dry. The samples were then freeze dried for 24 hours to remove any remaining moisture.

Two mg of powdered material from each sample were weighed into individual glass vials at the Memorial University of Newfoundland Stable Isotope Laboratory, under the direction of Lab Co-ordinator Allison Pye. The glass vials were capped and placed on a

heating block (at 50ºC) on a ThermoElectron Gas Bench II. Each vial was flushed with helium and phosphoric acid to dissolve the sample. The resulting gasses were separated by an ion source based on isotopic mass. The intensity of the separated gas signals were measured by a ThermoElectron DeltaVPlus Gas Source Isotope Ratio Mass Spectrometer, and the carbon and oxygen isotopic values were calculated using lab standards that were calibrated using international reference scale VPDB. The analytical error of carbonate analysis is reported in Table 4.

5.3.4 Strontium Analysis of Enamel and Dentine Bioapatite

Approximately 20 mg of solid enamel and dentine were sampled for strontium analysis. When possible, the samples were taken from the entire longitudinal length of the tooth's cusp. All samples were cleaned by ultrasonication in DI H_2O (17.5 MΩ) for five minutes. The DI H_2O was then removed, and the samples were covered with perforated parafilm and placed under a fume hood to air dry.

Strontium was extracted from dental tissues using the following procedure adapted from the work of Daniel and Pin (2001). Figure 8 outlines the steps for this procedure. A 1 ml column (fashioned from a 1 ml pipette tip with a frit fitted within the tip) was prepared by adding ~1 ml of DI H_2O to rinse the column and ~1 ml of 6M HCl to remove organics. Added to the column was ~200 microliters (µl) of clean Eichrom Sr resin, a substance designed to capture and thus extract strontium from a solution. The resin was further cleaned with ~1 ml of 6M HCl to remove organic particles and ~1 ml of DI H_2O to elute any strontium atoms. The resin was then prepped with ~1 ml of 8M nitric acid (HNO_3).

Each sample was placed within a Savillex vial, into which 1 ml of 8M HNO_3 was added. The vial was then placed on a hotplate to dissolve the sample. The sample solution was added to the prepared column, and the solution that passed through the column was then reloaded to maximise strontium retention. The Sr imbued resin was rinsed with three ~1 ml washes of 8M HNO_3 to remove any unwanted elements (e.g., calcium and rubidium). The strontium was eluted from the resin using 1 ml of DI H_2O. The elution was then acidified using HNO_3 to 0.3M in preparation for analysis.

All samples were analysed at Memorial University's Micro Analysis Facility at the Inco Innovation Centre, under the direction of Lab Co-ordinator Dr. Rebecca Lam. One ml of sample was introduced via an Apex Q inlet system into a Finnigan™ Neptune High Resolution Multi-Collector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS). Within the MC-ICP-MS, the sample was introduced to a plasma source which produces ions which are then accelerated and focused into a beam. Ions are separated from the main beam via a magnetic field based on their mass/charge ratio. Each ion beam was measured by a series of collectors which calculates isotopic ratios based on the voltage of different ion beams. The accuracy and precision of standard SRM987 (n=12) was measured at 0.710214 ± 0.000148 (Table 4).

5.3.5 Bioapatite Quality Control

Similar to collagen, isotopic preservation of enamel bioapatite is of great concern for isotopic analysis. To examine any diagenetic influences on dental tissues, dentine samples were taken from six faunal teeth and 10 human teeth. The isotopic values of the dentine samples were compared to the isotopic values of the same tooth's enamel sample. Since

dentine is more prone to post-burial uptake and exchange than enamel, the isotopic values of a tooth's dentine will have bioapatite isotopic values that are shifted towards local isotopic values (Bocherens et al. 1994a; Budd et al. 2000; Madgwick et al. 2012). A difference in the strontium concentration (sometimes accompanied by a shift in isotopic value) of dentine, as compared to enamel from the same tooth, is a strong indication that diagenesis has occurred within dentine, while a lower concentration and non-shifted isotopic value is an indicator that diagenesis has not occurred within enamel (Budd et al. 2000; Evans et al. 2007).

Chapter 6

Results

6.1 Collagen Preservation

Of the 91 faunal specimens sampled, 89 yielded an acceptable amount of collagen (above 1.0%) (Table 5). Two samples (MARC 493 from sheep specimen 55L28E5-3 and MARC 490 from avian specimen 55L28F16-3) yielded no collagen, likely because of burn damage. For those samples that did yield collagen, the % yield was between 1.81% and 31.08% with a mean of 13.17%. The C/N atomic ratios ranged from 3.10 – 4.09 with a mean ratio of 3.32. Four samples yielded C/N atomic ratios outside the accepted range of 2.9 – 3.6. These samples were MARC 527 (from chicken specimen 55L28E10-11), MARC 535 (from fish specimen 55L28E10-12), MARC 502 (from mouse specimen 55L28E105), and MARC 525 (from hare specimen 55L28E24-4) with values of 4.09, 3.68, 3.64, and 3.71, respectively. These samples had corresponding low (but acceptable) % yields of 8.39, 1.81, 2.97, and 5.28%, respectively. Figure 9a shows the relationship between % yield and C/N atomic ratio of all faunal samples which reveals that not all samples with low % yields have correspondingly out of range C/N atomic ratios and vice versa.

The above four samples (with C/N atomic ratios outside the accepted range) were all from the Ste. Marie site (which includes 58 faunal bone samples in total) as opposed those faunal remains excavated from the town site (n=33). This suggests that the preservation at the town site was better than the preservation at the Ste. Marie site. This may be the result of different soil compositions, waterlogged conditions, or the exposed

nature of the Ste. Marie site to sea spray and seasonal wave action. The above mouse, hare, and fish samples had isotopic values that were similar to other samples of the same species, but the chicken sample (MARC 527) was an outlier with $\delta^{13}C$ and $\delta^{15}N$ values of -23.51 and 15.22‰, respectively, possibly caused by diagenetic influences. Since a C/N atomic ratio outside the 2.9 – 3.6 range indicates diagenetic changes may have occurred, the above four samples were not considered further in this study. The total number of specimens included in the following chapters is 85 with a mean C/N atomic ratio of 3.29.

Of the 79 bone samples, representing 40 individuals, only one sample (MARC 1071) from A18 failed to yield any collagen (Table 6). All other samples yielded an acceptable amount of collagen ranging from 2.28% – 33.85% with a mean of 10.46%. Of these samples, the mean C/N atomic ratio is 3.23 and ranges from 2.97 – 4.11. Three samples yielded a C/N atomic ratio outside 2.9 – 3.6: MARC 1063, 1072, and 1139 from A14, A18, and A12, respectively, with values of 4.11, 3.82, and 3.82, respectively.

A14's two samples, MARC 1063 and 1064, came from a humerus fragment and a rib fragment, respectively, the former with a C/N atomic ratio of 4.11 and the latter of 3.22. Since the humerus fragment has likely undergone diagenesis (being outside DeNiro's [1985] range) the isotopic values for A14 will henceforth be represented by the rib fragment sample (MARC 1064) only. The first sample (MARC 1071) from A18 did not yield any collagen for analysis. The second sample (MARC 1072) yielded 2.28% collagen but had a C/N atomic ratio of 3.82, well outside DeNiro's (1985) established range and likely affected by diagenesis. Thus, there are no isotopic data for A18. Only one sample (MARC 1139) was analysed from A12 due to its fragmentary and

decomposed nature. This sample had a C/N atomic ratio of 3.82 which is outside DeNiro's (1985) range. As a result, sample MARC 1139 was not used further in this analysis, resulting in no isotopic data for A12. Figure 9b shows the relationship between C/N atomic ratio and % yield.

All the above human samples believed to be affected by diagenesis (according to collagen % yield and C/N atomic ratio) were excavated from sub-op A. This sub-op was located on the northeast portion of the root cellar and was heavily affected by erosion. The human remains within this sub-op were also the lowest in elevation and within a soil that was very wet, a burial condition which is known to alter bone collagen (Von Endt and Ortner 1984). Many remains in sub-op A were either partially, or in some cases, completely decomposed towards the northern portion of the root cellar. For example, A12's remains consisted of teeth and fragmentary unidentifiable bone fragments (Parish 2006). The remains for A18 were better preserved than A12's, while A14 was very badly preserved. The northernmost superior portion of A14 was very fragmentary, and in the case of the skull, completely disintegrated (Parish 2006). Considering the physical condition of the remains from sub-op A, it is not unexpected that many samples yielded low % yields and out-of-range C/N atomic ratios.

Overall, 75 human bone collagen samples (representing 38 individuals) have been deemed acceptable according to their collagen % yield and C/N atomic ratio. The isotopic values associated with these samples are considered the true biogenic values of the living individual.

6.2 Bioapatite Preservation

Although the pre-treatment steps outlined in Chapter 5.3.3 should theoretically remove any diagenetic carbonate, it is still important to check the preservation conditions of tooth samples. This was done by comparing the enamel and dentine, oxygen and strontium values within the tooth of a single specimen/individual (see Chapter 5.3.5). Assuming enamel and dentine isotopic values were similar in vivo, dis-similar values between enamel and dentine would indicate diagenetic changes (Bocherens et al. 1994a; Budd et al. 2000; Evans et al. 2007; Hillson 1996; Madgwick et al. 2012)

Enamel-dentine values for $\delta^{13}C$ and $\delta^{18}O$ ($\delta^{13}C_{E\text{-}D}$ and $\delta^{18}O_{E\text{-}D}$, respectively) of six faunal specimens (Table 7) have a mean of 0.88 ± 0.66‰ and -0.84 ± 1.44‰, respectively, with $\delta^{13}C_{E\text{-}D}$ values from 0.22 – 2.27‰, and $\delta^{18}O_{E\text{-}D}$ values from -3.31 – -0.02‰, respectively, and ranges of 2.05 and 3.29‰, respectively. In all instances, the faunal specimens' dentine $\delta^{13}C$ values were higher, and the dentine $\delta^{18}O$ values lower, than the same tooth's enamel $\delta^{13}C$ and $\delta^{18}O$ values (Figure 10). Since dentine is more prone to diagenesis than enamel (see Chapter 4.5), the material causing the large differences is likely dentine. These data indicate a diagenetic carbon influence that is isotopically heavier, and an oxygen influence that is isotopically lighter than each animal's biogenic values.

The strontium enamel-dentine values ($^{87}Sr/^{86}Sr_{E\text{-}D}$) for six separate faunal specimens (Table 8) have a mean of 0.000010 ± 0.000338 with values from -0.000423 – 0.000465 and a range of 0.000887. Three specimens with the highest $^{87}Sr/^{86}Sr$ enamel values have associated dentine with lower $^{87}Sr/^{86}Sr$ values, while three

samples with the lowest $^{87}Sr/^{86}Sr$ enamel values have associated dentine with higher $^{87}Sr/^{86}Sr$ values (Figure 11). This suggests a diagenetic influence on dentine with a $^{87}Sr/^{86}Sr$ value that is intermediary to the six sample's enamel strontium value.

The $\delta^{13}C_{E-D}$ and $\delta^{18}O_{E-D}$ values for 10 human teeth (Table 9) have a mean of 1.99 ± 1.22‰ and 0.33 ± 0.52‰, respectively, with values between -0.23 and 3.37‰ and -0.54 and 1.19‰, respectively and ranges of 3.60 and 1.73‰, respectively. All teeth have enamel $\delta^{13}C$ values greater than dentine values, except C7, who has the lowest enamel $\delta^{13}C$ value with a slightly higher dentine $\delta^{13}C$ value (Figure 12a). This indicates that the diagenetic carbon influence is lower than the enamel values of nine of the individuals, and higher than the enamel value of C7. Such a clear pattern is not present among the $\delta^{18}O$ values of enamel and dentine pairs. A majority of individuals with the highest enamel values have associated dentine with lower $\delta^{18}O$ values, while many of the lowest enamel values have associated dentine with higher $\delta^{18}O$ values (Figure 12b). This suggests that the $\delta^{18}O$ values of the diagenetic isotopes overlap with the $\delta^{18}O$ values of the individuals' biogenic isotopes.

The $^{87}Sr/^{86}Sr_{E-D}$ values for 10 human teeth (Table 10) have a mean of -0.000299 ± 0.000319 with values between -0.000733 and 0.000196 and a range of 0.000930. Seven individuals have enamel values that are higher than their associated dentine, while three individuals with the lowest enamel $^{87}Sr/^{86}Sr$ values have associated dentine with higher $^{87}Sr/^{86}Sr$ values (Figure 13). This indicates a diagenetic influence with a $^{87}Sr/^{86}Sr$ value lower than the enamel values of the seven individuals and higher than the enamel values of the three individuals.

Overall, the Ste. Marie individuals' enamel-dentine isotopic differences were greater than the faunal enamel-dentine isotopic differences. This may be because of some morphological, biochemical, or other difference whereby human teeth are more prone to diagenesis. Alternatively, since all the faunal teeth came from the town site and all the human teeth came from the Ste. Marie site on Rochefort Point, the larger enamel-dentine differences of the human teeth may be due to greater diagenetic influences on the Rochefort Point site. The latter scenario is likely the case since bone collagen preservation was also shown to be worse among Rochefort Point faunal bones than town site faunal bones (see Chapter 6.1).

6.3 Intra-Bone Element Variation in the Ste. Marie I*ndividuals' Bone* Collagen

As mentioned previously, each set of human remains was sampled twice (with the exception of A12). The sample size of those individuals sampled from different bone elements is too small (n=2) to make any definitive conclusions concerning isotopic variation of separate bone elements within a single individual (such studies have been performed elsewhere, e.g., Balasse et al. [1999] and DeNiro and Schoeninger [1983]). However, by comparing the $\delta^{13}C$ and $\delta^{15}N$ values of samples taken from the same bone type from a single individual (e.g., D12: both samples taken from the anterior mid-shaft portion of the left humerus), it is possible to comment on the isotopic variation within single bone elements.

Upon initial analysis, there was good agreement between $\delta^{13}C$ values for those samples taken from the same bone element (with values between 0.02 and 0.62‰), but

quite a wide range was observed for $\delta^{15}N$ values (with values between 0.03 and 3.06‰) (Table 11). The majority of sample pairs (84.4%) have an absolute $\delta^{15}N$ difference ($\Delta^{15}N$) between 0.03 and 0.74%. The other 15.6% (consisting of five sample pairs) have a $\Delta^{15}N$ between 1.01 and 3.06‰ (Table 12). It is unlikely that the intra-bone element variation observed in this study was due to a change of diet (behavioral change) since many of the samples were not only from the same element type but from adjacent portions of the same bone. Such samples would have been formed during the same time and should therefore show very similar values.

To determine if the large $\Delta^{15}N$ values were the result of some problem with the collagen or due to some error in the capsuling or analysing stage, the five problem sample pairs were reanalysed from each sample's original collagen yield (as were two sample pairs with good isotopic agreement and cow sample MARC 1299). Upon reanalysis of these samples, smaller $\Delta^{15}N$ values were achieved, and ranged from 0.02 – 0.99‰ (Table 12). It also became apparent that one sample from each sample pair from the original analysis had drastically different $\delta^{15}N$ values than the values received from the same collagen upon reanalysis. Furthermore, the similarity between the isotopic values of the control samples (from E13 and F25, and cow specimen 4L58K14-9) suggests no noteworthy changes in the collagen's isotopic values during the ~11-month period between analyses.

The results reported in Table 12 indicate that the problem was not with the collagen itself but in the capsuling or analysing stage. It is possible that there was some form of contamination in the capsuling/weighing procedure. It is also possible that there was

fractionation during the analysis. Such may be the case for MARC 1081a, whereby an adequate amount of sample was believed to be capsuled (1.080 mg), but the peak amplitude registered during analysis only reached 2413 and 2666 millivolts (mV) for the carbon and nitrogen readings, respectively. This amounts to just over half of the mV registered for other samples with a similar weight (Table 13 and Figure 14). Since peak amplitude values are a reflection of the amount of sample combusted during analysis, these values suggest that either a smaller amount of sample was capsuled or only a portion of the sample was combusted and analysed. While the weight/peak amplitude values of MARC 1081a were questionable, the other samples with erroneous $\Delta^{15}N$ values (1105a, 1107a, 1125a, and 1130a) had weight/peak amplitude values that were well in line with other sample pairs of similar sample weight. Therefore, the problems with weighing and/or analysing may not be the full explanation for the erroneous values of these samples. However, because of their questionable nature, samples MARC 1081a, 1105a, 1107a, 1125a, and 1130a were omitted from further consideration in this study. Of the remaining samples (including the reanalysis of the control samples) the $\Delta^{13}C$ values range from 0.02 – 0.90‰, from D11 and F28, respectively, while the $\Delta^{15}N$ values range from 0.03 – 0.99‰, from H3 and F28, respectively. These values are deemed adequate for the purposes of this study, as a difference <1.00‰ for $\delta^{13}C$ and $\delta^{15}N$ between sample pairs is relatively small compared to the isotopic variation that exists as a result of C_3 vs. C_4, N_2-fixing vs. non-N_2-fixing, and marine vs. terrestrial diets.

6.4 $\delta^{13}C$ and $\delta^{15}N$ Results

This sub-chapter presents the isotopic results pertaining to diet. This includes the carbon and nitrogen isotopic values from bone collagen, and the carbon isotopic values from the carbonate portion of tooth enamel bioapatite. For those specimens/individuals that were analysed more than once, the isotopic values shown represent the mean of all accepted data.

6.4.1 Faunal Collagen $\delta^{13}C$ and $\delta^{15}N$ Results

The results for 85 faunal specimens are reported in Table 14. These data have a typical spread of a mixed terrestrial C_3 plant based and marine plant based ecosystem with some small contributions from C_4 terrestrial plants. Table 15 reports the descriptive statistics and Figure 15 shows the mean $\delta^{13}C$ and $\delta^{15}N$ values ± 1 standard deviation (σ) of all faunal types. Figure 16 shows a scatterplot of the $\delta^{13}C$ and $\delta^{15}N$ values of all specimens sampled.

A single specimen each of moose and caribou had $\delta^{13}C$ values of -21.99 and -20.37‰, respectively, and $\delta^{15}N$ values of 0.77 and 2.80‰, respectively. These specimens likely had a diet consisting of N_2-fixing plants which are C_3 type plants that fix atmospheric nitrogen creating low $\delta^{15}N$ values. Sheep (n=4) and goat (n=2) specimens had mainly C_3 based diets with a $\delta^{13}C$ mean of -21.09 ± 0.27‰ and -20.89 ± 0.24‰, respectively, and $\delta^{15}N$ values of 5.69 ± 1.20‰ and 6.47 ± 0.79‰, respectively (see Figure 17 for all domestic mammalian specimens). Both groups had small ranges (sheep $\delta^{13}C$ range = 0.76‰ and $\delta^{15}N$ range = 2.99‰, goat $\delta^{13}C$ range = 0.47‰ and $\delta^{15}N$ range =

1.57‰) indicating isotopically similar diets between specimens. The same is not the case for cow (n=5) and deer (n=6) specimens. Although the cow and deer $\delta^{15}N$ values are constrained (with ranges of 2.54 and 1.42‰, respectively), the $\delta^{13}C$ values are varied with ranges of 6.30 and 5.24‰, respectively. The $\delta^{13}C$ means for cow and deer are -19.67 ± 2.60‰ and -19.88 ± 1.69‰, respectively, and the $\delta^{15}N$ means are 5.56 ± 0.95‰ and 5.79 ± 0.47‰, respectively, indicating a terrestrial C_3 diet for those specimens with lower $\delta^{13}C$ values and a small contribution of C_4 plants for those specimens with higher $\delta^{13}C$ values.

Pig specimens (n=5) have a $\delta^{13}C$ mean of -19.18 ± 2.51‰ and a $\delta^{15}N$ mean of 7.99 ± 2.06‰ and have a larger distribution than other domestic fauna with a $\delta^{13}C$ range of 6.91‰ and a $\delta^{15}N$ range of 5.99‰. The relatively large range values are because of one specimen who is isotopically heavier than the rest, likely caused by a marine component to its diet. Large isotopic distributions are also shown by hare specimens (n=8) (Figure 18). The $\delta^{13}C$ range is 9.97‰ and $\delta^{15}N$ range is 14.53‰ with a $\delta^{13}C$ mean of -19.91 ± 3.97‰ and a $\delta^{15}N$ mean of 7.26 ± 5.76‰. There are three hare specimens that show very low $\delta^{15}N$ values indicative of a N_2-fixing diet, two others show a non-N_2-fixing C_3 plant diet, and three others show very high $\delta^{13}C$ and $\delta^{15}N$ values indicating a strong marine component. The squirrel specimens (n=6) have a $\delta^{13}C$ mean of -15.92 ± 1.37‰ and a $\delta^{15}N$ mean of 11.25 ± 3.33‰, with a $\delta^{13}C$ range of 4.43‰ and a $\delta^{15}N$ range of 8.52‰. The distribution of isotopic values suggests an isotopically diverse diet. Four specimens show a C_3 or mixed C_3/C_4 diet, while two others exhibit values that suggest a strong marine component. Mouse specimens (n=4) show more constrained values with a $\delta^{13}C$

range of 1.85‰ and a $\delta^{15}N$ range of 3.56‰. This indicates that the mouse specimens had isotopically similar diets. The $\delta^{13}C$ mean is -15.99 ± 0.78‰ and the $\delta^{15}N$ mean is 13.85 ± 1.27‰ which suggests a diet of marine resources. The range for the rat specimens (n=10) is considerably larger due to an outlier. The $\delta^{13}C$ range is 6.20‰ with a mean of -16.62 ± 1.51‰, and the $\delta^{15}N$ range is 6.75‰ with a mean of 12.19 ± 1.87‰. The outlier is isotopically lighter than the rest, likely due to a C_3 terrestrial diet, while the other specimens show a marine diet similar to the mouse specimens.

The group showing the highest amount of isotopic variation is chicken (n=9), with $\delta^{13}C$ and $\delta^{15}N$ ranges of 10.85‰ and 14.97‰, respectively (Figure 19). The mean $\delta^{13}C$ and $\delta^{15}N$ values are -17.09 ± 3.41‰, and 11.45 ± 4.60‰, respectively. The distribution of isotopic values suggests an isotopically diverse diet. Some specimens show diets containing N_2-fixing C_3 plants, marine foods, herbivore or omnivore meat, or possibly freshwater fish. Other domestic bird specimens analysed in this study include goose (n=2) and turkey (n=3) specimens. These specimens have similar distributions with relatively constrained $\delta^{13}C$ values and varied $\delta^{15}N$ values. The high $\delta^{15}N$ values of some specimens suggest a marine component to their diet. The $\delta^{13}C$ ranges for goose and turkey specimens are 1.49 and 2.49‰, respectively, while the $\delta^{15}N$ ranges are 7.13 and 8.12‰, respectively. The goose and turkey specimens' $\delta^{13}C$ means are -16.55 ± 0.74‰ and -17.37 ± 1.09‰, respectively, and the $\delta^{15}N$ means are 10.42 ± 3.57‰ and 11.05 ± 3.67‰, respectively.

Wild bird specimens are fewer in sample size and include a single duck specimen with a $\delta^{13}C$ value of -19.26‰ and a $\delta^{15}N$ value of 7.11‰ suggesting a C_3 terrestrial diet,

a single spruce grouse specimen with a $\delta^{13}C$ value of -18.04‰ and a $\delta^{15}N$ value of 9.57‰, indicating a small marine component, and one eider specimen with a $\delta^{13}C$ value of -16.45‰ and a $\delta^{15}N$ value of 12.41‰ suggesting relatively greater marine contributions. The single avian specimen has an even stronger marine component with a $\delta^{13}C$ value of -16.30‰ and a $\delta^{15}N$ value of 15.10‰. Also showing a strong marine diet are the dove/robin specimens (n=4) with a $\delta^{13}C$ mean of -16.28 ± 0.36‰, and a $\delta^{15}N$ mean of 13.28 ± 0.92‰. These specimens show a tight isotopic grouping with a $\delta^{13}C$ range of 0.93‰ and a $\delta^{15}N$ range of 2.27‰, indicating isotopically similar diets.

The two fox specimens show consumption of isotopically heavy animals with a $\delta^{13}C$ mean of -16.20 ± 1.83‰ and a range of 3.65‰, and a $\delta^{15}N$ mean of 13.49 ± 1.33‰ and a range of 2.66‰. The isotopically lighter fox is comparable to the cat (n=2) and lynx (n=1) specimens. The former group has a $\delta^{13}C$ mean of -16.86 ± 0.48‰ and a range of 0.95‰, and a $\delta^{15}N$ mean of 11.74 ± 0.91‰ with a range of 1.82‰, while the latter has a $\delta^{13}C$ value of -17.09‰ and a $\delta^{15}N$ value of 12.00‰. The heaviest isotopic group is the fish specimens (n=6) with a $\delta^{13}C$ mean of -14.41 ± 0.39‰ and a $\delta^{15}N$ mean of 15.14 ± 0.58‰. This group is also isotopically constrained with a $\delta^{13}C$ range of 1.06‰ and a $\delta^{15}N$ range of 1.81‰.

6.4.2 Ste. Marie Collagen $\delta^{13}C$ and $\delta^{15}N$ Results

The $\delta^{13}C$ and $\delta^{15}N$ values of the Ste. Marie individuals (n=38) are presented in Table 16. The mean $\delta^{13}C$ and $\delta^{15}N$ values are -16.78 ± 1.92‰ and 9.77 ± 1.67‰, respectively, with

ranges of 8.48 and 7.32‰, respectively (Figure 20). When compared to the faunal data (Figure 15), the $\delta^{13}C$ and $\delta^{15}N$ means are isotopically heavier than the means for terrestrial herbivores and omnivores (e.g., cow, deer, and pig) and isotopically lighter than the means for the terrestrial carnivores (e.g., fox and lynx) and other isotopically heavy animals (e.g., rat, mouse, and fish). The $\delta^{15}N$ mean suggests a terrestrial carnivorous diet but not a significant marine protein contribution. The $\delta^{13}C$ mean suggests a small C_4 contribution to the individuals' diets, likely in the form of protein from terrestrial animals subsisting on C_4 plants. The higher $\delta^{13}C$ values of some of the individuals may also be from a diet including shellfish or other low trophic level marine animals, however, no remains of low trophic level marine animals were analysed in this study to allow for a direct assessment. For a comparison between the Ste. Marie group's data from this study and published data on shellfish and other low trophic level marine animals, please see Chapter 7.2.

The total range of $\delta^{13}C$ and $\delta^{15}N$ values is very large. The $\delta^{13}C$ range is 8.48‰ with values from -20.75 – -12.27‰ (by A20 and E13, respectively) and a $\delta^{15}N$ range of 7.32‰ with values from 7.63 – 14.95‰ (by F29 and F30, respectively). Figure 21 shows a scatter plot of the $\delta^{13}C$ and $\delta^{15}N$ values of each individual and faunal specimen. The scattering of isotopic values indicates that the diets among the Ste. Marie individuals were isotopically diverse.

A comparison between isotopic results and osteological information (Table 17) revealed that no significance was observed between carbon and nitrogen isotopic values and age, dental pathologies, muscle attachment stress indicators, or pipe smoking.

Significant differences were observed between the $\delta^{13}C$ values of males (n=23) and females (n=2) using a t-test for independent samples (t=4.40; df=4; p=0.012) (Figure 22). Whether these results reflect a broader trend whereby colonial females ate little or no C_4 based foods is unclear at this time and would require further examination. The significance observed here may simply be an artifact of a small sample size of females.

A significant difference was also observed using a t-test for independent samples (t=2.39; df=33; p=0.023) between those individuals illustrating bone pathologies (including porotic hyperostosis, periostitis, myositis ossificans, and cribra orbitalia) and those showing no evidence of pathological conditions. Individuals exhibiting bone pathologies (n=17) had significantly lower $\delta^{13}C$ values than individuals showing no bone pathologies (n=21) (Figure 23). This may suggest that those individuals with ill-health had diets containing less C_4 derived foods, however, it must be considered that the above bone conditions are only rough indicators of ill-health of the living individual. These conditions may be caused by malnutrition, metabolic disorders, or chronic disease or parasitic loads (Parish 2006, 2007). The same conditions experienced by another individual may not result in the same, or any bone condition, especially if this condition was only experienced for a short time or far enough into the past for the bone to have fully healed. Overall, any patterns between isotopic values and health are unclear at this time.

Statistical significance was observed using an independent sample t-test (t=4.01; df=6; p=0.007) between those individuals exhibiting deformations on muscle attachment areas of bone (indicating muscular strain or injury) and those individuals showing no

deformations (n=3 and n=35, respectively). Individuals identified as having muscular strain have lower $\delta^{15}N$ values, suggesting a terrestrial diet with no significant marine component (Figure 24). A statistical difference was also found concerning these individuals in reference to their $^{87}Sr/^{86}Sr$ values (Chapter 6.5.4).

6.4.3 Faunal Bioapatite $\delta^{13}C$ Results

A total of 35 faunal enamel samples were analysed for carbon isotopes within the carbonate portion of tooth enamel bioapatite. These data (Table 18) are typical of animals eating a C_3 plant based diet with some contributions from C_4 resources. Table 19 reports the descriptive statistics, and Figure 25 shows the mean $\delta^{13}C$ values ($\pm 1\sigma$) of all faunal types. Figure 26 shows a scatter plot of all faunal specimens grouped by faunal type.

The mean for all faunal bioapatite $\delta^{13}C$ values is -11.86 $\pm$ 2.65‰ with a range of 11.72‰ with values from -16.37‰ (hare specimen 4L55X99-2) to -4.65‰ (deer specimen 4L58K11-7). The lowest $\delta^{13}C$ values are consistent with a strict C_3 terrestrial diet, while those specimens with the highest $\delta^{13}C$ values had a diet containing relatively more C_4 resources than C_3.

The hare specimens (n=3) have the lowest $\delta^{13}C$ values with a mean of -15.86 ± 0.37‰, indicating a strict C_3 diet. The isotopic values of the hare specimens have a small range of 0.87‰, indicating isotopically similar diets. The beaver specimens' (n=2) range was also small at 0.16‰ and have a $\delta^{13}C$ mean of 14.18 ± 0.08‰, also indicative of a C_3 diet. Sheep (n=3) and goat (n=4) specimens also have low $\delta^{13}C$ values, but both groups illustrate wider ranges (5.08 and 5.77‰, respectively) indicating somewhat isotopically

diverse diets. The mean $\delta^{13}C$ values for sheep and goat are -12.63 ± 2.10‰ and -12.41 ± 2.06‰, respectively. The mean $\delta^{13}C$ for cow (n=5) and horse (n=2) specimens is -10.93 ± 1.55‰ and -9.99 ±1.94‰, respectively. These values are slightly higher than the sheep and goat means, likely due to a greater C_4 contribution for some specimens. The ranges for cow and horse are 4.20 and 3.88‰, respectively which suggests a measure of isotopic diversity among the specimens' diets.

The rat specimens (n=3) consist of two specimens with low $\delta^{13}C$ values suggesting a C_3 diet and one specimen with a higher $\delta^{13}C$ value indicating a small C_4 or marine contribution. The mean $\delta^{13}C$ for rat specimens is -11.74 ± 2.00‰, with a range of 4.32‰. The pig (n=4) and deer (n=5) specimens have $\delta^{13}C$ means of -11.14 ± 3.46‰ and -10.71 ± 3.11‰, respectively, and have the largest ranges (8.60 and 8.24‰, respectively) of all faunal groups. This is due to one outlying specimen in each group which have the highest $\delta^{13}C$ values of the Louisbourg fauna. The isotopically lighter pig and deer specimens were likely strict C_3 eaters, while the outlying specimens likely had a strong C_4 component to their diets, or for the pig, a strong marine component. The single moose specimen falls relatively close to the isotopically light deer with a $\delta^{13}C$ value of -11.06‰ and likely had a diet of C_3 plants only.

The carnivorous specimens, cat (n=1), fox (n=1), and lynx (n=1), all have $\delta^{13}C$ values greater than the hare and beaver specimens (-11.34, -11.24, and -9.99‰, respectively) and are comparable to the rat, deer, moose, and many domestic herbivore specimens. However, since the isotopic distribution of prey items is varied (and the isotopic values of dental tissues represent a mixing of different isotopic values from

various diet sources), predicting specific prey items was deemed problematic and was therefore not attempted in this study.

6.4.4 Ste. Marie Bioapatite $\delta^{13}C$ Results

A total of 33 individuals were sampled for $\delta^{13}C$ values in the carbonate portion of tooth enamel bioapatite. These data (Table 20) indicate a diet of C_3 plants with some C_4 contributions. Figure 25 shows the mean $\delta^{13}C$ values ($\pm 1\sigma$) of the Ste. Marie individuals, and Figure 26 shows a scatter plot of each individual sampled

The $\delta^{13}C$ mean for the individuals' bioapatite is -9.86 ± 3.53‰. When compared to the faunal data, the Ste. Marie group's mean is isotopically heavier and closest to the horse mean and single lynx $\delta^{13}C$ value (-9.99 ± 1.94‰ and -9.99‰, respectively). The Ste. Marie group's $\delta^{13}C$ range is 11.34‰ with values from -14.54 – -3.20‰ (from E15 and E13, respectively). The lowest $\delta^{13}C$ values are isotopically heavier than the hare group and two single sheep and goat specimens. Only two individuals (A19 and E13 with $\delta^{13}C$ values of -4.24 and -3.20‰) have higher $\delta^{13}C$ values than the highest faunal specimen (deer 4L58K11-7 with a $\delta^{13}C$ of -4.65‰). No statistical correlations exist between $\delta^{13}C$ values and observed biological, physiological, behavioral, or health-related characteristics.

6.5 $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ Results

The following sub-chapters report the oxygen and strontium data from the tooth enamel of the Louisbourg fauna and the Ste. Marie individuals. The strontium isotopic values

were analysed from the tooth enamel and the carbon isotopic values from the carbonate portion of tooth enamel bioapatite.

6.5.1 Faunal $\delta^{18}O$ Results

A total of 35 faunal enamel samples were analysed for oxygen isotopes within the carbonate portion of enamel bioapatite (Table 18). Table 19 reports the descriptive statistics, and Figure 27 shows the mean $\delta^{18}O$ values ($\pm 1\sigma$) of all faunal types. Figure 28 shows a scatter plot of individual faunal specimens grouped by faunal type.

The mean $\delta^{18}O$ value of all faunal specimens is -7.57 ± 1.50‰ with a range of 7.23‰. The lowest $\delta^{18}O$ value is -12.18‰, and the highest $\delta^{18}O$ value is -4.95‰. These values are from deer specimens 4L58K11-7 and 3L22N1-8, respectively. The $\delta^{18}O$ values, ranges, and distributions for most domestic animals are relatively similar, indicating isotopically similar water sources. The cow specimens (n=5) have a mean $\delta^{18}O$ value of -8.26 ± 0.81‰ with a range of 2.36‰. The range for pig specimens (n=4) is similar at 2.38‰ with a mean $\delta^{18}O$ value of -7.76 ± 1.08‰. Sheep (n=3) have a mean $\delta^{18}O$ value of -7.68 ±1.05‰ with a range of 2.27‰, while the range for goat specimens (n=4) is slightly larger at 3.28‰ with a mean $\delta^{18}O$ of -7.57 ± 1.18‰. The two horse specimens have a mean $\delta^{18}O$ value of -8.12 ± 0.62‰ and a range of 1.24‰. The single cat specimen has a $\delta^{18}O$ value of -5.85‰ which is at the high end of domestic animals. The rat specimens (n=3) have similar values with a mean $\delta^{18}O$ of -6.21 ± 0.31 and a range of 0.68‰.

The hare specimens (n=3) have $\delta^{18}O$ values on the lower end of the scale with a mean $\delta^{18}O$ value of -8.61 ± 0.28‰. These specimens also have the smallest range of all fauna (0.64‰) which suggests isotopically constrained water sources. Beaver specimens (n=2) have a $\delta^{18}O$ value of -8.08 ± 0.84‰ and a range of 1.67‰. The fox (n=1) and lynx (n=1) specimens have relatively similar $\delta^{18}O$ values of -6.15 and -6.21‰, respectively. The single moose specimen has a slightly lower $\delta^{18}O$ value of -7.04‰. The deer specimens (n=5), with a mean $\delta^{18}O$ value of -7.47 ± 2.47‰, have the largest $\delta^{18}O$ range at 7.23‰. This is because of one outlying specimen which has the lowest $\delta^{18}O$ value of all deer specimens and of all fauna analysed (-12.18‰).

6.5.2 Ste. Marie $\delta^{18}O$ Results

A total of 33 individuals were sampled for oxygen isotopes within the carbonate portion of tooth enamel bioapatite (Table 20). Figure 27 shows the mean $\delta^{18}O$ values (± 1σ) of the Ste. Marie individuals, and Figure 28 shows the distribution of $\delta^{18}O$ values for each individual.

The overall mean for the individuals' bioapatite $\delta^{18}O$ values is -5.20 ± 0.76‰. When compared to the faunal means, the Ste. Marie group's mean is isotopically heavier and closest to the rat specimens and carnivores (cat, lynx, and fox). The individuals' $\delta^{18}O$ range is 3.86‰ with values from -7.06 – -3.20‰ (A18 and F30, respectively). The lowest human $\delta^{18}O$ values are isotopically similar to many specimens in this study, but the highest human $\delta^{18}O$ value is higher than the highest faunal specimen (deer 3L22N1-8) by 1.75‰. The Ste. Marie group's mean (-5.20 ± 0.76‰, n=33) is significantly higher than

the faunal mean (-7.57 ±1.50‰, n=35) using a t-test for independent samples (t=-8.58; df=53; p<0.001) and suggests that Ste. Marie individuals as a group ingested water with higher $\delta^{18}O$ values than the faunal specimens.

No correlations exist between $\delta^{18}O$ values and observed biological, physiological, behavioral, or health-related characteristics, with the exception of dental pathologies (which includes the presence of carious lesions, abscesses, and periodontal disease) (Table 17). Using a t-test for independent samples, those individuals with dental pathologies (n=25) had $\delta^{18}O$ values that were significantly higher (t=3.02; df=12; p=0.011) than those individuals with no apparent dental pathologies (n=8) (Figure 29). This suggests a geographic difference between the two groups whereby individuals with healthier teeth originated from regions with lower $\delta^{18}O$ values (e.g., further north, higher altitude, or inland) than individuals with poor dental health. Whether this indicates a broader trend, is unclear, and requires further research.

6.5.3 Faunal $^{87}Sr/^{86}Sr$ Results

A total of 35 faunal enamel samples were analysed for strontium isotopes (Table 18). Table 19 reports the descriptive statistics, and Figure 30 shows the mean $^{87}Sr/^{86}Sr$ values ($\pm 1\sigma$) of all faunal types. Figure 31 shows a scatter plot of individual faunal specimens grouped by faunal type.

The mean $^{87}Sr/^{86}Sr$ value for all faunal specimens (n=35) is 0.710666 ± 0.001483 with a range of 0.005992. The majority of domestic animals have relatively wide ranges. The animal type with the largest $^{87}Sr/^{86}Sr$ range is cow (n=5) with a range of 0.005260.

The mean $^{87}Sr/^{86}Sr$ for cow specimens is 0.712169 ± 0.001897. Pig specimens (n=4) and goat specimens (n=4) have similar ranges with 0.003014 and 0.002754, respectively, and mean $^{87}Sr/^{86}Sr$ values of 0.710788 ± 0.001132 and 0.710039 ± 0.001180, respectively. The range for sheep specimens (n=3) is smaller at 0.001770. The mean $^{87}Sr/^{86}Sr$ value for sheep specimens is 0.710104 ± 0.000739. The mean $^{87}Sr/^{86}Sr$ value for horse specimens (n=2) is 0.710754 ± 0.000267 with a range of 0.000534. The single cat specimen has a $^{87}Sr/^{86}Sr$ value of 0.709801.

The majority of wild specimens have relatively smaller $^{87}Sr/^{86}Sr$ ranges. The two beaver specimens have the smallest range (0.000237) which suggests that they were likely from the same area (or isotopically similar areas). The mean $^{87}Sr/^{86}Sr$ value of beaver specimens is 0.709819 ± 0.00118. Rat specimens (n=3) have a mean $^{87}Sr/^{86}Sr$ of 0.710351 ± 0.000337 and a range of 0.000790. The range of $^{87}Sr/^{86}Sr$ values for hare specimens (n=3) is larger than the rat and beaver specimens' with a range of 0.002460 and a mean $^{87}Sr/^{86}Sr$ of 0.710197 ± 0.001047. The single fox, lynx, and moose specimens have $^{87}Sr/^{86}Sr$ values of 0.709070, 0.710061, and 0.709133, respectively. The deer specimens (n=5) have the largest distribution of $^{87}Sr/^{86}Sr$ values among the wild fauna with a range of 0.004329. This suggests that some deer specimens were from areas with differing $^{87}Sr/^{86}Sr$ values. The mean $^{87}Sr/^{86}Sr$ value for deer specimens is 0.711595 ± 0.001800.

6.5.4 Ste. Marie $^{87}Sr/^{86}Sr$ Results

A total of 33 enamel samples were analysed for strontium isotopes (Table 20). Figure 30 shows the mean $^{87}Sr/^{86}Sr$ values ($\pm 1\sigma$) of the Ste. Marie individuals, and Figure 31 shows the distribution of $^{87}Sr/^{86}Sr$ values for each individual.

The overall mean for the enamel $^{87}Sr/^{86}Sr$ values is 0.710784 ± 0.0012815. The Ste. Marie individuals' $^{87}Sr/^{86}Sr$ mean is isotopically lighter than the cow and deer means (0.712169 ± 0.001897 and 0.711595 ± 0.001800, respectively), isotopically similar to the pig and horse means (0.710788 ± 0.001132 and 0.710754 ± 0.000267, respectively), and isotopically heavier than all other faunal groups.

The overall range of $^{87}Sr/^{86}Sr$ values is greater than all other faunal groups at 0.005157 which suggests that the Ste. Marie individuals have varied origins. The individuals' values overlap with all faunal groups, and no significant difference was observed between the Ste. Marie individuals and fauna using a t-test for independent samples (t=-0.35; df=66; p=0.729). F12 has the lowest $^{87}Sr/^{86}Sr$ value (0.708560) of all individuals and faunal specimens, while D11/F11 has the highest $^{87}Sr/^{86}Sr$ value (0.713716) among the Ste. Marie individuals and places third highest among faunal specimens, below a cow (1L36B3-1) and deer (3L22N1-8) specimen (0.714752 and 0.713730, respectively). These values indicate that the Ste. Marie individuals ingested isotopically similar foods to many faunal specimens which suggests comparable origins between the two groups.

No correlations exist between $^{87}Sr/^{86}Sr$ values and sex, dental pathologies, bone pathologies, or pipe smoking (Table 17). However, a statistical significant difference was observed between adults (n=31) and sub-adults (n=2) using a t-test for independent

samples (t=-8.27; df=30; p<0.001), whereby the sub-adults have a higher $^{87}Sr/^{86}Sr$ mean (Figure 32). The sub-adults are discussed further in Chapter 7.6.5. The three individuals with muscular strains mentioned previously (Chapter 6.4.2) had a significantly higher $^{87}Sr/^{86}Sr$ mean (t=3.23; df=4; p=0.032) than those individuals showing no muscular strains or injuries (n=30). Although the strontium values of these individuals still overlap with the rest of the group (Figure 33), their correspondingly significantly different $\delta^{15}N$ mean (see Chapter 6.4.2 and Figure 34) may be additional evidence that these three individuals had differing diets and origins than rest of the individuals. This group is discussed further in Chapter 7.6.4.

Chapter 7

Discussion

The following is an interpretation of the carbon, nitrogen, oxygen, and strontium results reported in Chapter 6. Table 21 contains all data compiled for the Louisbourg fauna, and Table 22 contains all data compiled for the Ste. Marie individuals. In this study, bone collagen $\delta^{13}C$ ($\delta^{13}C_{Col}$) and $\delta^{15}N$ values reflect the protein portion of the consumer's diet, and tooth enamel carbonate bioapatite ($\delta^{13}C_{Carb}$) reflects total diet (protein, lipid, and carbohydrates) (Ambrose and Norr 1993; Tieszen and Fagre 1993).

7.1 Faunal Diet Reconstruction

The following sub-chapters reference ecological and historical information as well as isotopic data and discussions from previous studies to give further detail concerning the isotopic placement of animal groups, and in some cases, individual specimens. Where applicable, possible causal factors were provided for those data that appear to be atypical. Suggestions on areas that may merit further investigation are also discussed.

7.1.1 Moose and Caribou

Both the collagen and bioapatite $\delta^{13}C$ values of caribou (n=1) and moose specimens (n=2) indicate a C_3 diet (Table 21). The $\delta^{15}N$ values are much lower than the other herbivorous specimens (e.g., sheep, goat, and cow, Figure 16), likely due to a diet based largely on N_2-fixing plants (DeNiro 1987). N_2-fixers have a symbiotic relationship with bacteria and

can fix atmospheric nitrogen as well as soil nitrogen, with the result that legumes have much lower delta value than other C_3 plants, because atmospheric nitrogen is typically isotopically lighter than soil nitrogen (Cheng et al. 1964; DeNiro 1987; Parwel et al. 1956). N_2-fixing plants include a wide variety of shrubs, trees, ferns, and lichens, as well as mosses and legumes (DeNiro 1987; Evans and Barber 1977; Virginia and Delwiche 1982) which are common components in the diets of moose and caribou (Crête 1999; Peterson1999). Moose generally eat woody plants such as willow, aspen, balsam fir (Peterson 1999), while caribou eat leaves, shrubs, grasses, and large quantities of lichen (Crête 1999).

The moose in this study has a $\delta^{13}C_{Col}$ value on the heavier end of isotopic data of modern moose (Derbridge 2010; Urton and Hobson 2005) (even after adjusting +1.5‰ for the alteration of carbon isotopes in atmospheric CO_2 since industrialisation [Marino and McElroy 1991]). These differences can likely be attributed to small regional variations in the carbon values of N_2-fixing plants. The caribou specimens in this study are comparable to caribou analysed from Newfoundland colonial sites (Guiry et al. 2012).

7.1.2 Goats, Sheep, Horses, and Cows

The domestic herbivores analysed in this study include sheep (n=5), goat (n=4), horse (n=2) and cow (n=10) (Table 21). The sheep and goat specimens have low $\delta^{13}C_{Col}$ and $\delta^{15}N$ values which suggest a terrestrial diet of C_3 plants. The distribution of $\delta^{13}C_{Carb}$ values for cow (n=5) sheep (n=3), goat (n=4), and horse (n=2) are relatively similar (Figure 26). The lightest specimens likely had a strict C_3 diet, while the heaviest

specimens likely had a diet containing some C_4 plants. The cow specimens' $\delta^{13}C_{Col}$ values are more varied (range = 6.30‰, n=5) than the collagen data for sheep (range = 0.76‰, n=4) and goat specimens (range = 0.47‰, n=2) (Table 15 and Figure 17). Those cow specimens with lower $\delta^{13}C_{Col}$ values likely had a strict C_3 plant diet, while those specimens with higher $\delta^{13}C_{Col}$ values (specimens 4L50K12-8 and 4L50K16-4) likely had C_4 components to their diets. The high $\delta^{13}C_{Col}$ values of these two specimens (-16.93‰ and -16.20‰, respectively) fall outside the $\delta^{13}C_{Col}$ values of cow, sheep, and goat specimens sampled from a Newfoundland colonial site (-22.64 – -18.84‰, n=22 [Guiry et al. 2012]). There are a number of possibilities that may explain the difference between the $\delta^{13}C$ values of cow specimens, and the sheep and goat specimens in this study. The following is a short discussion addressing some potential causes.

Natural grazing habit: Goats, and to a lesser extent sheep, naturally browse/graze on leaves from plants (e.g., woody plants such as shrubs and trees), while cows naturally graze on a combination of leaves and grasses (Klippel 2001). Woody plants have a C_3 mode of photosynthesis, while grasses can have either a C_3 or C_4 mode of photosynthesis. In a study of grasses in modern Nova Scotia, C_4 grasses made up 18% (Roland and Smith 1969 in Wan and Sage 2001). C_4 grasses in Nova Scotia include Spartina alterniflora, S. patens (Patriquin 1981; Roland and Smith 1969), Cyperus esculentus, C. filiculmis (Mei-Rong et al. 1999; Roland and Smith 1969), and Distichlis spicata (Roland and Smith 1969; Seliskar and Gallagher 2000), among others. Since cows have a tendency to graze on grass, the higher $\delta^{13}C$ values of some cow specimens may be the result of ingesting

wild C_4 grasses, and similar values would not be expected to show up in goat since they do not have a natural tendency to browse on grass (Klippel 2001). Although sheep tend to have a natural diet consisting of a mix between leaves and grasses (Klippel 2001), the sheep in this study do not have high $\delta^{13}C$ values to indicate any C_4 plants were consumed. Furthermore, the sheep and goat values are not notably different from one another to suggest that their diets differed.

The proportion of C_3 to C_4 plants in the Louisbourg or Cape Breton coast is currently unknown, and future studies of faunal diet would benefit from local investigations into the presence and isotopic values of C_4 plants. Furthermore, the effects of natural browsing/grazing habits on the isotopic values of Louisbourg's domestic animals may be a moot point since their diets may have been subject to considerable change due to unnatural grazing or foddering practices imposed by local farmers. Such animals' isotopic values would reflect the isotopic values of the plant material within the imposed grazing area or of the foddering material provided.

Imposed grazing: The higher $\delta^{13}C$ values of cow specimens compared to sheep and goat could be the result of grazing practices that were not natural for the animal but imposed by local farmers. One such practice was to graze cows in salt marshes or along the coast to increase the animal's salt intake, a practice which was not commonly implemented for goats and sheep at Louisbourg (A. M. Lane Jonah, personal communication 2012). Since C_4 plants are common in these environments (Cloern et al. 2002; Seliskar and Gallagher

2000; van der Merwe 1982; Wan and Sage 2001), it is possible that this was the cause of the high $\delta^{13}C$ values of cow specimens 4L50K12-8 and 4L50K16-4.

Foddering materials: It is also possible that the relatively high $\delta^{13}C$ values of the cow specimen (and also the isotopically heavy horse specimen 3L22N1-5 [$\delta^{13}C$ = -8.05‰, Table 21]) were caused by occasional foddering with maize or other C_4 plants. Foddering with maize was not uncommon at the Fortress of Louisbourg (A. M. Lane Jonah, personal communication 2012). A maize diet does not seem to have been significant for the sheep and goat specimens (and isotopically light cow and horse specimens), as evident by their low $\delta^{13}C$ values.

New England Origins: Although C_4 grasses are found in Nova Scotia, there is a higher proportion of wild C_4 grasses to C_3 grasses further south (Wan and Sage 2001). While C_4 grass species comprise 18% of grasses in Nova Scotia, the C_4 abundance in New England ranges from 16% in Maine, to as high as 50% in New York (Wan and Sage 2001). Furthermore, while C_3 plants and products appear to have been dominant at Louisbourg (Chard 1995; Clark 1980; Lane Jonah and Véchambre 2012; McLennan 1918; Moore 1995; Varkey 2002), maize and corn were the staple crops in New England (Fisher et al. 1997; McMahon 1985; Walcott 1936). Farmers used corn as fodder and were known to have sustained their cows on maize products during the winter months (Fisher et al. 1997; Klippel 2001; McMahon 1985). Since Louisbourg meat and livestock are known to have been imported from New England, it is possible that the two cow specimens and the

single horse specimen with higher $\delta^{13}C$ values were imported from these locations where they ingested relatively higher portions of C_4 fodder or wild C_4 grasses. If this is indeed the case, there exists the possibility of differentiating between foreign-raised specimens and locally raised specimens by their $\delta^{13}C$ values. Unfortunately, there are no oxygen or strontium data from the cow specimens to elaborate further on their origins. The horse specimen has oxygen and strontium values that fall within the local range (see Chapter 7.4), but these values could also have been acquired by having New England origins.

Carbon isotopic values in bovid specimens (e.g., cow, sheep, and goat) have been used as a means for identifying origins in a study conducted by Klippel (2001). Bovid bones from a 17th- to 19th-century British West Indies slave site were analysed in an attempt to examine the ability of isotopic analysis to identify imported meat vs. locally raised meat. Meat raised in the study site in the area of the Caribbean was expected to reflect a very high C_4 diet (with more positive $\delta^{13}C$ values), whereas meat imported from England and North America would have a relatively higher C_3 contribution (and more negative $\delta^{13}C$ values). From this study, Klippel (2001) concludes that sheep and goats (which showed a high C_4 intake) were raised locally and that cows (which showed a more C_3 based diet) were imported from North America. This conclusion agreed with conclusions based on number of individual specimen (NISP) counts and skeletal part frequency calculations, in consideration with factors involving butchering and shipping practices.

It is possible that a similar study could be conducted on Louisbourg bovids, whereby relatively high $\delta^{13}C$ values indicate origins further south and lower $\delta^{13}C$ values

indicate local origins. Such a study would also benefit from full isotopic mapping of bovid specimens, historical information on the use of C_4 products at Louisbourg, and investigations into the abundance and isotopic values of local C_4 plants.

In addition to the variation in $\delta^{13}C_{Col}$ values of cow specimens, there is also a noted difference in $\delta^{15}N$ values, in that one specimen (4L50K16-4) is isotopically heavier than the other four cow specimens with a $\delta^{15}N$ value of 7.44‰ (Table 21). The other cow specimens have a $\delta^{15}N$ distribution between 4.90 and 5.24‰. Such a distinction does not seem to be apparent for other bovids (with $\delta^{15}N$ values equally distributed between 4.40 and 7.39‰). This outlier may be a reflection of the small sample size (n=5) which may be small in comparison to the variety of potential origins and diets of Louisbourg cows. However, this specimen also has the highest $\delta^{13}C_{Col}$ and was therefore deemed worthy of further discussion.

If cow specimen 4L50K16-4 was young at time of death, and either still suckling from its mother or only recently weaned, the high $\delta^{15}N$ values may simply be the result of isotopic enrichment due to a variation of the trophic effect, whereby a calf is essentially a carnivore of their mother's milk (Richards et al. 2002). The distinctly high $\delta^{15}N$ and $\delta^{13}C_{Col}$ value may also be caused by grazing in coastal, salt marsh, or wetland areas. Soils from these areas have high $\delta^{15}N$ values due to a number of factors such as contributions of isotopically heavy nitrogen via sea spray (Virginia and Delwiche 1982) or as a result of biochemical processes such as denitrification (Cloern et al. 2002), a process whereby soil bound nitrogen is returned to the atmosphere as gaseous nitrogen via microbial action:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$ (van Spanning et al. 2007). Because of the preferential transfer of the lighter nitrogen isotope (^{14}N) towards the final nitrogen gaseous product (N_2), any residual soil NO_3 becomes isotopically enriched in the heavier nitrogen isotope (^{15}N) (Delwiche and Steyn 1970; Wellman et al. 1968). This isotopically heavy NO_3 is then absorbed by plants with little discrimination against the heavier ^{15}N isotope (Van Cleemput et al. 2007) and is passed through the food chain to animals (Britton et al. 2008). Although denitrification is known to occur in waterlogged areas, such as marshes and wetlands (Van Cleemput et al. 2007), it is unclear to what degree denitrification occurs in the marshes and wetlands in the area of Louisbourg, and whether denitrification and other ^{15}N enriching processes have a significant effect on the isotopic values of soil NO_3 and local flora or fauna. However, many studies on bovids have interpreted elevated $\delta^{15}N$ values as evidence of salt marsh (Atahan et al. 2011; Britton et al. 2008) or freshwater marsh utilisation (Oelze et al. 2011). It is possible that specimen 4L50K16-4 received its high $\delta^{15}N$ values from grazing in similar areas.

As for the elevated $\delta^{13}C_{Col}$ value of specimen 4L50K16-4 ($-16.20‰$), coastal areas and salt marshes (which were common grazing grounds for cows at Louisbourg [A. M. Lane Jonah, personal communication 2012]) are also the home of halophytic plants, many of which have C_4 photosynthetic pathways (Chmura and Aharon 1995; Choi et al. 2001; Cloern et al. 2002; Patriquin 1981; Seliskar and Gallagher 2000; van der Merwe 1982; Wan and Sage 2001). In addition, wild marsh hay was cut and collected for foddering livestock at the Fortress (Clark 1965, 1980). This wild marsh hay likely refers to the wild Spartina patens (Nixon 1982; Roland and Smith 1969), a common C_4 grass species with a

relatively high $\delta^{13}C$ values around -13 and -12‰ (Chmura and Aharon 1995; Choi et al. 2001; Emery et al. 1967; Stribling and Cornwell 1997). The isotopically heavy cow (4L50K16-4) may have ingested local C_4 marsh plants which created a relatively high $\delta^{13}C$ value in addition to a high $\delta^{15}N$ value. This may also be true of the isotopically heavy horse specimen (3L22N1-5, $\delta^{13}C_{Carb}$ = -8.05‰), unfortunately this specimen had no associated bones, and as a result, there is no nitrogen data.

This argument does not necessarily indicate that such an animal was raised locally. Many other contemporaneous communities took advantage of the same environments for grazing animals and harvesting hay including the early settlements in New England (Nixon 1982), as well as the Acadians who utilised the nutrient rich salt marshes along the Bay of Fundy to great effect (Hilchey 1981; Wynn 1979). Whichever location this animal was grazed, it is possible that the cow specimen with high $\delta^{15}N$ and $\delta^{13}C_{Col}$ values (and possibly the horse specimen with the high $\delta^{13}C_{Carb}$ value) was grazed in, or ate plants from a coastal, salt marsh, or wetland environment.

Another explanation for the high $\delta^{13}C$ and $\delta^{15}N$ value of cow specimen 4L50K16-4 is the use of seaweed as fodder. The isotopic values of seaweed have been found to be extremely varied with $\delta^{13}C$ between -32 and -10‰ (Cloern et al. 2002; Dunton and Schell 1987; Parker 1963; Smith and Epstein 1971) and $\delta^{15}N$ values between 1‰ and 16‰ (Cloern et al. 2002; Miyake and Wada 1967). Since seaweed is higher in protein than terrestrial plants (and since collagen tissue reflects dietary protein), the $\delta^{13}C_{Col}$ and $\delta^{15}N$ values of an animal eating a mix between isotopically heavier seaweed and isotopically lighter terrestrial plants will show a bias towards the isotopic values of seaweed (Stevens

et al. 2006). This hypothesis would benefit from historical investigations and isotopic analysis of local seaweed.

As mentioned previously, the practice of grazing in salt marshes was not used for sheep and goat specimens at Louisbourg (A. M. Lane Jonah, personal communication 2012), however, many of these specimens have high $\delta^{15}N$ values (i.e., above 6.00‰, Figure 16). This may be due to isotopic enrichment if these specimens were young and still suckling, or recently weaned from their mothers (Richards et al. 2002). A high $\delta^{15}N$ value may have been obtained by eating C_3 flora elevated in ^{15}N due to sea spray activity (Virginia and Delwiche 1982), denitrification, or other processes that may increase an animal's $\delta^{15}N$ values. A similar conclusion to this one is presented for medieval goat/sheep specimens from an archaeological site in Orkney, Scotland (Richards et al. 2006). It is also possible that the sheep and goat specimens with high $\delta^{15}N$ values foddered on salt marsh C_3 plants that have low $\delta^{13}C$ values and high $\delta^{15}N$ values, or seaweed species that have low $\delta^{13}C$ and $\delta^{15}N$ values (Cloern et al. 2002).

The possible causal factors presented here in relation to the carbon and nitrogen isotopic values of the domestic herbivores in this study, are many, and would greatly benefit from further investigation. Not only would such a study benefit from further historical investigations but also a more in depth isotopic examination that involved creating a full complement of isotopic data for each specimen (including $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data). Such an examination was not the purpose of this study and not possible since only some specimens had bone and teeth available and could therefore be analysed for those elements that reflect diet and origins). In addition, it is unclear to what degree

feeding on local flora (e.g., salt marsh grass, seaweed, or vegetation affected by sea spray) would have on the isotopic values of locally raised herbivores. These hypotheses would also benefit from a more in depth isotopic analysis of local soil, flora, and fauna.

7.1.3 Deer

The $\delta^{13}C_{Col}$ spread demonstrated by deer specimens (range = 5.24‰, Table 15) is relatively comparable to the cow specimens (Figure 16). A majority of deer specimens exhibit $\delta^{13}C_{Col}$ and $\delta^{13}C_{Carb}$ values indicating a C_3 diet, while two deer specimens, 55L28F6-8 and 4L58K11-7, exhibit much higher values: $\delta^{13}C_{Col}$ = -16.58‰ and $\delta^{13}C_{Carb}$ = -4.65‰, respectively (Table 21). The former specimen likely had a diet of isotopically heavy C_3 plants or a small C_4 component, while the latter had a mixed C_3/C_4 plant diet.

The isotopically light deer specimens likely foraged on C_3 varieties of herbaceous plants, berries, grasses, seeds, acorns, leaves, and twigs (Laerm 1999). The distributions of these specimens (which are likely white-tailed deer) have carbon and nitrogen isotopic values that are on the heavy end of isotopic distributions of white-tailed deer observed elsewhere (Cormie and Schwarcz 1994; Derbridge 2010; Little and Schoeninger 1995; Urton and Hobson 2005). However, similarly high nitrogen values among deer have been observed in Ontario (Katzenberg 1989) and Nova Scotia (Cormie and Schwarcz 1994) which were likely caused by varying environmental conditions that affect plant or soil chemistry (e.g., sea spray [Virginia and Delwiche 1982] or denitrification [Delwiche and Steyn 1970]).

Of the isotopically heavier deer specimens (55L28F6-8 and 4L58K11-7), the associated $\delta^{15}N$ value of the former (6.11‰) is not higher than the nitrogen values of the 'C_3 deer', to suggest that the C_4 plants originated from salt marsh, wetland, or coastal environments. However, without knowing the $\delta^{15}N$ values of local C_4 plants in these environments, such a possibility cannot be ruled out. The same goes for local seaweed species (see Stevens et al. [2006] for information on deer eating seaweed). A more plausible explanation that would account for higher $\delta^{13}C$ values with no increase in $\delta^{15}N$ values is a diet that included plants from agricultural C_4 crops (Cormie and Schwarcz 1994; Laerm 1999). Since agricultural crops were not common to Cape Breton Island, these specimens may have originated from elsewhere. Unfortunately, deer specimen 4L58K11-7 did not have any associated bone material, and as a result, there are no nitrogen data to allow for further speculation on the origin/source of the C_4 plants on which this specimen subsisted.

7.1.4 Pigs

The pig specimens' isotopic range (6.91‰) is larger than ranges for the domestic herbivores (Table 15). This was expected since pigs are often fed omnivorously. Three specimens have isotopic values comparable to the majority of sheep, goat, and cow specimens analysed in this study (Figures 16 and 26). Their collagen and bioapatite data suggest a mainly C_3 plant diet. Two pig specimens have distinct values. One specimen (4L58K14-7) has $\delta^{13}C_{Col}$ and $\delta^{13}C_{Carb}$ values consistent with a C_3 diet (-21.47 and -12.95‰, respectively, Table 21), but a high $\delta^{15}N$ value (9.46‰). This specimen may

have been fed meat from herbivorous animals eating a C_3 diet since the isotopic values fall approximately one trophic level (~3‰ [DeNiro and Epstein 1981; Mingawa and Wada 1984; Schoeninger and DeNiro 1984]) above many herbivore specimens. If this specimen was particularly young, then it may have high $\delta^{15}N$ values from the enrichment effect of a suckling animal (Richards et al. 2002). An alternative explanation may be that the animal was fed freshwater fish since many freshwater specimens are known to have low $\delta^{13}C$ values (similar to or even less than C_3 herbivores) and high $\delta^{15}N$ values, often above 10‰ (Dufour et al. 1999; Müldner and Richards 2005; Schoeninger and DeNiro 1984). This is only conjecture since the isotopic values of freshwater fish can be extremely varied (Dufour et al. 1999), and no freshwater fish specimens were analysed in this study.

The second outlying pig specimen (4L52L12-12) has much higher $\delta^{13}C_{Col}$, $\delta^{15}N$, and $\delta^{13}C_{Carb}$ values (-14.56, 11.01, and -5.19‰, respectively). This is consistent with a diet including marine resources and possibly C_4 based resources. Foddering with terrestrial grains was believed to result in tastier meat, as opposed to foddering with fish scraps which resulted in fishy tasting meat, however, since fish offal was readily available at the Fortress, foddering with fish was commonly practiced (A. M. Lane Jonah, personal communication 2012). In a study of Newfoundland pigs from French and English colonies, it has been suggested that a strong marine diet indicates local origins (where pigs were foddered on fish offal), while a terrestrial diet suggests Old World origins (where a terrestrial diet was prominent) (Guiry et al. 2012). If this hypothesis can be applied to the Fortress of Louisbourg, only one specimen (4L52L12-12) has isotopic

values that are similar to the 'marine pigs' in Guiry et al.'s (2012) study. All other specimens (n=4) have isotopic values that are similar to the 'terrestrial pigs' in Guiry et al.'s (2012) study. However, within the context of Louisbourg, a terrestrial diet may not indicate Old World origins since pig livestock and pork were also imported from several other regions (e.g., Acadia and New England, Chapter 2.3.1) where grains may have been the preferred foddering material. The oxygen and strontium data from these specimens do not help clarify this matter. Only one specimen (with a terrestrial diet) showed potential non-local origins (Chapter 7.4), and although all other specimens have isotopic values that match Louisbourg, these values are also likely found in regions of New England, making definitive conclusions concerning pig origins problematic (see Chapter 7.5.2 for more discussion of New England oxygen and strontium isotopes).

7.1.5 Birds

The isotopic values of the bird specimens in this study are difficult to assess because of the small sample sizes of some bird types (n=1 each for duck, eider, spruce grouse, and unidentified avian, Table 21). Dietary variation among the wild birds ranges from low carbon and nitrogen isotopic values, indicating strict C_3 plant diets, to high carbon and nitrogen values, indicating marine diets (Figure 16). The unidentified avian, with a $\delta^{15}N$ value of 15.10‰, was likely a marine bird since marine birds typically have $\delta^{15}N$ values above ~10‰ and terrestrial birds typically have $\delta^{15}N$ values below ~10‰ (Schoeninger and DeNiro 1984). A marine diet was also indicated by the high $\delta^{13}C$ and $\delta^{15}N$ values of the dove/robin specimens ($\delta^{13}C_{Col}$ mean = -16.28 ± 0.36 and $\delta^{15}N$ mean = 13.28 ± 0.92‰,

n=4, Table 15). These specimens were not able to be identified as one animal or the other. If the specimens are wild robins, it is unclear why they would have very high $\delta^{13}C$ and $\delta^{15}N$ values. However, if these specimens were domesticated doves, then it is likely they were foddered on marine products. It seems probable that a high proportion or possibly all of these specimens were doves since these bones were excavated from the Ste. Marie site which was close in proximity to two dovecots within the nearby Carrarot property.

There are two distinct groupings concerning the goose and turkey specimens (n=2 and n=3, respectively), of which, all were domestic varieties. One specimen each of goose and turkey (3L6N13-1 and 55L28G7-6, respectively) has $\delta^{13}C_{Col}$ and $\delta^{15}N$ values indicative of a terrestrial diet that likely included some C_4 plants or grains (Figure 19). The other goose and other two turkey specimens have high $\delta^{15}N$ values that indicate a high marine component. It is likely that these specimens were foddered with fish offal.

There is a great deal of isotopic variation among the chicken specimens ($\delta^{13}C_{Col}$ range = 10.85‰ and $\delta^{15}N$ range =14.97‰, n=9). All samples yielded an appropriate amount of collagen (between 11.93% and 25.68% with a mean of 19.14%) and had acceptable C/N atomic ratios (between 3.10 and 3.38 with a mean of 3.28) (Table 5). It is thus reasoned that the isotopic variation is biogenic in origin. This variation is likely the result of isotopically diverse fodder or grazing foods which appear to be more isotopically diverse than the diets of other domesticated birds examined in this study (goose, turkey and potentially dove/robin, a total of nine specimens) and of the chicken and turkey specimens from Dos De Cheval, a French seasonal fishing station in Newfoundland ($\delta^{13}C_{Col}$ range = 1.02‰, $\delta^{15}N$ range = 1.68‰, n=6 [Guiry et al. 2012]).

Five chicken specimens show consumption of marine resources, one of which (55L28E20-51b) has even higher $\delta^{13}C$ values than the fish specimens in this study (Figure 16). Two chicken specimens (55L28E10-7 and 55L28F6-13) show a mixed C_3 plant and marine diet. Two others fall greatly outside this distribution. One specimen (55L28E20-51a) has a relatively low $\delta^{13}C$ value (-21.51‰) indicative of a C_3 plant diet but a very high $\delta^{15}N$ value (13.86‰) not typical of a terrestrial diet. The placement of this specimen may indicate a diet including freshwater fish which can have isotopic values low in $\delta^{13}C$ and high in $\delta^{15}N$ (Dufour et al. 1999; Müldner and Richards 2005; Schoeninger and DeNiro 1984). The second specimen (55L28F4-3) has $\delta^{13}C$ and $\delta^{15}N$ values of -23.51‰ and 0.02‰, respectively, indicating a diet based on N_2-fixing plants. It is unclear at this time if chickens were foddered on N_2-fixers (such as legumes, peas, and beans) at the Fortress of Louisbourg. It is also possible that this specimen originated from elsewhere (e.g., New England [Chard 1995; McLennan 1918]) where such fodder was used.

7.1.6 Hare

Similar to the chicken specimens in this study, the 11 hare specimens have large isotopic ranges ($\delta^{13}C_{Col}$ range = 9.97‰ and $\delta^{15}N$ range = 14.53‰, Table 15). The isotopic variation of hare specimens falls into three distinct groupings. One group (n=3) has very high $\delta^{13}C_{Col}$ and $\delta^{15}N$ values, the second group (n=2) has isotopically lighter values indicative of a C_3 diet, and the third group (n=3) has even lower isotopic values that are typical of N_2-fixing plant eaters (Figure 18). A further three hare specimens analysed for bioapatite, have $\delta^{13}C_{Carb}$ values indicative of a C_3 plant diet (Figure 26). Hares have a

natural diet of various herbs, shrubs, grasses, and woody plants (Murray 1999; Peterson ed. 1966). The two 'C_3 hares' with higher $\delta^{15}N$ values likely ingested non-N_2-fixing woody plants such as maples and grasses. The specimens with the lowest $\delta^{15}N$ values likely ingested those N_2-fixers common to eastern Cape Breton Island such as birches, firs, spruces, and clovers (Bouman et al. 2004).

The $\delta^{13}C$ values for 'C_3 hares' in this study overlap with the ranges of hare specimens analysed from a coastal archaeological site in Newfoundland (Guiry et al. 2012) but are somewhat isotopically heavier than modern snowshoe hares from across Canada and northern US (Roth et al. 2007; Urton and Hobson 2005) even after adjusting for the alteration of carbon isotopes in atmospheric CO_2 since industrialisation (modern ‰ value +1.5‰ [Marino and McElroy 1991]). It should be noted that the data from the Roth et al. (2007) and Urton and Hobson (2005) studies were from the analysis of hair, however, hair and bone collagen have yielded very similar isotopic values in domestic rabbits with consistent diets (Hilderbrand et al. 1996). These differences can likely be attributed to isotopic variations between coastal and inland environments.

The occurrence of three specimens (specimens 55L28G7-2, 55L28E10-9, and 55L28F6-10) with isotopically heavy values (with $\delta^{13}C_{Col}$ values between -15.93 and -14.17‰ and $\delta^{15}N$ values between 13.49 and 15.48‰, Table 21) is surprising, and indicates a diet significantly different from the isotopically lighter hare specimens. These values are believed to be biogenic in origin since they had acceptable % collagen yields between 7.91 and 31.08%) and acceptable C/N atomic ratios (between 3.23 and 3.37) (Table 5).

One hypothesis involves the ingestion of isotopically heavy seaweed, however, this is believed unlikely since hares are not known for eating seaweed. A second hypothesis involves the ingestion of local C_4 grasses. Although, C_4 grasses with $\delta^{15}N$ values as high as 16‰ have been reported in San Francisco Bay (Cloern et al. 2002), it is currently unknown whether local C_4 grass species are elevated enough in ^{13}C and ^{15}N to produce the high values observed in this study. If the isotopic values of C_4 grasses were high enough, an animal would have to have a diet including relatively very little C_3 plant species since the animal's bone collagen would simply average between the two isotopic values. Overall, this is believed unlikely considering the low abundance of C_4 grasses in Nova Scotia (Roland and Smith 1969 in Wan and Sage 2001) and indeed within the hare's natural forest/shrub habitat (Peterson ed. 1966).

A third hypothesis involves the ingestion of isotopically heavy terrestrial animals. These specimens are likely snowshoe hares which are mostly herbivorous animals, but snowshoe hares are known to scavenge on the carcasses of caribou and other hares in the winter months (Naughton 2012). However, a consumer of caribou or isotopically light hare meat would not produce the high isotopic values of the isotopically heavy hares (based off the caribou and hare data from this study, see Table 21). To achieve these high $\delta^{15}N$ values, the hares in question may have had a diet that included a high quantity of meat from isotopically heavy animals, as is believed to be the case for many of the rodent, bird, and carnivore specimens.

A fourth hypothesis involves the ingestion of fish. While there is no current information on snowshoe hare eating fish, the arctic hare has been known to scavenge on

frozen fish (as well as meat bait from hunters' traps) (Best and Henry 1994). However, the closest location within the artic hare's geographic range is Newfoundland (Howell 1936), and since Newfoundland is not mentioned in historical studies as an exporter to Louisbourg (see Chapter 2.3.1), it is unlikely that these specimens are imported arctic hares.

Since snowshoe hares are known to eat meat (Naughton 2012), it is not unreasonable to speculate that they would also ingest fish like their arctic hare cousins (Best and Henry 1994). Furthermore, it is very likely that any wild scavenger in the area would have access to fish or fish offal created by Louisbourg's involvement in the small boat cod fishing industry. In this industry, codfish were brought back to shoreline stages for gutting and drying which created copious amounts of fish offal around Louisbourg harbour as well as many other locations on Cape Breton Island (A. M. Lane Jonah, personal communication 2013). It is very likely that if hares were willing to eat fish, such a diet would have been readily available. Furthermore, fish and meat are higher in protein than plant matter (fish in particular is very high in protein [McNeill 1985]). Even a small amount of these isotopically heavy foods have the potential to strongly shift the $\delta^{13}C_{Col}$ and $\delta^{15}N$ values of an animal's collagen (Ambrose and Norr 1993; Krueger and Sullivan 1984). If such is the case, then fish does not seem to have been a food item for hares excavated from a French cod fishing site in Newfoundland (hare $\delta^{15}N$ maximum = 4.03‰, n=3 [Guiry et al. 2012]).

It is important to note that the hares with marine-like isotopic values and the isotopically heavy C_3 hares came from the Rochefort Point site (proveniences start with

55L28), whereas the three lightest specimens came from the town site (proveniences start with 4L and 3L) (Table 21). This may be hinting towards a distinction between the types of hares sourced by the inhabitants of Rochefort point vs. the inhabitants of the town, whereby the hares sourced by the different inhabitant groups had different diets. Further examination (possibly including a re-assessment of the morphological identification) is needed to investigate the existence of such a phenomenon and understand the causal factors behind the isotopic variations observed in this study.

7.1.7 Red Squirrels

There is likewise a scattering of isotopic values for red squirrel specimens (n=6, Figure 18). This was likely caused by the varied food items that are eaten by red squirrels which include conifer seeds, nuts, berries, fungi, insects, and small vertebrates (Peterson ed. 1966; Young 1999). Red squirrels are also known to prey on juvenile snowshoe hares and are referred to as the main predators of songbird chicks and eggs (reviewed in Callahan 1993; Peterson ed. 1966; Tewksbury et al. 1998; Young 1999). The varied diet of red squirrels was likely the cause of the isotopic variation observed in this study.

Two specimens (55L28E23-25 and 55L28E19-4) have very high $\delta^{15}N$ values (15.60 and 16.13‰, respectively, Table 21). The placement of these specimens is comparable to the three isotopically heavy hare specimens discussed previously. As such, the hypotheses in reference to the diets of the 'marine-like' hares may also apply to these two isotopically heavy squirrel specimens: isotopically heavy seaweed, salt marsh, coastal or wetland C_4 grasses, terrestrial animals, and fish or fish offal. Considering the possibility

of predation on juvenile snowshoe hares, the hypothesis concerning terrestrial animals may well include the ingestion of isotopically heavy hares.

The other red squirrel specimens (n=4) (with lower $\delta^{15}N$ values), still have carbon and nitrogen values higher than, or on the high end of isotopic data reported in other studies (Rosing et al. 1998; Roth et al. 2007). The tissue analysed in the former study was muscle and the latter was hair, however, previous research illustrates that an animal's hair, and to a lesser extent muscle, is similar in isotopic value to the same animal's bone collagen (Fox-Dobbs et al. 2007; Hilderbrand et al. 1996). The $\delta^{13}C$ values in Rosing et al. (1998) and Roth et al. (2007) place within the C_3 plant range, while many of the specimens in this study have values which suggest diets that range from isotopically heavy C_3 plants, to C_4 plants. Specimen 55L28F12-3 has a $\delta^{13}C_{Col}$ value of -13.93‰, the highest $\delta^{13}C_{Col}$ value of any mammal in this study. This specimen may have been eating wild C_4 grasses local to the area, scavenging on maize (or other C_4 products) used as fodder by local farmers, or stealing the inhabitants' C_4 grain stores. Also, considering the high $\delta^{15}N$ values of these specimens (between 7.62 and 9.65‰) and considering the omnivorous diet of squirrels is potentially driven by the need/desire for high protein foods (Callahan 1993), it cannot be ruled out that these specimens were also ingesting such high protein foods as marine invertebrates or seaweed, (for isotopic data on marine invertebrates and seaweed see Lesage et al. [2001], Mateo et al. [2008], Miyake and Wada [1967], Parker [1963], Smith and Epstein [1971], and Stapp [2002]).

Overall, it must be noted that all of these specimens were excavated from the root cellar on Rochefort Point. If these specimens lived on the point, they would have been out

of their natural coniferous forest habitat (Peterson ed. 1966) and may have adjusted their dietary habits towards foods that were available on the grassy point, resulting in very different isotopic values. If this was the case, such a diet may well have included C_4 grasses and grains, fish offal, marine invertebrates, or seaweed.

7.1.8 Mice and Rats

A majority of mouse (n=4) and rat specimens (n=11) group tightly with one another and have relatively high $\delta^{13}C_{Col}$, $\delta^{15}N$, and $\delta^{13}C_{Carb}$ values (Table 21) that place slightly lower than the fish specimens (Figure 18). This indicates that these specimens supplemented their diet with fish, likely scavenged from local codfish processing activities. Overall, rats and mice have various diets of mosses, seeds, nuts, fruits, worms, insects, marine invertebrates, and rats in particular are known to eat fish and scavenge/prey on seabird adults, chicks, and eggs, as well as juvenile sea turtles (Caut et al. 2008; Handley 1999; Pisanu et al. 2011; Stapp 2002; Whitaker 1999).

Two rat specimens (17L45A4-12 and 4L19D7-1) are isotopically lighter than the rest and likely had mainly herbivorous diets of C_3 plants. It is important to note that these specimens are the only rodent specimens retrieved from excavations from within the fortress, rather than from the Ste. Marie site on Rochefort point. This may be hinting towards a diet variation between town site rodents vs. Rochefort point rodents (see also the discussion of hare diet variation in Chapter 7.1.6). It is very likely that a mouse living on Rochefort point would have greater access to marine products, especially fish since Rochefort point was a common area where the near shore fishermen gutted their fish and

laid out the filets to dry. Such a diet distinction between the two sites is possible since mice and rats have small home ranges (Davis et al. 1948; Handley 1999; Quadango 1968).

It is also important to note that, whereas all the Rochefort point rats date to around the time of occupation, the town site rat 17L45A4-12 is from a layer dated between 1751 and 1784 (Table 21). It is possible that this rat lived after the French occupation (which ended in 1758) and during a point in Louisbourg's history when the fishing industry had ceased and fish as a food item was less available. If this is the case, the isotopic values of this rat may be reflecting a more natural C_3 diet. Unfortunately, the other town site rat (4L19D7-1) is undated. Overall, these hypotheses would require further investigation and indeed a greater sample number of specimens from within the town site or from post-occupation layers.

7.1.9 Beavers

The two beaver specimens have very similar $\delta^{13}C_{Carb}$ values of -14.26 and -14.10‰ which suggests a C_3 diet (Table 21 and Figure 26). Beaver collagen data from other studies also suggest a C_3 diet (Derbridge 2010, Derbridge et al. 2012; Fox-Dobbs et al. 2007; Guiry et al. 2012; Katzenberg 1989; Urton and Hobson 2005). Beavers typically eat the wood, bark, and leaves of evergreen and deciduous trees (such as aspen and willow) as well as various aquatic plants (Jenkins and Smith 1999).

7.1.10 Red Foxes

The carbon and nitrogen isotopic values of red fox specimens (n=2) in this study are comparable or higher than red fox specimens from other isotopic studies (Rick et al. 2011; Urton and Hobson 2005). Compared to the isotopic data from prey items in this study, the red fox specimens' diets likely included animals that had high $\delta^{13}C$ and $\delta^{15}N$ values such as fish or isotopically heavy animals (e.g., hares, squirrels, and birds, Figure 16). This is very possible since red foxes are known to have a varied diet that includes rodents, rabbits, birds, fruit, and small invertebrates (Meckstroth et al. 2007; Seidensticker 1999). Foxes are also scavengers (Conteese et al. 2004) and will eat marine foods (Meckstroth et al. 2007; Roth 2003). Furthermore, foxes have been known to adjust their dietary habits when living around humans. This includes scavenging on refuse and preying on livestock and pets (Conteese et al. 2004; Meckstroth et al. 2007; Seidensticker 1999). Thus, along with a diet of wild animals, it is also possible that these specimens (specimen 4L20F11-3 in particular) scavenged on discarded fish scraps produced by local processing activities and on isotopically heavy domestic animals (Figure 16).

In reference to the distinct isotopic values between the two specimens in this study, this may be a reflection of the degree of contact that these specimens had with humans and the by-products and side effects of fishing activities. The isotopically heavier red fox (4L20F11-3, $\delta^{13}C = -14.37‰$ and $\delta^{15}N = 14.82‰$) came from an excavation level dating between 1713 and 1731 (Table 21), a time when the French were actively exploiting the fishing industry, and fish and fish offal would have been readily available to a wild scavenger. The isotopically lighter red fox (3L6N10-9, $\delta^{13}C = -18.02‰$ and $\delta^{15}N =$

12.16‰) came from a stratigraphic layer with a date range between 1774 and 1784. This date range was during a time when large scale fishing had long since ended, and the area had been significantly de-populated. During this period, fish by-products would have been less available to a scavenger and human refuse and isotopically heavy domestic animals less abundant than they may have been in the past. Therefore, the lighter isotopic values of 3L6N10-9 may reflect a natural diet in the absence of isotopically heavy anthropogenic food. A study aimed at investigating the impact of the Louisbourg population on 18th-century fauna would necessitate larger sample sizes with distinct occupation vs. pre- or post-occupation date ranges.

7.1.11 Lynx

Similar to the red fox specimens, the two lynx specimens in this study are isotopically heavy compared to other lynx data (Bocherens et al. 1994b; Urton and Hobson 2005) The main source of food for Canadian lynx is snowshoe hare, and to a lesser extent, red squirrel (Parker et al. 1983; Roth et al. 2007), but lynx will also prey on other small mammals as well as birds, frogs, and invertebrates (Peterson ed. 1966). Lynx specimen 4L51M11-9 has very high isotopic values ($\delta^{13}C$ = -17.09‰ and $\delta^{15}N$ = 12.00‰, Table 21). This specimen likely did not subsist solely on isotopically light hares but also isotopically heavy hares, squirrels, and other isotopically heavy animals (Figure 18). Unlike red fox, lynx are not scavengers and typically stay away from human populated areas, making it unlikely that these specimens ingested fish offal or isotopically heavy domestic animals.

7.1.12 Cats

The isotopic values of cat specimens (n=2) from Louisbourg are similarly high, indicating a carnivorous diet. Considering the domestic nature of cats, these specimens' diets could have consisted of table scraps of terrestrial animals and fish, as well as natural prey items such as mice, rats, and birds. The cat specimen with the lowest $\delta^{13}C_{Col}$ and $\delta^{15}N$ values (specimen 3L21E3-3, $\delta^{13}C$ = -17.33‰ and $\delta^{15}N$ = 10.83‰,Table 21) may have had a diet of mainly terrestrial animals since the isotopic values are not much higher than one trophic level above many domestic herbivores from this study (Figure 16). The other cat specimen (1L34D5-39, $\delta^{13}C$ = -16.38‰ and $\delta^{15}N$ = 12.65‰) has relatively higher isotopic values than the former, and likely ate a higher proportion of isotopically heavier foods such as fish, mice, rats, chicken, and squirrels.

7.1.13 Fish

The heaviest isotopic grouping in this study belongs to the fish specimens (Figure 16). This grouping is very tight ($\delta^{13}C$ range = 1.06‰ and $\delta^{15}N$ range = 1.81‰, Table 15), indicating a similar diet. However, since the majority of specimens (five out of six) came from the same provenience it cannot be ruled out that they came from the same animal (Table 21). These specimens were not identified further, but their isotopic values are very similar to archaeological cod specimens from Newfoundland (Guiry et al. 2012) and modern cod specimens from the St. Lawrence (Lesage et al. 2001) (after adjusting for post-industrial $\delta^{13}C$ values [Marino and McElroy 1991]). Furthermore, considering the context surrounding the site (wherein the codfish industry was the basis of the economy)

and the location wherein these specimens were found (on Rochefort point where codfish were processed and dried), it is likely that these specimens are Atlantic cod (*Gadus morhua*).

7.1.14 Conclusion

The faunal data in this study have revealed a number of noteworthy characteristics. There appears to have been a variety of foddering materials and grazing habits among the domestic animals, from terrestrial products (mostly C_3 but some C_4 products), to marine and possibly freshwater resources. C_3 and C_4 grains were both used as foddering material at the Fortress, as was fish offal (A. M. Lane Jonah, personal communication 2012). The use of fish materials is evident in the isotopic values of many domestic animals such as the chicken, pig, and possibly the dove/robin specimens. Another interesting factor is the likely influence of cod fishing on the isotopic values of not only the domestic animals but also the wild fauna. Many specimens have extremely marine-like isotopic values, indicating that fish (or isotopically similar items) featured strongly in some specimens' diets.

It must be noted that many of the specimens in this study may have been from animals or preserved meat imported from other areas via trade with other colonial towns or with Native peoples. Thus, the $\delta^{13}C$ and $\delta^{15}N$ values may be reflecting those isotopic values of non-local areas.

7.2 Ste. Marie Diet Reconstruction

In comparison with the Louisbourg faunal data (Figure 21), and considering a $\delta^{15}N$ trophic shift between diet and consumer of ~3‰ (DeNiro and Epstein 1981; Mingawa and Wada 1984; Schoeninger and DeNiro 1984), a majority of the individuals (n=28, 74%) have isotopic values that are approximately one trophic level above the domestic herbivores (i.e., no higher than 10.44‰). Thus, these individuals' dietary protein likely came from animals that subsisted on terrestrial foods. Those individuals with $\delta^{15}N$ values above one trophic level of the herbivores (i.e., above 10.44‰, n=10, 26%), likely had a diet consisting mainly of omnivores or some marine foods. Considering a $\delta^{13}C$ trophic shift of ~1‰ (DeNiro 1977; DeNiro and Epstein 1978), and the ~5‰ shift between a herbivore and their diet (Ambrose and Norr 1993), the individuals with the lowest $\delta^{13}C_{Col}$ values likely obtained their dietary protein from animals that subsisted on C_3 resources, and the individuals with the highest $\delta^{13}C_{Col}$ values likely obtained their dietary protein from animals with a mixed C_3/C_4 diet (Bender 1971; Smith and Epstein 1971; van der Merwe 1982). Those individuals with the lowest $\delta^{13}C_{Carb}$ values (Figure 26) likely had diets of C_3 based resources, and those individuals with the highest $\delta^{13}C_{Carb}$ values likely had diets of mixed C_3/C_4 based resources or some marine foods (Kohn and Cerling 2002).

Although few herbivores have high $\delta^{13}C_{Col}$ values, many individuals have high $\delta^{13}C_{Col}$ and low $\delta^{15}N$ values (Figure 21, Table 22) which may have been from a diet consisting of low trophic level marine animals. Marine shellfish and oysters in particular were a common food item at the Fortress of Louisbourg, especially during periods of low food supply (Lane Jonah and Véchambre 2012; McLennan 1918). Oysters have $\delta^{13}C$

values of -18.6‰ and $\delta^{15}N$ values of 2.8‰ (Little and Schoeninger 1995), and if eaten in high amounts, may be the cause of some individuals' high carbon and low nitrogen values. Unfortunately, there are no marine invertebrates analysed in this study (although marine invertebrate materials are present in the Fortress of Louisbourg collection).

Carbon and nitrogen isotopic values of plants and animals can vary from one region to another (Ambrose 1991; Heaton 1999; Virginia and Delwiche 1982). Since it is possible that these individuals did not originate from Louisbourg, the Ste. Marie individuals are also compared to 'benchmark' human groups with diets that were well studied and are isotopically and compositionally distinct.

Compared to the human diet groups reported in Honch et al.'s (2012) study, most of the Ste. Marie individuals fall closely around those human groups that subsisted on terrestrial C_3 diets or between C_3 and C_4 diet groups (Figure 35). The terrestrial C_3 groups in Honch et al.'s (2012) study are from various Neolithic sites in Bulgaria, Serbia, and Romania, and the terrestrial C_4 groups are from numerous sites in Belize and Guatemala. None of the Ste. Marie individuals fall within the human groups with high marine protein (HMP) diets from Greenland and Japan. A few individuals from the Ste. Marie group fall between Honch et al.'s (2012) C_3 and HMP groups, and close to the freshwater protein diet groups (from Romania and Serbia) and may have subsisted on a mixture of C_3, marine, and freshwater based foods. One individual from the Ste. Marie group falls between HMP and C_4 groups and likely had a mixed marine-C_4 diet.

Overall, comparisons between the Ste. Marie data, and the Louisbourg faunal data and data from human groups with well-studied diets (Honch et al. 2012) have resulted in

a single conclusion: most of the Ste. Marie individuals subsisted on terrestrial animals and plants (mostly C_3 based and some mixed C_3/C_4 based), while a few individuals subsisted on a mixed marine/terrestrial diet.

7.2.1 Does a Low Marine Contribution Mean Non-Local Origins?

Historical literature concerning Louisbourg subsistence describes numerous protein sources including domestic animals (e.g., pigs, bovids, and domestic birds), wild animals (e.g., hare, fowl, and deer), and marine foods (e.g., oysters and muscles) (Cumba 1976; Downey 1965; Lane Jonah and Véchambre 2012; McNeill 1985). However, codfish was the staple at Louisbourg more so than any other food item (Cumba 1976; Downey 1965; Lane Jonah and Véchambre 2012). Codfish was a reliable food since it did not need to be imported and could be salted and dried or kept in brine for long periods of time (Balcom 1995). This was especially important when provisions were low or when food shipments were halted which was a common occurrence in the late winter, early spring, or in times of warfare (Cumbaa 1976; McLennan 1918). Codfish was consumed by both the rich and poor. The lower classes ate filets of poor quality, and the upper classes ate well-cured codfish cooked in fancy dishes (Lane Jonah and Véchambre 2012). Furthermore, fish was a common item on days when eating meat was prohibited by the Catholic church which included a total of 150 days a year (Lane Jonah and Véchambre 2012; Varkey 2002).

It must also be considered that codfish has a higher protein content than meat, with ~250% more protein per calorie than beef (McNeill 1985). As a result, the isotopic values of fish would be expressed to a greater degree than terrestrial meat within a consumer's bone collagen (Ambrose and Norr 1993; Krueger and Sullivan 1984). Codfish express

very high $\delta^{13}C$ and $\delta^{15}N$ values (Guiry et al. 2012), similar to the marine fish analysed in this study (Table 21). If the Ste. Marie individuals were from Louisbourg, it would be expected that a greater number of individuals would express values consistent with a diet of marine fish. Because a majority of the Ste. Marie individuals show isotopic ratios consistent with a terrestrial diet, it is believed that they were not locals. The Ste. Marie individuals likely had origins in a location where high $\delta^{15}N$ marine products were not readily available or where terrestrial meat was the preferred protein source.

If these individuals were from New England, it is likely that a majority lived inland or in rural areas where agriculture and animals provided the main subsistence, and marine foods were less common in comparison to the coastal and urban areas where fish was a more significant food item (Landon 1996). Although fish was available and plentiful in New England, it may not be surprising to find that most individuals show a terrestrial diet since the English preferred beef over the fish and poultry preferred by the French (Lane Jonah and Véchambre 2012). However, it is unclear the degree to which this preference would influence the actual diets (and isotopic values) of New Englanders vs. Louisbourgeois.

It must be noted that there is no control group for this study (i.e., individuals who lived at Louisbourg and subsisted on a Louisbourg diet) against which the results of this study could be compared. Such a study would provide a more comprehensive understanding of the influence marine foods had on the diets and isotopic values of Louisbourg inhabitants (see Chapter 7.7.2 for further discussion of a control group). Furthermore, there are no isotopic dietary studies of New England inhabitants to which

the Ste. Marie data can be compared. However, previous to this study, a single individual excavated from the Fortress of Louisbourg had been isotopically analysed from a hair sample (Schwarcz 2010). From the presence of British coins found over the individual's eyes, it is believed they were from Britain or New England. The isotopic values of this individual ($\delta^{13}C$ = -18.8‰ and $\delta^{15}N$ = 10.4‰) are similar to those Ste. Marie individuals with the lowest carbon and nitrogen isotopic values (Schwarcz 2010). Since this is only one individual, and it is not known whether they were from Britain or New England or how long they resided at Louisbourg, these data are somewhat limited for the purpose of dietary comparisons with the Ste. Marie individuals.

7.2.2 Isotopic Visibility

It is important to note the time span that is visible via isotopic analysis. Over half (n=23, 61%, Table 23) of the individuals analysed in this study are represented by rib samples, while approximately one-quarter (n=10, 26%) are represented by isotopic data from long bones of the arm or leg. A further two individuals (5%) have isotopic values averaged from one sample each of rib and arm long bone, and three individuals (8%) are represented by unidentified bone fragments. Due to bone turnover, analysis of rib bones will represent isotopic intake in the last ~20 years of an individual's life, and long bones of the arm or leg will represent over 50 years of an individual's life (Table 2). Because of this, it is theoretically possible that the Ste. Marie individuals were indeed Louisbourg inhabitants who were recent immigrants (e.g., within the last 10 years), whose original terrestrial isotopic values were not yet rewritten via bone turnover to their new high

marine diet. However, since a majority of the individuals (n=23, 61%) were sampled from ribs (which have a relatively quicker turnover rate), and a majority of these (n=17, 74%, Table 23) still have isotopic values indicating a strict terrestrial diet (i.e., lower than 10‰ [Richards and Hedges 1999; Schoeninger et al. 1983; Walker and DeNiro 1986], Figure 36), it is still believed unlikely that these individuals were Louisbourg inhabitants. These results would benefit from further investigation, for example, the analysis of collagen containing different/shorter temporal visibilities.

7.2.3 Isotopic Variation

The $\delta^{13}C$ and $\delta^{15}N$ isotopic ranges observed among the Ste. Marie group ($\delta^{13}C_{Col}$ range = 8.48‰, $\delta^{15}N$ range = 7.32‰, Table 16, and $\delta^{13}C_{Carb}$ range = 11.34‰, Table 20) are larger than the ranges observed from other contexts. The C and N isotopic ranges of other community groups are often smaller (e.g., $\delta^{13}C_{Col}$ range = 2.7‰, $\delta^{15}N$ range = 9.20‰, and $\delta^{13}C_{Carb}$ range = 7.50‰, n=89 [Keenleyside et al. 2009], and $\delta^{13}C_{Col}$ range = 2.30‰ and $\delta^{15}N$ range = 3.4‰, n=46 [Müldner and Richards 2005]), and if large ranges are observed, there is often a linear distribution between two isotopically different dietary sources (Crowe et al. 2010; Richards et al. 2006). In comparison, the isotopic values of the Ste. Marie individuals show a somewhat diffuse spread between C_3, mixed C_3/C_4 resources, and mixed terrestrial/marine resources (Figures 21, and 26). The following is a discussion concerning potential causes of the Ste. Marie group's isotopic variation.

The New England Garrison Hypothesis: If the Ste. Marie individuals are deceased members of the New England garrison, the varied life histories of the recruited soldiers may be the cause of the isotopic variation observed. Those involved in the campaign against Louisbourg were recruited from a variety of areas in New England. From a recorded total of 4272 recruited, 11% were from New Hampshire, 12% were from Connecticut, and 77% from Massachusetts and Maine (Baker 1978; Rawlyk 1999). In the 18th-century, these regions were also the home of a small number of immigrants from European countries (Greene 1988). The original occupation of the recruited was documented as fishermen, deckhands, longshoremen, farmers, mechanics, and merchants (Baker 1978; Clark 1965; Hassler 1982).

The availability of C_3 vs. C_4 grains, produce, and meat varied across colonial New England (Fisher et al. 1997). Some areas were self-sufficient when it came to food production, while others relied on the importation of food from the Old World and other New World colonies. Thus, the isotopic values of New England food may vary significantly from region to region. An individual's occupation may also affect their diet (Crowe et al. 2010; Kusaka et al. 2011). For example, a farmer or lumberjack from inland areas of New England would be expected to have a terrestrial diet and less of a marine protein component than a fisherman living on the coast. Indeed, expansion and settlement inland was up to 70 miles by the early 18th-century (Greene 1988), making such a distinction a possibility. Overall, the isotopic variation observed in the Ste. Marie group may be the result of the variation in life histories and lends a measure of support to the hypothesis that the Ste. Marie individuals were from the New England garrison of 1745.

Soldier Groups: The isotopic variation observed in the Ste. Marie group is relatively large compared to other groups and may be the result of variation in diet and life histories of the New England garrison. Isotopic comparisons with groups with similar contexts are valuable and may further illuminate such a possibility. Comparisons with other soldier groups may seem a likely route considering the hypothesis that the Ste. Marie individuals were New England soldiers, however, this must be taken under careful consideration since the Ste. Marie individuals were not a typical soldier group but were recruited from other occupations only shortly before their death.

Soldiers were typically recruited from various regions and backgrounds and would therefore initially hold various isotopic values, but the relatively homogeneous nature of a military diet may result in a shifting or muting of the soldiers' original isotopic values towards a different or more constrained grouping. This change would necessitate a homogeneous diet being consumed over long periods of time, such that the new isotopic values would replace the old, via bone turnover.

A study by Roberts et al. (2012) investigated this phenomenon by analysing the isotopic ratios of servicemen from Nelson's Navy excavated from naval hospital burial grounds in southern England dating from the late 18th-century to the early 19th-century. This study investigated each individual's isotopic intake during different stages of their life (by analysing dentine, femora, and ribs), and thus, the change in diet from preadolescence to what the authors of this study call a 'naval average'. The study found that a diet change was isotopically visible, but the expression of this change depended on the naval posting and the types of food available at that location (e.g., C_4 grains on the

east coast of North America). It was also shown that the soldiers' diets before their recruitment were indeed more varied than after their recruitment.

This phenomenon would not affect the New England soldiers from the 1745 campaign to capture Louisbourg since these individuals were not long term soldiers but recruited the summer previous to their death. The soldiers' diet consumed during this period (less than a year) was too short relative to the turnover time of bone (over a decade) to be reflected in the isotopic values of their bone collagen (Table 2). As a result, the Ste. Marie group's isotopic values, potentially illustrating their various life histories, would remain largely unchanged rather than muted or shifted.

For these reasons, the isotopic variation observed in the Ste. Marie group may be more extreme than the variation observed in other soldier groups. An example of this is the Snake Hill group investigated by Katzenberg (1991). A total of 29 soldiers were excavated from a War of 1812 site in Fort Erie, Ontario and analysed for bone collagen isotopic content (Katzenberg 1991). The Snake Hill group had $\delta^{13}C$ values that ranged from ~-18.5 – -12.5‰ and $\delta^{15}N$ values from ~8.5 – 13‰ (Katzenberg 1991). The soldiers had varied origins and likely isotopically varied diets as a result (Katzenberg 1991). These ranges are indeed smaller than the Ste. Marie individuals (with $\delta^{13}C$ values from -20.75 – -12.27‰ and $\delta^{15}N$ values from 7.63 – 14.95‰, Table 22). However, the Snake Hill soldiers' original diets may have been muted due to long term ingestion of a more homogeneous diet. It is unclear at this time how long these individuals were soldiers. It is possible that the original diet of the Snake Hill group may have compared to the variation seen in the Ste. Marie group, but this remains to be seen. Overall, since a change from a

civilian's diet to a soldier's diet would not be apparent for the New England soldiers, the isotopic variation of the Ste. Marie group is better compared to a non-service group.

Colonial Origins: An alternative hypothesis for the Ste. Marie's isotopic variation is that the individuals were affected by the colonial nature of the contexts under study. Isotopic variability within a colonial community may be caused by the availability of isotopically varied foods, the importation of foreign foods, and the immigration of people who contain isotopic values from their place of origin.

A valuable comparison for such a hypothesis is the isotopic study performed by Ubelaker and Owsley (2003) of 27 cemetery burials from a 17th-century Chesapeake Bay colonial site. The values observed ranged from -20.51 – -10.52‰ for $\delta^{13}C_{Col}$, 9.94 – 14.40‰ for $\delta^{15}N$, and -12.51 – -5.11‰ for $\delta^{13}C_{Carb}$. The isotopic ranges were 9.99‰ for $\delta^{13}C_{Col}$, 4.46‰ for $\delta^{15}N$, and 7.40‰ for $\delta^{13}C_{Carb}$. The Ste. Marie group in comparison express more constrained $\delta^{13}C_{Col}$ values (range = 8.48‰ with values from -20.75 – -12.27‰), likely due to fewer C_4 based protein contributions, more varied $\delta^{15}N$ values (range = 7.32‰ with values from 7.63 – 14.95‰), likely caused by a higher reliance on isotopically lighter terrestrial foods, and more varied $\delta^{13}C_{Carb}$ values (range = 11.34‰ with values from -14.54 – -3.20‰), likely because of a reliance on both C_3 and C_4 based lipids, carbohydrates, and proteins.

While the Chesapeake Bay group's isotopic values express a degree of variation, as with other studies (Crowe et al. 2010; Richards et al. 2006), the distribution is relatively linear, whereas the Ste. Marie's isotopic variation is spread out and much more diffuse

(Figure 37). If the isotopic variation in the Ste. Marie group was the result of some type of colonial characteristic, the same effect does not seem to have the same degree of influence on the Chesapeake Bay group. It may be that the Chesapeake Bay area, although colonial in essence, may not have seen as many isotopically varied food imports as the Fortress of Louisbourg or New England.

The Fortress of Louisbourg was a colonial town that was deeply involved in trans-Atlantic trade and had a population of individuals from various regions from around the Atlantic. Food was imported from France, Britain, and other areas of Europe as well as the West Indies, New England, Acadia, Canada, and other parts of North America (see Chapter 2.3.1). Although locally caught codfish provided the main protein source (Cumba 1976; Downey 1965; Lane Jonah and Véchambre 2012; McNeill 1985), and locally made bread, the main calorie source (Donovan 2006; Lane Jonah and Véchambre 2012), the Fortress saw a variety of meat, vegetables, and grains (see Chapter 2.3.1).

As discussed in Chapter 2.3.1, few animals were raised locally, and livestock and meat were imported from a variety of areas. Bread for the wealthy was made from refined wheat flour, while the lower classes ate bread made from whole wheat or rye flour or a mixture of both (Lane Jonah and Véchambre 2012). Another common C_3 grain was rice which was imported from Italy and South Carolina (Lane Jonah and Véchambre 2012). A variety of fruits and vegetables were imported from all corners of the Atlantic (including some rare items such as grapes from Europe), while some items were transported from locations closer to home such as apples, wheat, peas, beans, and other vegetables from nearby Ste. Anne and Mira River (Donovan 2006; Lane Jonah and Véchambre 2012). All of these varieties are C_3 plants, although corn (a C_4 plant) was mentioned as being

imported from New England (McLennan 1918). While much of Louisbourg's produce was imported, many inhabitants gathered local fruits including wild strawberries, cranberries, raspberries, and blueberries (Donovan 2006). Furthermore, every house within the town had a garden which typically held vegetables, beans, peas, and herbs (Donovan 2006; Lane Jonah and Véchambre 2012).

The variety of isotopically different foods, and the varied origins of these foods, would likely create isotopic variation among Louisbourg inhabitants, however, since cod was the main protein source (Cumba 1976; Downey 1965; Lane Jonah and Véchambre 2012; McNeill 1985), marine isotopic values should play a strong role in the isotopic variation of Louisbourg inhabitants. Such values are not seen among the Ste. Marie group, as discussed in Chapter 7.2.1.

If the Ste. Marie individuals were recent immigrants who did not reside in Louisbourg long enough to retain strong marine values (via bone turnover, see Chapters 4.5 and 7.2.2), the foods of their homeland may explain some of the isotopic variation observed. Indeed, most of the Fortress's inhabitants were not born in the New World but originated from a number of areas. Of the military men, most were from France with a minority from Switzerland and Germany, and the fishermen were mostly from western France with less from Newfoundland and other areas of New France (see Chapter 2.3.2). Most of the townsfolk were from France, with less from New France and fewer still from foreign countries such as Ireland or Germany. Depending on residence time and the tissue in question, a new immigrant's skeletal tissue has the potential to hold a large variety of isotopic values reflecting the different types of food available in their homeland.

Although lacking in marine isotopic values, the variation observed in the Ste. Marie group could be a result of the entrepôt status and colonial nature of the Fortress of Louisbourg. However, until further isotopic examinations can be performed (see Chapter 7.7.2), this remains to be seen. Furthermore, this does not rule out the possibility that the mass burial individuals were from New England since New England as a British colony would be influenced by similar factors.

The colonies of New England boasted a variety of different foods which were locally produced, hunted, or imported (Fisher et al. 1997). Domestic meats (salted or fresh) and poultry was an important staple food, and both pork and beef were plentiful and available to all socioeconomic groups (Fisher et al. 1997). Hunting local deer, rabbit, and fowl was also a common practice, especially in the 17th-century (Fisher et al. 1997; McMahon 1985). Shellfish was a common food item in New England (Fisher et al. 1997), as was fish which included both marine and freshwater varieties (Fisher et al. 1997; Landon 1996; McMahon 1985)

Grains, nuts, and cereals were available, and after 1650, maize became the staple crop above rye, wheat, barley, and oats (Fisher et al. 1997; McMahon 1985; Walcott 1936). Maize was a popular ingredient in cakes and porridge-like dishes and was commonly used as fodder for domestic mammals and birds (Fisher et al. 1997). All types of vegetables, fruits, beans, and peas were available in New England, some known to the Old World and others introduced to the colonists by the local natives (Fisher et al. 1997; McMahon 1985). Alcohol consumption was also prevalent among all classes and included beer, cider, and rum, both imported and locally made from varieties of grains, fruit, vegetables, and molasses (Fisher et al. 1997; McMahon 1985).

During the 18th-century, a New Englander's diet was subject to seasonal variations in abundance and quality as well as an individual's preference and socioeconomic class. In the winter when food stores were low, colonists supplemented their diet with wild game, salted meat, and fish (Fisher et al. 1997; McMahon 1985). Produce, legumes, and grain of all kinds were also stored to support families until the following spring (McMahon 1985; Walcott 1936). Social class did not significantly affect an individual's diet, however, wealthier families were more likely to have better varieties of grain, beverages, and fish and larger quantities of meat especially during the winter months, while families with lesser means were more likely to rely on preserved goods (Fisher et al. 1997; McMahon 1985).

Compared to the Fortress of Louisbourg and the Chesapeake Bay colonies, the dietary isotopes of New England inhabitants may be less affected by immigration factors. New England experienced an immigration boom prior to 1642 which thereafter fell into decline (Greene 1988). By the 18th-century, the New England population had expanded predominantly from the initial influx of immigrants (Greene 1988), but the Chesapeake colonies experienced a constant inflow of immigrants throughout the colonial period (Ubelaker and Owsley 2003). Therefore, while immigration would have influenced the diversity of the Chesapeake Bay group's diet (Ubelaker and Owsley 2003) the 'immigration effect' may have had less influence on the diet of New England inhabitants. If the Ste. Marie individuals were New England inhabitants (see Chapter 7.5 for further discussion on the group's origins), considering the higher proportion of colonial-born individuals, the isotopic variation of carbon and nitrogen isotopes observed in this study may be more of a reflection of food type and food origin rather than isotopic variation

from an immigrant's diet of Old World foods. Such deduction is important for understanding the isotopic variation of the Ste. Marie group and the degree of influence a society's colonial status has on the isotopic values of its inhabitants.

Overall, the diet in New England included a large variety of different foods from both the Old and New World. The consumption of these goods was influenced by an individual's preference or socioeconomic class, and the availability of these foods depended on a colony's access to market items, their interactions with native groups, and their ability to grow crops and raise animals locally. Although a diverse diet was obviously not unique to New England, this summary shows that such a location, hosting a vast variety of food items, has the potential to cause the isotopic variation observed among the Ste. Marie group. Currently, there are no known isotopic studies on New England inhabitants that involve dietary reconstruction to allow for a direct comparison.

Overall, three possibilities remain concerning the isotopic variation of the Ste. Marie individuals. If the Ste. Marie individuals were Louisbourg inhabitants, the isotopic variation may be the result of the colonial nature of the town, whereby the transportation and variety of foodstuffs meant that individual inhabitants could have isotopically diverse diets, and the transportation of people meant that new immigrants could have foreign $\delta^{13}C$ and $\delta^{15}N$ values from their homeland. If these individuals were New England garrison members, the isotopic variation may be due to the 'colonial influence' or due to the varied life histories of the recruited soldiers (or a combination of both). It is believed that if the mass burial individuals were Louisbourg inhabitants marine isotopic values would be

more strongly represented, even when considering bone turnover rates and the town's immigrant status (see Chapter 7.2.2). Without control data from a group of known Louisbourg inhabitants, this remains a tentative conclusion (see Chapter 7.7.2). It is believed more likely that the Ste. Marie group was of New England origin, and while the isotopic variation may be caused by the colonial nature of New England, it is believed that the major factor causing the variation observed in this study is the varied New World origins of the New England soldiers. This factor would likely amplify the amount of isotopic variation possible from a single New England location alone.

7.2.4 Conclusion

In conclusion, The Ste. Marie individuals exhibit various diets. Most individuals have a terrestrial diet of C_3 foods, few individuals show a mixed C_3/C_4 terrestrial diet, and fewer still show a mixed marine/terrestrial diet. Furthermore, it is believed that the isotopic variation is a strong indication that the Ste. Marie individuals are deceased New England garrison members, whereby the soldiers' various origins and occupations created a diversity of isotopic values. It is likely that the colonial nature of the New World also played a role in the group's isotopic variation, and while the large scale movement of food and people was a prominent feature of the town of Louisbourg, the lack of marine values is believed to be an indicator of the group's non-local origins. It should be noted that this is not a conclusive interpretation, and furthermore, the determination of local vs. non-local origins is not best accomplished by examining diet but is better achieved by examining those isotopes that directly reflect some aspect of a geographic location (e.g., geology and climate).

7.3 Determining Local Isotopic Ranges for Reconstructing Origins

One of the best methodologies for determining the biologically available strontium values of an area is through the analysis of local fauna (Laffoon et al. 2012; Price et al. 2002). The animals chosen to identify the local isotopic values were based on the animals' natural behavior as well as their relationship to humans. Since many domestic animals may have foreign origins because of the importation of livestock and meat, domestic animals were not used to define Louisbourg's local isotopic values. However, not all wild animals were appropriate either. The bedrock and surficial geologies of Cape Breton Island are quite complex and varied. The geologic materials span from the Precambrian to the Carboniferous, and the water sources are variable (Barr et al. 1996; Grant 1988; Keppie 2000). These factors have the potential to create a variety of $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values across the island. Therefore, the wild animals chosen to define local isotopic values needed to be those non-migratory animals with small home ranges, so that the end result is an isotopic range that is more or less specific to the general area of Louisbourg. As a result, deer, moose, and lynx, with home ranges typically much greater than 11 square kilometers (km^2) (Cederlund and Sand 1994; Lesage et al. 2000; Parker et al. 1983) were excluded from this selection.

The bedrock geology of the Louisbourg area is mainly volcanic and sedimentary rocks from the late-Proterozoic (Fry 1995; Keppie 2000). The bedrock is composed of volcanic tuffs, basalt, rhyolite, sandstone, siltstone, and chert and is described as the Kennington Cove member of the Forchu group (Barr et al. 1996; Keppie 2000). The surficial geology of Louisbourg is mainly soil developed from a parent material of glacial till deposited by the retreat of the last glaciation (Fry 1995). The origin of the glacial till

was from Mississippian and Pennsylvanian rocks from the Carboniferous period (359 – 299 million years ago) (Cumbaa 1976). In the immediate area of Louisbourg, the deposited glacial till is a sandy loam with silt and clay till along the west and north shore of Louisbourg harbour and areas of wetland to the west and south of the fortress (Grant 1988). To determine the biologically available strontium values of Louisbourg's local geology, wild specimens with small home ranges were used. This includes rats, hares, beavers, and foxes, all of which have home ranges typically no greater than 5 km^2 (Ables 1969; Bloomquist et al. 2012; Davis et al. 1948; Handley 1999; Quadango 1968; reviewed in Sievert and Keith 1985).

Rats are not wild in the strictest senses but are invasive animals introduced by human activity. However, while the first generation of rats would exhibit the isotopic values of their birthplace, their descendants would exhibit local values. Since the odds of sampling a first generation rat is less likely than sampling a descendant (considering the reproductive capabilities of rats), the rat specimens included in this study were assumed to be local specimens. Furthermore, since rats were not imported for food and the isotopic values of all rat specimens grouped closely with other wild small home-range specimens, the rat specimens in this study were included in the selection of fauna that defined Louisbourg's local isotopic values.

Overall, a total of nine fauna were selected to define the biologically available isotopic values of the Louisbourg area. This includes three rats, two hares, two beavers, and one fox specimen (Table 24). A methodology commonly used to define a location's strontium variation, is to calculate a range of two standard deviations (2σ) from the mean of all selected fauna (Price et al. 2002). This range is meant to describe the isotopic

variability around a location's biologically available $^{87}Sr/^{86}Sr$ values and was developed by Price et al. (2002) using field mice strontium isotopes in comparison to the known proportions of local to non-local humans (derived from archaeological evidence). This methodology has been used elsewhere and is believed to constitute a conservative estimate of an areas isotopic variation (Conlee et al. 2009; Giblin 2009; Nafplioti 2008; Shaw et al. 2009).

The $^{87}Sr/^{86}Sr$ mean ± 2σ for these fauna is 0.710039 ± 0.001499, and the 2σ range is 0.002999 with $^{87}Sr/^{86}Sr$ values from 0.708540 – 0.711539 (Table 24). Materials with $^{87}Sr/^{86}Sr$ values within this range were considered local in origin, while materials with $^{87}Sr/^{86}Sr$ values outside this range were considered non-local in origin. The same technique has been utilised in this study to define the local oxygen ranges (the mean ± 2σ is 7.42 ± 2.41‰ and the range is 4.81‰, with values from -9.83 – -5.01‰, Table 24). However, since the use of local faunal $\delta^{18}O$ values as a method for analysing human origins has raised concerns (White et al. 2004a) because of the small differences in oxygen fractionation that exist among different animals (Kohn 1996), local/non-local status was also examined using drinking water calculations (Chenery et al. 2012; Coplen et al. 1983) in comparison to regional precipitation $\delta^{18}O$ values accessed from published data. Although one does not have the same concerns with $^{87}Sr/^{86}Sr$ values (since strontium isotopes do not fractionate as they pass from the environment and through the food chain [Blum et al. 2000]), the Ste. Marie group's strontium isotopic values were also compared to published data.

The 2σ ranges place within expected strontium and oxygen values for the Louisbourg area. Within Louisbourg's strontium range is the $^{87}Sr/^{86}Sr$ value of seawater (0.70923, [DePaolo and Ingram 1985]). This is expected because Louisbourg is a coastal site and may be subject to significant contributions of marine strontium to the soil via sea spray (Whipkey et al. 2000). A diet containing marine products would also contribute marine strontium to skeletal tissue (Nelson et al. 1986; Price and Gestsdóttir 2006; Wright 2005), as could the use of seaweed as a fertilizer (Montgomery et al. 2007) which was a common practice among local farmers (Lane Jonah and Véchambre 2012).

While no data exist on the $^{87}Sr/^{86}Sr$ values of Louisbourg soil or bedrock, local strontium is often diagenetically absorbed by archaeological tooth dentine, and the values of which are often used to identify the $^{87}Sr/^{86}Sr$ values of labile strontium (Budd et al. 2000; Madgwick et al. 2012). The dentine values reported in this study (n=16, see Chapter 6.2 and Tables 8 and 10) have $^{87}Sr/^{86}Sr$ values that range from 0.709649 – 0.711834. While the latter value falls 0.000295 above the 2σ local strontium range defined by select wild fauna (Figure 38), it is possible that the dentines' biogenic values have not been completely exchanged with available soil and water strontium (Budd et al. 2000). This may indeed be the case since the associated enamel of the two dentine samples that fall outside the local strontium range have even greater values (Figure 38). It is likely that the dentines' biogenic isotopic values were in the process of shifting towards local values. Perhaps with more time or worse diagenetic conditions the $^{87}Sr/^{86}Sr$ values of the dentine would have shifted further towards the local strontium range. Overall, the dentine values in this study may not represent 100% $^{87}Sr/^{86}Sr$ exchange and as a result may not fully match local strontium values, however, the closeness of the dentine values

to the 2σ range of select wild fauna gives support to the local strontium range defined in this study.

The local oxygen range can be examined in a similar fashion. The dentine $\delta^{18}O$ values reported in Chapter 6.2 have minimum and maximum values of -7.85 and -4.65‰, respectively (Tables 7 and 9). The latter value is 0.36‰ above the 2σ local oxygen range defined by select fauna (Figure 39). Again it is possible that the dentine has not completely equilibrated with available water oxygen. However, the closeness of the dentine values to the values of local small home-range fauna gives support to the local oxygen range defined in this study.

Further support for the local oxygen range is determined via comparisons with the $\delta^{18}O$ value of local precipitation as documented in the IAEA and WMO database (IAEA/WMO 2013). The closest collection station to Louisbourg is Truro (which is ~266 kilometers (km) west-southwest from Louisbourg on the mainland of Nova Scotia) and should experience relatively similar precipitation $\delta^{18}O$ values. The annual weighted mean precipitation $\delta^{18}O$ value ($\delta^{18}O_{PPT}$) of rainwater samples collected from 1975 – 1983 is -9.23‰ (VSMOW) (IAEA/WMO 2013).

To account for the fractionation that occurs between precipitation/drinking water and tooth enamel, 9.23‰ (VSMOW) was translated using the following equation:

$$\delta^{18}O_{E(VSMOW)} = 0.629\ \delta^{18}O_{DW(VSMOW)} + 30.587$$

The above equation was rearranged from the following equation from Chenery et al. (2012):

$$\delta^{18}O_{DW(VSMOW)} = 1.590\ \delta^{18}O_{E(VSMOW)} - 48.634$$

The $\delta^{18}O_{E(VSMOW)}$ value was then converted from VSMOW to VPDB using the following equation from Coplen et al. (1983):

$$\delta^{18}O_{(VPDB)} = 0.97002\ \delta^{18}O_{(VSMOW)} - 29.98$$

The $\delta^{18}O_{E(VPDB)}$ value calculated from the $\delta^{18}O_{PPT}$ value of Truro is -5.94‰ which means that in theory, a human residing in the local area drinking local precipitation should have a $\delta^{18}O_{E(VPDB)}$ value around -5.94‰. This value falls well within the 2σ range of the selected fauna (between -7.85 and -4.65‰) and gives further support to the use of the local oxygen range defined in this study for examining the Ste. Marie group's origins.

Overall, nine specimens qualified for identifying the local isotopic values of the Louisbourg area. Any animal or human with $^{87}Sr/^{86}Sr$ values between 0.708540 and 0.711539, and (with a lesser degree of certainty) $\delta^{18}O$ values between -9.83 and -5.01‰, were interpreted as having local origins (or origins in an area with similar $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values). These data, as well as data from published studies, were used to interpret the origins of the Louisbourg fauna and the Ste. Marie individuals in the following sub-chapters.

7.4 Faunal Origins Reconstruction

Figure 40 shows a scatter plot of $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data for all specimens sampled (n=35, Table 25) as well as the local oxygen and strontium ranges described previously (Chapter 7.3). Since different species fractionate water slightly differently (Kohn 1996), comparisons of $\delta^{18}O$ values between species and indeed with the local oxygen range defined by select species, must be considered with a measure of uncertainty. Therefore, the following is an approximate interpretation of each specimen's origins.

In total, 27 specimens (77%) fall within the Louisbourg strontium and oxygen ranges (Table 25). This includes all nine wild specimens (26%) that were used to define the 2σ local range, four of the wild specimens (11%) with large home ranges, and 14 domestic specimens (40%). The large home-range wild specimens that show local oxygen and strontium isotopic values include the single lynx and moose specimens, as well as two deer specimens. The domestic specimens that fall within Louisbourg's isotopic ranges include the cat specimen, both horse specimens, two cow specimens, and three each of goat, sheep, and pig. Because these specimens' place within the local range, they are believed to have lived in the Louisbourg area or possibly from an area with similar $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values.

A total of eight specimens (23%) fall outside both the strontium and the oxygen range. Most (n=6, 17%) had $\delta^{18}O$ values within Louisbourg's oxygen range but $^{87}Sr/^{86}Sr$ values that were higher (i.e., above 0.711539). These specimens include most of the cow specimens (n=3) and one specimen each of pig, goat, and deer. These animals likely had origins from an area with a similar water $\delta^{18}O$ value as Louisbourg but with a biologically

available $^{87}Sr/^{86}Sr$ value that was more radiogenic. A single deer specimen (3%) had a $^{87}Sr/^{86}Sr$ value within Louisbourg's strontium range but a $\delta^{18}O$ value that was out of range and lower than the $\delta^{18}O$ local minimum of -9.83‰. It is likely that this deer grew up on soil with a similar strontium value but drank water that was isotopically lighter than water from the Louisbourg area. This specimen (4L58K11-7), with a $\delta^{18}O$ value of -12.18‰, is 2.35‰ below the Louisbourg oxygen range and very likely originated either further north, further inland towards Canada, from an area of higher altitude, or some combination of these factors. Considering this in conjunction with the relatively high $\delta^{13}C_{Carb}$ value (-4.65‰, Chapter 7.1.3) indicative of a mixed C_3/C_4 diet, it is possible that this specimen originated from an inland area where C_4 crops were grown (e.g., southern Ontario [Katzenberg et al. 1995]). One other specimen (3%) is outside both the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ ranges defining the Louisbourg area. Deer specimen 3L22N1-8 is only 0.06‰ above Louisbourg's oxygen range (a minor difference) but is well above (0.002191) the $^{87}Sr/^{86}Sr$ range. It is likely that this specimen did not originate from Louisbourg but from an area with much higher $^{87}Sr/^{86}Sr$ values.

Of the wild fauna (n=16), only three specimens fell outside Louisbourg's isotopic ranges and are therefore identified as having non-local origins. All of these specimens were deer. Two deer specimens (4L19A5-7 and 3L22N1-8) have very high $^{87}Sr/^{86}Sr$ values, while one deer (4L58K11-7) has a very low $\delta^{18}O$ value. These data suggest that deer utilised by Louisbourg inhabitants have origins from various locations which were isotopically distinct from the Louisbourg area. Although moose and lynx typically have large home ranges (Cederlund and Sand 1994; Parker et al. 1983), their 'in-range'

isotopic values do not suggest that they lived in an area with a differing isotopic value than Louisbourg. It is possible that the non-local deer came to Louisbourg via trade with Native peoples or other colonies.

Of the domestic animals (n=19), a total of five specimens do not fall within Louisbourg's isotopic ranges, and are therefore identified as having non-local origins. This includes three cows and one each of goat and pig. The greater proportion of cow specimens of non-local vs. local origins (3 vs. 2) may suggest that cows or their meat were more likely to be imported rather than raised locally, while horses and cats and to a lesser extent pigs, goats, and sheep may have been more likely to have been raised in the Louisbourg area. This conclusion is hampered by the small sample sizes. A study of larger sample sizes may discover that cows, pigs, goats, and sheep would be more likely to have non-local origins, while horses, cats, doves, and dogs would be more likely to exhibit local isotopic values. This hypothesis is based on the idea that animals, such as cows, pigs, goats, and sheep, served the purpose of feeding and clothing Louisbourg's inhabitants, while horses, cats, doves, and dogs were more often a luxury item/service animal. The former group of animals would need to be imported in high quantities in order to support the increasing non-self-sufficient population, and the latter group of animals would initially have been imported but not used for food (unless necessary). These animals would be allowed to mate producing generations of locally raised animals. This hypothesis would benefit from historical research and further isotopic analysis which would expand on our knowledge of livestock/food importation and animal rearing at the Fortress of Louisbourg.

Many specimens in this study fall very close to the $^{87}Sr/^{86}Sr$ value of seawater: 0.70923 (DePaolo and Ingram 1985). This includes several wild and domestic specimens, but in particular three of the four goat specimens fall very close to the $^{87}Sr/^{86}Sr$ value of seawater with values from 709329 – 709418. These specimens may have ingested plants highly influenced by sea spray (Whipkey et al. 2000) or marine products (Nelson et al. 1986; Turner et al. 2009). One of these specimens (3L22N1-6) has a $\delta^{15}N$ value of 7.25‰ which is on the higher end of a typical terrestrial diet. This value does not indicate consumption of fish, but it may have been attained from consumption of seaweed (Cloern et al. 2002; Miyake and Wada 1967). Indeed, the use of seaweed as foddering materials for goats was proposed for an archaeological site in Scotland (Balasse et al. 2006). At this site, it was believed that the use of seaweed fodder was a response to a reduction of suitable terrestrial pastures during the winter months (Balasse et al. 2006). It is possible that local seaweed was used as foddering material at Louisbourg during the harsh winter months. Further investigation into the foddering habits of goats may benefit from historical research, isotopic analysis of serial sectioned goats' teeth (Balasse et al. 2006), and isotopic analysis of local seaweed for comparison purposes.

It should be noted that these discussions are only rough conclusions regarding local vs. non-local origins. This is because isotopic values are not exclusive to one area, and Louisbourg imported a great deal of their livestock and meat.

7.5 Ste. Marie Origins Reconstruction

The $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of select wild fauna described in Chapter 7.3 were utilised in this sub-chapter to examine local vs. non-local origins of the Ste. Marie mass burial individuals. Individuals with isotopic values between both ranges were interpreted as having originated from the Louisbourg area (or from an area with similar isotopic values), while individuals with values outside the above ranges were interpreted as having non-local origins. Since the $\delta^{18}O$ values of animals are not the best analogs for interpreting human $\delta^{18}O$ values (White et al. 2004a), further analysis is presented in the form of comparisons between calculated drinking water $\delta^{18}O$ values (using equations developed by Chenery et al. [2012] and Coplen et al. [1983]) and regional precipitation water $\delta^{18}O$ values (using published data [IAEA/WMO 2013; Jamieson and Wadleigh 1999; Lee et al. 2006]). Comparisons were also made between the Ste. Marie individuals' $^{87}Sr/^{86}Sr$ values and published strontium data.

7.5.1 Ste. Marie Data and Local Faunal Data Comparison

Figure 41 shows a scatter plot of the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ data of all individuals examined (n=33), as well as the isotopic ranges that define the Louisbourg area (reported in Chapter 7.3). A total of 16 individuals (48%) fall within the Louisbourg range (Table 26). A majority of these individuals have $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values on the higher end of both ranges. The lowest $\delta^{18}O$ value is from A18 with a value of -7.06‰, while the highest $\delta^{18}O$ value is from F24 with a value of -5.02‰ (only 0.01‰ below the upper limit of Louisbourg's oxygen range, a minor difference). The lowest $^{87}Sr/^{86}Sr$ value is from

A15/F23 with a value of 0.709257, while the highest $^{87}Sr/^{86}Sr$ value among the group is from F29 with a value of 0.711344 (only 0.000195 below the upper limit of Louisbourg's strontium range). Overall, the 16 individuals that fall within the Louisbourg range could have originated from the Louisbourg area or from an area with similar oxygen and strontium isotopic values.

Approximately half of the Ste. Marie individuals (n=17, 52%) have isotopic values outside Louisbourg's isotopic ranges. Five individuals (15%) have $\delta^{18}O$ values that fall within Louisbourg's oxygen range but have $^{87}Sr/^{86}Sr$ values that fall above Louisbourg's strontium range. It is believed that these individuals did not have local origins. They likely consumed water with a similar $\delta^{18}O$ value as Louisbourg's water but originated in an area with higher $^{87}Sr/^{86}Sr$ value. Nine individuals (27%) fell within Louisbourg's strontium range but had $\delta^{18}O$ values that were higher than Louisbourg's oxygen range. The lowest $\delta^{18}O$ value is from F33 with a $\delta^{18}O$ value of -4.99‰, only 0.02‰ above the limit of Louisbourg's oxygen range. The highest $\delta^{18}O$ value is from F30 with a $\delta^{18}O$ value of -3.20 which is 1.81‰ outside Louisbourg's oxygen range. These individuals were likely not born and raised at Louisbourg but in an area with a more positive $\delta^{18}O$ value (e.g., further south). Three individuals (9%) had isotopic values that did not overlap with either of Louisbourg's oxygen or strontium ranges. Their isotopic values suggest origins southward on geology that was more radiogenic.

Using the Louisbourg oxygen and strontium isotopic ranges defined by select wild fauna, approximately half of the Ste. Marie individuals have been identified as having possible local origins (n=16, 48%). However, it must be remembered that the Louisbourg

population was made up of many non-locals (see Chapter 2.3.2). While much of the town's population resided at Louisbourg for many years, the oxygen and strontium values presented in this study are all from enamel which reflects each individual's childhood residency. In terms of origins, by 1734 most of Louisbourg's heads of households were from various regions of France (73%), particularly the western regions of France (47%), with fewer from New France (21%), or Foreign countries (6%) (Johnston 2001). Louisbourg's brides were mainly from New France (84% between 1722 and 1745 [Johnston 1995b, 2001]), the fishermen were mainly from the coastal territories of France (Basque country, Normandy, and Brittany), but a small number were from New France (mainly Plaisance) (Johnston 1995b, 1995c). Most soldiers (which made up 27% of the total population by 1737) were from France, but around one-fifth were from Switzerland or Germany (Johnston1995b, 2001).

Therefore, it would be expected that only a minority of Louisbourg's inhabitants would have local values, and a high majority would exhibit non-local values (if these locations had isotopic values that were different from Louisbourg's isotopic values). While it is difficult to assess the true percentage of individuals who were born and raised at Louisbourg (based on the demographic information), it is believed that locals would constitute less than 50% of Louisbourg's total population. However, because the sample size in this study is small (n=33) and may not reflect the true proportions of locals to non-locals, and because the census and parish records are not considered a comprehensive description of the total Louisbourg population, it cannot be ruled out that the Ste. Marie individuals were not Louisbourg inhabitants based on local vs. non-local proportions alone.

It is important to note that this discussion is only accurate if the local area is isotopically distinct from non-local areas, which is not the case. It is very possible that individuals with foreign origins have similar isotopic values to the Louisbourg area, making it seem as though there are more locals than there really were. As a result of this phenomenon, further evidence is required before a final conclusion can be made.

7.5.2 Ste. Marie Data and Published Data Comparison

Overall, if the Ste. Marie individuals were Louisbourg residents, a large majority of their isotopic values should match the isotopic values of France (especially western France), while fewer should match the isotopic values of Louisbourg, Switzerland, Germany, and New France.

Unfortunately, the strontium isotopic values in the above areas are too similar to allow for speculation concerning the origins of the Ste. Marie group (Bentley and Knipper 2005; Britton et al. 2011; Chiaradia et al. 2003; Kelly 2007). The strontium range observed among the Ste. Marie individuals overlaps with ranges observed in eastern France (Britton et al. 2011, Kelly 2007), southwest Germany (Bentley and Knipper 2005), southwest Switzerland (Chiaradia et al. 2003), and likely many other areas.

Clearer results are found when observing precipitation $\delta^{18}O$ values ($\delta^{18}O_{PPT}$) of these regions using the IAEA/WMO database (2013) and data from Jamieson and Wadleigh's study (1999). For comparison with these data, the $\delta^{18}O$ of drinking water ($\delta^{18}O_{DW}$) was calculated for each individual (Table 27) using the following equations:

$$\delta^{18}O_{(VSMOW)} = 1.03091\ \delta^{18}O_{(VPDB)} + 30.91 \text{ (Coplen et al. 1983)}$$

$$\delta^{18}O_{DW(VSMOW)} = 1.590\ \delta^{18}O_{E(VSMOW)} - 48.634 \text{ (Chenery et al. 2012)}$$

The collection sites selected for this comparison were Dax and Breast in France (Table 28), the former representing Basque country and the latter representing Brittany and Normandy. The weighted mean $\delta^{18}O_{PPT}$ values were calculated from rainwater samples taken from 1999 – 2005 and 1996 – 2002, respectively. A more interior region of France is represented by $\delta^{18}O_{PPT}$ data of Orléans rainwater collected from 1996 – 2005 (IAEA/WMO 2013). Switzerland and Germany are represented by data from Bern and Berlin, respectfully. Rainwater samples were collected between 1969 and 2008 for Bern and 1978 – 2005 for Berlin (IAEA/WMO 2013). New France in the 18th-century describes numerous areas including, but not limited to, Acadia, Canada, and Plaisance. Acadia, being on the mainland of current day Nova Scotia is represented by the Truro site mentioned in Chapter 7.3. Canada in the 18th-century is described by a large region, however, a majority of Canadian French settlements were along the St. Lawrence (McNeill 1985). The collection site used to represent this area is in Ste. Agathe, Quebec which is ~79 km northwest of Montreal and ~250 km west-southwest of Quebec City. Weighted mean $\delta^{18}O_{PPT}$ values were calculated from rainwater samples collected between 1975 and 1982 (IAEA/WMO 2013). Plaisance (current day Placentia) is represented by St. John's (which is ~101 km to the east-northeast of Placentia). The annual weighted

mean $\delta^{18}O_{PPT}$ value for St. John's was calculated from intermittent samples of rainwater collected between May 1994 and May 1995 by Jamieson and Wadleigh (1999).

Figure 42 shows the calculated $\delta^{18}O_{DW}$ values (and $^{87}Sr/^{86}Sr$ values) of all individuals and the $\delta^{18}O_{PPT}$ in the areas mentioned above. A majority of individuals have $\delta^{18}O_{DW}$ values that cluster around Truro, St. John's, and Berlin $\delta^{18}O_{PPT}$ values which suggests that a majority of the Ste. Marie individuals may have origins in these regions. The intra-population variation that is typically reported for static UK populations is ± 2.8‰ around a location's $\delta^{18}O_{PPT}$ mean (Evans et al. 2006), and using this value as a rough indicator of isotopic variation among local individuals, some of the Ste. Marie individuals may also have had origins in Switzerland and central or eastern areas of France. A single individual (A18) has values that may indicate origins further north or inland, due to their low $\delta^{18}O_{DW}$ value and their relative closeness to the $\delta^{18}O_{PPT}$ value of Ste. Agathe, Quebec. A18 is discussed further in Chapters 7.6.6 and 7.6.7. Only a small number of individuals from the Ste. Marie group (n=13, 39%) exhibit $\delta^{18}O_{DW}$ values that could be derived from areas in western France. Almost all of these have isotopic values within the lower range from the mean $\delta^{18}O_{PPT}$ value of Dax, France, and could potentially have origins in Britain, New England, and New France.

The $\delta^{18}O_{DW}$ values observed among the Ste. Marie group would be unexpected of a selection of the Louisbourg population. Most of Louisbourg's inhabitants had origins in France, especially western France. If the Ste. Marie individuals were Louisbourg inhabitants, it would be expected that most would have $\delta^{18}O_{PPT}$ values that group within or around the values for western France (e.g., Dax and Breast) and to a lesser extent

around central France (e.g., Orléans). Such a pattern is not observed among the Ste. Marie individuals. While it is still theoretically possible that the Ste. Marie individuals could be composed of local, New French, and German inhabitants (and possibly Swiss or central/eastern French inhabitants), this is believed not to be the case since it is very unlikely that such a small subsection of Louisbourg's population could all have died within a short period of time (as is believed to be the case for the Ste. Marie mass burial [Parish 2006, 2007]). Overall, while a few French individuals may be included within this study, these data support the belief that the Ste. Marie individuals were not Louisbourg residents.

Since these individuals are not believed to be Louisbourg inhabitants, the next line of inquiry is investigating the possibility that these individuals are the deceased members of the New England garrison. If this is true, then the oxygen and strontium values of the Ste. Marie individuals should correspond to the isotopic values of areas in New England.

As was the case for France, Germany, Switzerland, and New France, the methodology of matching the $^{87}Sr/^{86}Sr$ values observed in this study to $^{87}Sr/^{86}Sr$ values present in New England, is not feasible. First, the recruitment areas for the Louisbourg expedition were many and spanned across a vast geographic range including Connecticut, New Hampshire, Massachusetts, and Maine (Baker 1978; Rawlyk 1999). These regions have bedrock geologies containing a variety of igneous, metamorphic, and sedimentary materials, surficial geologies containing glacial, and riverine deposits, geologic ages spanning from the Precambrian to the Mesozoic, and coastal soils that may hold strontium contributions from marine sources (Billings 1980; Crosby 1876; Marvinney 2002, 2003; Rodgers 1985; Stone et al. 1992). As a result, New England would hold a variety of

$^{87}Sr/^{86}Sr$ values, such that any one $^{87}Sr/^{86}Sr$ values could be present in a number of different geographic areas. Second, even if these values could be predicted (based on mineral content, geologic age, etc.), such predictions would describe only the $^{87}Sr/^{86}Sr$ values of each individual source and not the $^{87}Sr/^{86}Sr$ values that are biologically available. Indeed, biologically available strontium values are an averaging of a number of different materials from various sources and have often been found to be very different from bedrock $^{87}Sr/^{86}Sr$ values alone (Laffoon et al. 2012). What can be said is that the $^{87}Sr/^{86}Sr$ values of the Ste. Marie individuals are typically equal to or higher (more radiogenic) than the Louisbourg area which indicates that for some individuals, the biologically available strontium of their place of origin is derived from older geologic materials, or materials that had a higher Sr/Rb ratio. Materials of this description are found in Connecticut, New Hampshire, Massachusetts, and Maine (and likely in a number of other areas).

The more telling evidence again comes from the oxygen values of the Ste. Marie individuals. Each individual's calculated $\delta^{18}O_{DW}$ values are reported in Table 27. $\delta^{18}O_{PPT}$ datasets available for New England regions include a collection site in Hanover, New Hampshire which is geographically central to the four recruitment areas of the New England soldiers (New Hampshire, Connecticut, Massachusetts, and Maine). Rainwater samples from Hanover were taken bimonthly between 1997 and 1998 (IAEA/WMO 2013, Table 28). Additional New England data come from a study by Lee et al. (2006) of precipitation in New Haven, Connecticut. The geographic position of New Haven represents the southernmost region of recruitment for the Louisbourg expedition. Annual

$\delta^{18}O_{PPT}$ values for New Haven are averaged from samples taken between 2003 and 2004 (Lee et al. 2006). To account for potential British origins among the New England population, $\delta^{18}O_{PPT}$ data were also included for two sites in Britain, one in Wallingford, England and the other in Inchnadamph, Scotland (IAEA/WMO 2013). $\delta^{18}O_{PPT}$ values were averaged from monthly samples taken between 1979 and 2007 for the former location and between 2003 and 2005 for the latter location (IAEA/WMO 2013). Wallingford is a relatively south central location in England, and Inchnadamph is in the Scottish highlands.

Figure 43 shows the calculated $\delta^{18}O_{DW}$ values (and $^{87}Sr/^{86}Sr$ values) for the Ste. Marie individuals and the $\delta^{18}O_{PPT}$ values for the areas mentioned above. A majority of the Ste. Marie individuals cluster around and between Hanover and New Haven $\delta^{18}O_{PPT}$ values, while fewer individuals cluster around Wallingford and Inchnadamph $\delta^{18}O_{PPT}$ values. This suggests that these individuals were potentially from New England and fewer were from Britain. A small number of individuals from Britain would be expected since by the 18th-century most people within the New England population were descendants of immigrants rather than first generation immigrants (Greene 1988). Furthermore, all individuals fall within a ± 2.8‰ range around the Hanover and New Haven $\delta^{18}O_{PPT}$ values with the exception of F30, who exhibits the lowest $\delta^{18}O_{DW}$ value of the group. However, this individual does fall within range of the $\delta^{18}O_{PPT}$ values of Wallingford and Inchnadamph, making British origins a possibility. F30 is discussed further in Chapter 7.6.2.

7.5.3 Conclusion

While it is expected that a high majority of Louisbourg inhabitants would have origins in France (especially western France), few individuals exhibited matching $\delta^{18}O_{DW}$ values. Considering this (and the diet information in Chapter 7.2.4), it is believed unlikely that the Ste. Marie group were Louisbourg inhabitants. The $\delta^{18}O_{DW}$ data suggest that the Ste. Marie individuals could have origins in New England and possibly Britain. However, the data presented by the $\delta^{18}O$ comparisons are not exclusively indicative of such origins since many individuals' $\delta^{18}O$ values could also have been obtained by German, New French, and Swiss origins. Unfortunately, the strontium data were largely inconclusive for determining the group's birthplace. Overall, these results do not confirm New England origins for the Ste. Marie individuals but lend further support to the theory.

7.6 The Ste. Marie Individuals: Reconstructing Life Histories

An examination of all the isotopic evidence ($\delta^{13}C_{Col}$, $\delta^{15}N$, $\delta^{13}C_{Carb}$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$, Table 22) showed intermittent statistical significance in correlation to information retrieved via osteological analysis (e.g., sex, age, dental pathologies, bone pathologies, muscular strain, and pipe smoking) as reported in Chapters 6.4 and 6.5. However, by taking an alternative approach that combines the quantitative and the qualitative, a number of trends became apparent. The following is a selection of individuals who by some combination of isotopic, osteological, or other characteristic, stand out. Rough interpretations are made from the perspective that the Ste. Marie mass burial individuals were New England garrison members from the siege of 1745. All information regarding

an individual's sex and age or evidence pertaining to smoking habits, pathological conditions, muscular strains, or cause of death is referenced from Parish's (2006, 2007) osteological reports.

7.6.1 H3

As mentioned previously, while 48 individuals at the site were contained within the root cellar, one individual, H3, was excavated from outside the cellar wall on the northeast corner. Osteological analysis indicated that H3 was a male adult likely between the ages of 18 and 25 and may have had scurvy. He also suffered a blunt force trauma to the right side of the head from a single pronged instrument. Because of the pit style of H3's burial and un-articulated nature of his remains, it is believed that this individual was reinterred from another grave. The French relocated many burials from within the town to Rochefort Point (Johnston 1996, 2001), making it likely that this individual was a Louisbourg inhabitant, or at the very least, died at Louisbourg during French occupation. The date of this individual's death and re-interment is unknown.

The isotopic evidence suggests that this individual had a terrestrial C_3 based diet with contributions from C_4 based foods and possibly a small contribution from marine foods. H3's oxygen and strontium isotopes fall within Louisbourg's local isotopic ranges. Furthermore, the closeness of H3's calculated $\delta^{18}O_{DW}$ oxygen value (Table 27) to the $\delta^{18}O_{PPT}$ value of Truro (Figure 44) makes it possible that this individual was an inhabitant of Louisbourg during childhood, however, the small (possibly nonexistent) amount of

marine foods in this individual's diet may indicate otherwise. Further research on H3 would be required before a definitive conclusion could be drawn.

7.6.2 F30

Over 45 Louisbourgeois were not deported with the rest of the Louisbourg's population when the Fortress was capitulated in 1745. These individuals stayed at Louisbourg during the New England and British occupation (Johnston 1996, 2001). Furthermore, a journal account of the New England garrison's winter occupation, taken by Chaplain Stephen Williams, mentions a number of French men and a French child among the dead (De Forest ed. 1932). Considering the numerous deaths and burials taking place at the time, it is possible that French individuals were buried alongside the soldiers. Thus, it may be possible that some of the Ste. Marie individuals were inhabitants of Louisbourg. Of the Ste. Marie group, one individual may indeed be of French origin and possibly a Louisbourg inhabitant or transient worker. This individual is F30, a 40 – 45 year old pipe smoker of unknown sex who may have had difficulty walking due to odd bone formations on the distal ends of their tibiae and fibulae. As discussed in Chapter 7.5.2, F30 has a $\delta^{18}O_{DW}$ value that is outside the expected isotopic range of a New England inhabitant. The calculated $\delta^{18}O_{DW}$ value of F30 (-4.73‰, Figure 44) is very close to the $\delta^{18}O_{PPT}$ values of Breast and Dax (-4.84 and -4.92‰, Table 28) which suggests origins on France's west coast. Furthermore, this individual had the highest $\delta^{15}N$ value of the Ste. Marie group (14.95‰, Table 22) which suggests a diet containing a large amount of marine foods. Such values would be expected of a Louisbourg inhabitant (and possibly a

fisherman). However, F30's $\delta^{18}O_{DW}$ value could also be the result of origins in Britain or colonies south of New England (e.g., Virginia), making it still possible for this individual to be a member of the New England garrison.

7.6.3 D7A/F8, D11/F11, E8/F22, E12/F26, and E16

Also worthy of note is a small group of individuals that appear to have similar diets and origins. These individuals are D7A/F8, D11/F11, E8/F22, E12/F26, and E16. This group of individuals have $\delta^{18}O$ values between -5.27 and -3.95‰, and $^{87}Sr/^{86}Sr$ values between 0.712269 and 0.713716 (Table 22). The $^{87}Sr/^{86}Sr$ values of this small group are almost exclusively the highest $^{87}Sr/^{86}Sr$ values among the entire Ste. Marie group (Figure 45a) and are indeed outside Louisbourg's strontium range. These individuals all had diets containing low (or no) marine consumption and strongly based on C_3 resources (with $\delta^{15}N$ values between 7.91 and 8.72‰ [except E16 with a $\delta^{15}N$ value of 11.26‰], $\delta^{13}C_{Col}$ values between -19.80 and -17.63‰, and $\delta^{13}C_{Carb}$ between -13.80 and -11.08‰) (Figure 45b). Although the above values are not exclusive to this group (e.g., F33, an adult male with similar $\delta^{13}C$ and $\delta^{15}N$ values, Figure 45b), the consistency of their isotopic values may indicate a commonality, perhaps origins in the same region where a strict terrestrial diet was prominent.

Osteological analysis had revealed a great deal of information concerning these individuals. D11/F11 was a 20 – 23 year old male, possibly of mixed Aboriginal/Caucasian ancestry, with multiple wormian bones and bone pathologies suggesting long-term illness. E12/F26 was a male between the ages of 15 and 20 at time

of death, had a number of bone pathologies, and showed osteological indications that he performed a repetitive motion of the arms. D7A/F8 was a tall 15 – 18 year old female who was buried with a child (D7B) in her lap. Although there are no teeth available for D7B (and thus no oxygen or strontium data) child D7B does have a similar diet to female D7A/F8 and the other individuals within this small group ($\delta^{13}C_{Col}$ = -19.62‰ and $\delta^{15}N$ = 8.95‰, Table 22) (Figure 45b) and may be another member of this proposed group. D7A/F8 and D7B are discussed further in Chapter 7.6.5. D3, of unknown sex and age, is another individual for whom there are no oxygen and strontium data that exhibits similar carbon and nitrogen values as the others ($\delta^{13}C_{Col}$ = -18.21‰ and $\delta^{15}N$ = 8.72‰, Table 22 and Figure 45b) and may be an additional member of this group.

E8/F22 was an adult male (likely over 35) who smoked a pipe and showed indications of death by hanging (fractures to cervical vertebrae and mandible, and possible noose wear). Attempts were made to find a potential identity for this individual by examining council of war documents (Massachusetts Historical Society 1899). While a number of crimes and breach of orders were committed during the winter months of the garrison's stay, there is no mention of any executions (Massachusetts Historical Society 1899). However, in De Forest's (1932) compiled book of various journals from the Louisbourg expedition, the first anonymous journal gives mention of a "Swister" (i.e., a Swiss man) that was found trying to desert the city and flea to the English Army carrying a letter. The man was hanged the next day (De Forest ed. 1932). Unfortunately no further information could be uncovered.

It is possible that with further historical research and possibly DNA analysis, this individual can be given a positive identification. Such an identification would not only be valuable in of itself, but any records of the execution may also give a date which would correspond roughly to the creation of the mass burial. Coupling this information with available documents containing the dates and names of other deceased may allow for further identifications to be made.

7.6.4 F29, F32, and E12/F26

Another curiosity worthy of note is those individuals who showed indications of stress and straining of muscles within the arm and/or shoulder. These are individuals F29, F32, and E12/F26 (Table 17). As mentioned in Chapters 6.4.2 and 6.5.4, statistical significance was found between the mean nitrogen ($t=4.01$; $df=6$; $p=0.007$) and strontium ($t=3.23$; $df=4$; $p=0.032$) values of these individuals compared to the rest of the Ste. Marie group. More specifically, the dietary information for these individuals indicate that F29 and E32 had a similar diet, mainly mixed C_3 and C_4 terrestrial foods, while E12/F26 showed little or no C_4 based contributions (Figure 46a). However, all three have $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ values that suggest similar origins (Figure 46b). It may be that these individuals represent a small group who originated from a common location and took part in the same activities involving repetitive stress and strain of their arm muscles. E12/F26 (the young male discussed in Chapter 7.6.3) had muscular strain indications involving muscular attachment sites on the humeri and clavicle, while F29 (a muscularly robust 30 – 40 year old pipe smoking male) and F32 (a sub-adult) both showed muscular strain indications on

their humeri. It is possible that these three were involved in the same or similar occupation.

7.6.5 Women and Sub-Adults

Another interesting feature of the Ste. Marie site concerns the burial arrangement of the three women and the three sub-adults. Although the presence of women and children among a garrison group may seem unlikely, journals written by New Englanders during their occupation of Louisbourg mention the presence of women and children, and that women and children became ill (De Forest ed. 1932).

Sub-adult F32 (mentioned in Chapter 7.6.4) was buried directly adjacent to the 40 – 49 year old female, F12. Sub-adult A3 (possibly of Aboriginal or Asian descent) was buried adjacent to adult female A18 (a pipe smoking adult), and sub-adult D7B was buried in the lap of female D7A/F8. The question that has arisen is: what were the relationships between the sub-adult/female pairs (if any existed)? Were they biologically related or from the same household and therefore buried together? Is it possible that the children were placed next to the women out of some superstition, burial custom, or belief that the women's spirit would guide the child in the afterlife? Or was this arrangement purely coincidental?

Although any similarities between the isotopic values of sub-adult/women pairs would result in very speculative inferences concerning relationships, comparisons were made for the sake of inquiry, with the reasoning that similar oxygen and strontium values may suggest origins from the same region, and similar carbon and nitrogen values could be caused by origins from the same household. Child and female pair F32 and F12 likely

had very different origins (Figure 47a) with absolute differences of 1.21‰ for $\delta^{18}O$ and 0.004007 for $^{87}Sr/^{86}Sr$. These data do not support the idea that they had a childhood in the same region, however, since large scale movement of people was common during this time, a possible relationship between the two cannot be ruled out. For example, a mother may move to a new location before having a child, and the two individuals' $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values could be different as a result. The diet of these individuals (Figure 47b) was also different (with absolute differences of 5.29‰ for $\delta^{13}C_{Col}$, 6.59‰ for $\delta^{13}C_{Carb}$, and 1.66‰ for $\delta^{15}N$), suggesting that they ate different diets which loosely suggests they did not live in the same household in the recent years of their lives. Sub-adult A3 and female A18 do not have diet information, however, the large differences between their $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values (1.66‰ and 0.001919, respectively) do not suggest they were raised in the same area. D7A/F8 and D7B do not have oxygen and strontium data, but their relatively similar $\delta^{13}C_{Col}$ and $\delta^{15}N$ values (with absolute differences of 0.98 and 0.92‰, respectively) indicate they consumed isotopically similar diets and may have lived in the same household. Interestingly, sub-adults A3 and F32 have very similar oxygen and strontium values with absolute differences of 0.39‰ and 0.000038. These sub-adults may have come from the same area, but they may have come from different areas that have similar oxygen and strontium values. Unfortunately, there are no carbon and nitrogen data available for A3 for a dietary comparison between the two. Overall these data do not lend themselves to any conclusion regarding potential relationships between the sub-adults and females excavated from the Ste. Marie site. More conclusive results could be obtained from nuclear or mitochondrial DNA analysis.

7.6.6 Women

All the women in this study, A18, D7A/F8, and F12 are noteworthy, in that they all have strontium and oxygen isotopic values that place them as outliers relative to the rest of Ste. Marie individuals (Figure 47a). D7A/F8, the young female buried with a child, has the third highest strontium value, the third highest oxygen value, and is relatively separated from the other individuals analysed. F12, the older female, has the lowest $^{87}Sr/^{86}Sr$ of any human or animal analysed in this study. A18, an adult of unknown age, has the lowest $\delta^{18}O$ value of the group and falls well inside the Louisbourg range, identifying her as a possible Louisbourg inhabitant. These values suggest that these women may not have come from the same locations as the rest of the Ste. Marie group. D7A/F8 and A18 in particular have very distinct isotopic values compared to the others.

Questions that have arisen are: who were these women, and what was their relationship to the garrison or to the overall Louisbourg campaign? Were they traveling with the soldiers, as women did during the 1758 siege of Louisbourg (Lane Jonah and Véchambre 2012)? Unfortunately, there is scant information on women's involvement with these campaigns. The few mentions of women in contemporaneous documents include a woman named Catherine Farrell who was accused of adultery in a Council of war document dating to December 6th 1745 (Massachusetts Historical Society 1899), and the arrival of Shirley's and Warren's wives and other women in a journal entry made in September of 1745 by Private George Mygate (De Forest ed. 1932). Whether these women stayed at Louisbourg over the winter and became sick and perished is unknown.

7.6.7 A18

A18 has the lowest oxygen value among the Ste. Marie individuals (see Chapter 7.5.2), with a $\delta^{18}O_{DW}$ value that falls between precipitation data from Ste. Agathe, Quebec and Truro, Nova Scotia (Figure 44). It is possible that this woman belonged to the small group of over 45 individuals known to have stayed at/around Louisbourg throughout the New England and British occupation (Johnston 1996, 2001). Of this group, only a small number were women (Johnston 2001: n.114). From the historical information available, the only female known to have been present during the New England occupation that fits A18's description is Anne-Madeleine LaChaume, Madame Guyon (or Dyon), who was born at Port Royal in 1707 and was the daughter of an Acadian woman and a soldier (A. M. Lane Jonah, personal communication 2013). Anne-Madeleine married in 1725 at Louisbourg to Jean-Baptiste Guyon (or Dyon) (A. M. Lane Jonah, personal communication 2013). They lived much of their lives a short way down the coast at Havre St. Esprit and had many children, the last of which was a son born in 1744 (A. M. Lane Jonah, personal communication 2013). Some point after this, Anne-Madeleine died (A. M. Lane Jonah, personal communication 2013). During the English occupation of Louisbourg, Jean-Baptiste worked as a pilot, and he remarried in the fall of 1746 (A. M. Lane Jonah, personal communication 2013; Johnston 1996; Moore 1982). It may be that Anne-Madeleine was living at the Fortress with the New Englanders, died of the diseases spreading there, and was buried with the New Englanders in the root cellar of the Ste. Marie house. At this juncture the identity of A18 is unknown and the discussion offered here is only speculative since it is possible that A18's low $\delta^{18}O_{DW}$ value could have been

attained in other areas (e.g., Newfoundland or in northern or inland areas of Europe) and also because of the likelihood that other local women perished in the winter of 1745-46 that were not documented. However, such examinations offer an insight into the kind of information that can be combined with isotopic data to help reconstruct the life histories of the deceased.

7.7 Closing Remarks

7.7.1 Utilising Published Data

The results of this thesis support the use of published isotopic data in addition to isotopic data from local fauna. In theory, while an isotopic similarity between local fauna and the Ste. Marie individuals supports a determination of local origins, it does not rule out the possibility that they originated from an area with similar isotopic values. Utilising published data from areas of the individuals' suspected origins give further information on such a possibility. Concerning oxygen comparisons, this is especially important since local fauna may have slightly different $\delta^{18}O$ values than local humans (Kohn 1996; White et al. 2004a). Along with concerns over oxygen fractionation, there is also an issue of differential water sources utilised between fauna and humans. The specimens used in this study to define the local oxygen range were wild and may differ from humans in that they are more likely to ingest water from streams, rivers, lakes, food, etc., while humans may be more reliant on imported drink, locally made beverages, milk, well water, etc., (A. M. Lane Jonah, personal communication 2013). The differential ingestion of isotopically varied water sources between fauna and humans is another reason why faunal oxygen

isotopic data may not be the best proxy for local human oxygen values (White et al. 2004a). Although isotopic data of fauna are very valuable, and should be given a degree of consideration in the examination of human origins, greater emphasis should be placed on comparisons between calculated human $\delta^{18}O_{DW}$ values and published data of regional $\delta^{18}O_{PPT}$ values.

7.7.2 Control Group

Another topic that has been raised throughout this thesis is the absence of a control group. Data from a control group would not only benefit further investigations into the origins of the Ste. Marie individuals but would also be of great use for any future isotopic studies examining the origins of Louisbourg inhabitants. Such a control group would need to include Louisbourg inhabitants only and exclude any possible deceased from the New England or British occupations. For example, skeletal remains from Rochefort Point would not make for a good control group since both the French and New Englanders/British used the point for a burial site (Johnston 1996). A good candidate for a control group may be those burials within the first parish cemetery located within the town site in Block 3 (Jerkic 1974; Johnston 1996, 2001). In 1722-23 this cemetery was reinterred to another site, however, many graves were left behind (Johnston 1996, 2001). Twenty-three of these graves were excavated in 1974 (Jerkic 1974). The use of Block 3 as a cemetery site ceased before the New Englanders or British occupied Louisbourg, making it an ideal candidate for a control group. However, it is possible that this cemetery was limited to individuals of the Catholic faith. A control group including only these

individuals would not account for those Louisbourg inhabitants who were Protestant, etc., who made up a small, but not an insignificant portion of the Louisbourg population. The possibility of this requires further historical investigation.

7.7.3 The Possible Influence of Foreign Food and Drink

Isotopic data from a control group would also help to define the degree of influence foreign food and drink had on the strontium and oxygen isotopic values of colonial peoples. The Fortress of Louisbourg in particular was a colonial site wherein much of the food and drink was imported. Even soil for backyard gardens was brought in from elsewhere (Donovan 2006; Lane Jonah and Véchambre 2012; O'Neill 1995). These items would carry foreign isotopes that would then be ingested and incorporated into a consumer's skeletal tissue. Could these foreign isotopes significantly shift an individual's isotopic values, or completely overwrite local values? Such influences could result in an under-estimation of local status determinations. Concerning this study, it is believed that since imported drink was of an alcoholic variety, which was unlikely to have been ingested by children (with the possible exception of diluted low alcohol drinks, e.g., cider or beer [A. M. Lane Jonah, personal communication 2013]), the $\delta^{18}O$ values of enamel (which forms during childhood [Hillson 1996]) are unlikely to be affected by imported drink, and more likely to have been influenced by local milk and well water. Thus, the conclusions in this study concerning oxygen isotopes are believed to be unaffected and accurate.

However, imported food would have been ingested at any age, making it possible for foreign strontium isotopes to affect the $^{87}Sr/^{86}Sr$ values of an individual's enamel. Indeed, the $^{87}Sr/^{86}Sr$ values of many domestic animals in this study exhibited a wide range (Figure 31), greater than the strontium range of select (local) fauna. These (likely foreign) $^{87}Sr/^{86}Sr$ values may have had the potential to significantly shift a Louisbourg inhabitant's $^{87}Sr/^{86}Sr$ values away from the local strontium range. These issues are rarely addressed in the published literature (some exceptions include studies by Kendall et al. [2013], Turner et al. [2009] and Wright [2005]), and since Louisbourg is something of an extreme example of a town reliant on imported food, an isotopic study of Louisbourg inhabitants has the potential to contribute greatly to our understanding of the effects of foreign foods on the isotopic values of local inhabitants. Overall, there is great potential for future research to greatly enhance our current knowledge of the Fortress of Louisbourg and our understanding of the uses and shortcomings of isotopic analysis within colonial and historical contexts.

Chapter 8

Conclusions and Suggestions for Future Research

The primary goal of this thesis was to empirically investigate the hypothesis that the Ste. Marie mass burial individuals are deceased members of the New England garrison from the winter of 1745-46. This goal was accomplished by reconstructing the diet and origins of the Ste. Marie individuals using stable and radiogenic isotopic analysis of their skeletal remains. These data were compared to published data of other human groups as well as faunal data from this study and others and has resulted in a detailed interpretation of the individuals and specimens sampled.

The Ste. Marie Individuals: The dietary reconstruction of the Ste. Marie individuals revealed a diverse diet. While most individuals subsisted on C_3 foods, fewer had a mixed C_3/C_4 based diet, and only a small number had a mixed marine/terrestrial diet. The lack of marine foods is believed to be an indication of the group's non-local origins. It is also suggested that the individuals' diverse diets may be the result of the New England soldiers' varied origins and original occupations. However, it is also believed possible that such diversity could also have been obtained from a colonial diet which could be achieved from either Louisbourg or New England.

The strontium and oxygen isotopes revealed that, in comparison to the faunal data, approximately half of the Ste. Marie individuals had non-local origins. This is believed to be too low for the largely European-born population. By calculating the individuals' drinking water $\delta^{18}O$ values, few individuals were identified as having possible French

origins. This would indeed be unexpected of a group of Louisbourg inhabitants since the Fortress's population was largely French in origin. These conclusions further suggest non-local origins for the Ste. Marie group. The Ste. Marie individuals' drinking water $\delta^{18}O$ values, in comparison to New England precipitation $\delta^{18}O$ values, show good agreement. This suggests that the Ste. Marie individuals may have originated from New England which further supports the archaeologically and historically founded hypothesis. In conclusion, it is believed very likely that the Ste. Marie individuals are deceased members of the New England garrison.

No conclusions could be drawn regarding correlations between the individuals' isotopic values and sex, age, dental health and pathological conditions. There are many avenues through which these individuals can be studied further. Given the amount of historical records concerning the siege and the New England occupation, the short time frame for the creation of the mass burial, and the fact that the siege was only 269 years ago, there is promise for genealogical investigations to reveal possible descendants which may lead to positive identifications via DNA analysis. Such investigations may lead to a positive identification for F30, the possible French man, A18, the possible local woman, or E8/F22, the hanged man. Genetic comparisons among the Ste. Marie individuals may help identify potential relationships, for example, between sub-adults and women, among those individuals with muscular strain, and among those individuals whose isotopic values group closely together. Overall, there is great potential for historical research, genetic analyses, or other methodologies to further illuminate the lives of the Ste. Marie individuals.

Future investigations into Louisbourg inhabitants (or indeed the Ste. Marie individuals) could involve the analysis of bioapatite from bone elements as well as tooth enamel which will allow for the investigation of residency, mobility, and migration. This type of analysis may involve oxygen and strontium isotopes but can also involve carbon isotopes since it has been suggested that the appearance and amount of C_4 to the diet may reflect the time that an immigrant spent in the New World, where C_4 resources were more common (Ubelaker and Owsley 2003). Bone bioapatite analysis was not attempted in this study due to logistic and time restraints as well as concerns over bone bioapatite preservation. However, since the Ste. Marie and town site bones are young and in relatively good condition, they may retain their biogenic isotopic values (Kohn and Cerling 2002). If this can be determined by analytical means (Nelson et al. 1986), valuable information on the movement of Louisbourg inhabitants can be attained.

Considering the theory by Ubelaker and Owsley (2003), it is also proposed that by analysing collagen nitrogen isotopes from different skeletal elements reflecting different time periods, it may be possible to observe the appearance of a high marine diet, as would be expected of a European immigrant to the Fortress of Louisbourg (where fish consumption was high). This technique would have to assume that fish consumption at the immigrants' previous home was lower, however, such an investigation may yield further information regarding the mobility and migration of Louisbourg residence.

The Louisbourg Fauna: The aim of the faunal analysis was to outline the type of food items and isotopic values available to Louisbourg inhabitants, however, these data have also exhibited a number of noteworthy patterns and characteristics. There were many

different types of grazing habits and foddering materials used for domestic animals. These include terrestrial C_3 and C_4 products as well as marine and possibly freshwater resources. Marine products also appear to have substantially affected many of Louisbourg's wild fauna. These materials were likely obtained as a result of the local cod fishing practices.

It is possible that many of the faunal specimens sampled came from areas outside of Louisbourg. This was especially true for domestic animals since Louisbourg imported much of their meat and livestock. Few animals were identified as having non-local origins, however, it is important to note that an isotopic similarity between a specimen and the Louisbourg area suggests local origins, but does not rule out the possibility that the animal originated in a non-local area with similar isotopic values. Furthermore, since Louisbourg's strontium and oxygen isotopic ranges can be similar to the isotopic values of New England or New France, the use of isotopic analysis for identifying a specimen's origins is somewhat limited. Future studies aimed at reconstructing the origins of Louisbourg fauna should take this into account.

Potential avenues for future research concerning Louisbourg fauna include the possible isotopic distinction between the diet of local vs. non-local cows, the apparent dietary diversity among chickens, hares, and red squirrels, the possible distinction between natural and anthropogenic diets of foxes, hares, rats, and mice, and the possibility of examining local vs. non-local differences between food animals and luxury/service animals. For these studies, it may also be pertinent to conduct historical research, analyse local flora (e.g., grasses and seaweed), local isotopic values (in soil or

well water) and environmental influences (e.g., sea spray) which will allow for more accurate interpretations.

The secondary goal of this thesis was to contribute to a growing database of isotopic information from colonial and historical contexts. This thesis has culminated in a large isotopic dataset of human and faunal materials from the Fortress of Louisbourg, has raised a number of questions and concerns related to the use of isotopic analysis for diet and origin reconstruction within colonial contexts, and has also illuminated many possible avenues for future research. It is believed that the best approach, as was used in this study, is a multi-isotopic and multi-disciplinary approach which provides a more comprehensive and dependable platform for interpreting archaeological information. Concerning this study, no single type of analysis could have led to a definitive conclusion concerning the Ste. Marie individuals' origins. It was only by a combination of different isotopic analyses, and indeed a combination of historical, archaeological, and isotopic evidence, that a confident interpretation was established.

Tables

Table 1. Permanent dentition enamel development. Revised after Schour and Massler (1940) in Hillson (1996).

Tooth	Range in Years
1st Incisor	4 – 5
2nd Incisor	4 – 5
Canine	6 – 7
1st Premolar	5 – 6
2nd Premolar	6 – 7
1st Molar	2.5 – 3
2nd Molar	7 – 8
3rd Molar	12 – 16

Table 2. Annual turnover rates and the number of years for 100% turnover (turnover = 100/mean) for different bones from a study group of adults from the United Kingdom. Revised after Bryant and Loutit (1964) and Bryant and Loutit (1961) in ICRP (1975).

Bone Type	Mean (%)	Number of years for 100% turnover
Skull	1.8	55.6
Vertebra	8.3	12.0
Rib	4.7	21.3
Ilium	6.5	15.4
Tibia (shaft)	1.1	90.9
Femur (shaft)	2.0	50.0

Table 3. Sex, age at time of death, dental pathologies, bone pathologies and other information on the 49 individuals excavated from the Ste. Marie site paraphrased from the osteological reports (Parish 2006, 2007).

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
X99$^{\alpha}$					
A3	?	12 ± 3 years	Dental caries including large caries on LP^4.		
A12	?	?			
A13/F19	Male	23 – 24			
A14	Male	20 – 21			
A15/F23	Male	>35	Dental wear moderate to severe. Carries on LP^4 and LM^1. Low calculus on half of teeth.		
A16	?	?			
A17'A'	?	?	Linear enamel hypoplasias (LEHs) present. Light to medium wear. Several carious lesions.	Severe periosteal reactive bone on right tibia.	
A17'B'$^{\alpha}$	?	?			
A18	Female	?	LEHs present.		Pipe wear on all canines. Iron fragment in cranial fragment near front of skull.
A19	Male	?	Medium wear on all teeth. Very little disease.		Pipe wear on LC_1 and LI_2.
A20/F20	?	?			

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
C7	Male	?			
D3	?	?			
D4	?	?			
D5	?	15.5 – 21.5		Non-specific periostitis on tibiae and fibulae likely caused by nutritional deficiencies or chronic disease loads.	
D6	Male	24 ± 3 years	Minimal amounts of wear, with massive wear on all four first molars. Abscess on LM_1.		
D7A/F8	Female	15 – 18	Considerable amounts of wear possibly due to carious lesions. Many LEHs.	Bony enthesopathy on left humerus	
D7B	?	3 – 4			Possible congenital disorder involving incomplete fusion of cervical vertebrae possibly related to death.

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
D8	?	>21		Abnormal periosteal and cortical bone loss on the right patella (cause unknown). Reactive woven or fibre bone formation on right femur and right tibia possibly caused by nutritional deficiencies or chronic disease loads.	
D9	?	>18	Moderate wear. A few carious lesions. Several LEHS.		
D10	?	?			
D11/F11	Male	20 – 23	High amount of dental wear considering individuals age. Wear was caused by or was the cause of large carious lesions. Calculus present.	Active and healed porotic hyperostosis in parietals possibly caused by iron deficiency, nutrition deficiencies, infectious disease, or parasitic load.	
D12/F9	Male	18 – 20	Slight dental wear. Light to moderate calculus. Large caries present in five teeth.		Below-knee amputation on the right leg likely related to cause of death.
D13	?	?	Moderate dental wear. Small black pits on LM^1 and LP^4.		
D14	?	>20		Porosity on vertebral centra.	
E6	Male	25 – 30	Three carries in two teeth. Low calculus on most teeth, moderate on LC^1. Eight abscesses.		

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
E7	Male	50 – 55	Tooth wear variable from severe to mild/moderate in posterior dentition. Several carious lesions. Many LEHs.	Schmorl's nodes on T6 – T10 and L3 vertebrae.	Pipe wear on right canines and lateral incisors. Two (possibly three) puncture wounds to right side of cranium.
E8/F22	Male	>35	Antemortem loss of all molars. Dental wear from moderate to severe. LEHs present.		Pipe wear on mandibular canines, LC^1, and LI^1. Greenstick fractures on C1 – C3 and wear pattern and fracture on right side of mandible indicating possible death by hanging.
E9	Male	20 – 24	Poor dental health considering age. Low to moderate calculus throughout. Caries on maxillary dentition, one large.	Extensive periostitis and porotic hyperostosis on leg bones. Healed porosity on frontal and both parietal bones. Both likely caused by continual generalised nutritional stress, malnutrition, metabolic disorders, or chronic disease loads.	
$E11^{\alpha}$	?	?			

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
E12/F26	Male	15 – 20	Bad dental health for his age. Six carries. Calculus low to moderate.	Diffuse bone loss on femur. Bone loss on left clavicle and myositis ossificans on humerus likely caused by ligament and muscular stress involving repetitive motion of arms. Periostitis on femora and tibiae. Active and healed porotic hyperostosis and cribra orbitalia lesions on cranium.	
E13	Male	30 – 40	Moderate to severe tooth wear with low calculus. Five abscesses.	Bone loss and cavitation on left radius with minimal remodelling. Porotic osteoblastic bone deposit on T1 and C6.	
E15	Male	35 – 50	Dental wear moderate and consistent with age. Mostly moderate calculus, but also low and severe calculus present. Three absences. One carries.	Porotic hyperostosis and osteomyelitis on the frontal, parietals, and occipitals. Cribra orbitalia present. Coalescing foramina on frontal. The latter two with lesions active at time of death and likely caused by severe anemia.	Pipe wear pattern between right incisors and also right lateral incisor and canine.
E16	Male	33 – 44	One abscess. Low to severe calculus throughout dentition, most with low calculus. Several carious lesions on ⅔^{rds} of dentition. Antemortem tooth loss of five teeth with partial or full resorption.	Leg bones had periostitis and sclerotic bone deposits likely caused by malnutrition or nutritional stress.	Pipe wear pattern on RI^{2} and RC^{1}.

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
E18	Male	17 – 19	Low to moderate dental wear higher than expected for age. Free of calculus and caries except for low level calculus on LI^2. Two lingual abscesses.	Periostitis and sclerotic deposits on femora and tibiae. Right eye orbit had active cribra orbitalia at time of death.	
F12	Female	40 – 49	Severe dental wear consistent with her age. Antemortem tooth loss at 12.5%. Remaining teeth have many carious lesions. Low calculus on anterior mandibular dentition and right premolars. Several abscesses.		
F18	Male	20 – 26	Moderate dental wear, heavier than expected for his age. Fourteen carries on nine teeth. Low to moderate calculus on 14 of 32 teeth. Many abscesses present.	Periostitis on humerus, femora and tibiae. Fovea on proximal humerus at muscle attachment site indicating that muscle may have been pulled and healed improperly. Sclerotic reaction and reactive woven bone on lower legs. Schmorl's nodes on T8, T9, T13, and L3.	
F24	Male	25 ± 2 years	Low to moderate dental wear (consistent with age). Fourteen carious lesions. Low calculus in six teeth.	Sclerotic periostitis on femora.	
F25	Male	16 – 19		Periostitis on femora and tibiae. Schmorl's nodes on T1 – L5 vertebrae.	

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
F28	Male	>35	Low to severe dental wear. Six carious lesions on five teeth. Low calculus on five teeth. Three abscesses.		Pipe smoker's wear on LC_1, LI_2, and RI_2.
F29	Male	30 – 40	Dental health fairly good considering age. Antemortem tooth loss of RI_1 and RI_2. Low to moderate wear. Eleven carious lesions on seven teeth. Low level calculus on half of the teeth. Brown staining on 15 teeth.	Focal bone loss on right calcaneus. Periostitis, bone loss and/or breakage on tibiae. Sclerotic reaction on right tibia. Schmorl's nodes on T6 to L4 vertebrae.	Pipe smoker's wear on two spots involving LC^1, LI^1, LP_3, and LC_1, and LI^1, LI^2, LC_1, and LI_2. Muscular insertions on humeri are robust indicating repeated stress and strain of arms.
F30	?	40 – 45	Good dental health for individual's age. Moderate wear. Severe periodontal disease especially in maxillary dentition. Low levels of calculus.	Focal bone loss and porotic hyperostosis on inner table of frontal. Active and healed porotic hyperostosis on outer table of frontal parietals and occipital. Bone loss on clavicles. Sclerotic and woven bone on tibiae and fibulae (likely made walking difficult). Moderate expressions of Schmorl's nodes on T3, L1, T8, L4, vertebra.	Pipe wear on RI^1.

Table 3. Continued.

Individual (55L28…)	Sex	Age	Dental Pathologies	Bone Pathologies	Other Information
F32	?	12 ± 3 years		Woven and pitted bone at muscle insertion sites on humeri indicating heavy strain and stress of arm muscles.	Congenital or genetic defect of incomplete fusion of thoracic vertebrae, possibly related to death.
F33	Male	33 – 42	Moderate dental wear. One lesion and low calculus. Suspected abscesses.	Schmorl's nodes on L3 vertebra.	
F34	Male	18 – 25			
H3	Male	18 – 25	Low dental wear. No carious lesions. Low calculus. Periodontal disease in all dentition and prominent in maxillary teeth.	Odd expression of porotic hyperostosis on frontal and left parietal possibly caused by scurvy or similar condition. Bone loss on right temporal. Roof of maxilla is heavily pitted.	Blunt force trauma to right parietal causing death.
Unp.$^{\alpha, \beta}$	?	?			
Dis.$^{\alpha, \chi}$	?	?			

$^{\alpha}$ Individual could not be sampled. $^{\beta}$ Unprovenienced remains within 55L28A. Remains do not belong to adjacent individuals. MNI of 1.
$^{\chi}$ Disassociated remains within 55L28A. Remains do not belong to adjacent individuals. MNI of 1.

Table 4. Known/accepted and measured carbon, nitrogen, oxygen, and strontium isotopic data of standards used in analysis.

	$\delta^{13}C$ ‰ VPDB		$\delta^{15}N$ ‰ AIR		$\delta^{18}O$ ‰ VPDB		$^{87}Sr/^{86}Sr$	
Standard ID	Known	Measured	Known	Measured	Known	Measured	Known	Measured
MUN-CO-2 ($CaCO3$)$^{\alpha}$	-40.11 ± 0.15	-40.11 ± 0.07 (n=35)						
D-Fructose$^{\alpha}$	-10.53 ± 0.11	-10.53 ± 0.12 (n=7)						
IAEA-CH-6 (sucrose)$^{\alpha}$	-10.45 ± 0.13 [2]	-10.45 ± 0.04 (n=28)						
B2155 (protein)$^{\alpha}$	-27.03 ± 0.13	-27.22 ± 0.12 (n=25)	+5.97 ± 0.08	+5.85 ± 0.08 (n=25)				
IAEA-N-1 ($(NH_4)_2SO_4$)			+0.43 ± 0.07 [1]	+0.47 ± 0.10 (n=33)				
IAEA-N-2 ($(NH_4)_2SO_4$)			+20.32 ± 0.09 [1]	+20.24 ± 0.20 (n=35)				
CBM ($CaCO_3$)$^{\beta}$	+0.75 ± 0.06	+0.68 ± 0.05 (n=11)			-8.58	-8.60 ± 0.11 (n=11)		
NBS-19 ($CaCO_3$)$^{\beta}$	+1.95$^{\chi}$	+1.95 ± 0.03 (n=11)			-2.20$^{\chi}$	-2.20 ± 0.05 (n=11)		
MUN-CO-1 ($CaCO_3$)$^{\beta}$	-21.02 ± 0.10	-21.02 ± 0.02 (n=11)			-13.40 ± 0.12	-13.40 ± 0.04 (n=11)		
SRM987							0.71024	0.710214 ± 0.000148 (n=12)

$^{\alpha}$ Used in collagen isotopic analysis. $^{\beta}$ Used in carbonate isotopic analysis. $^{\chi}$ Exact, defines VPDB scale.

[1] Coplen et.al. 2002: USGS WRIR 01-4222. [2] Coplen et.al. 2006: New guidelines for $\delta^{13}C$ measurements Analytical Chemistry.

Table 5. Faunal bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, % collagen yield and C/N atomic ratios. Rejected samples are positively indicated with a star (*). Any letters (a, b, c, etc.) at the end of proveniences were added by the author (for the purposes of this thesis only) to differentiate between different specimens from the same provenience.

Provenience	Animal	Element	MARC	Yield (%)	$\delta^{13}C$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	C/N atomic ratio	Rejected Samples
3L20E5-7	Cow	L radial carpal	1295	15.17	-20.77	5.24	3.29	
4L50K12-8	Cow	R rib	1296	16.97	-16.93	5.23	3.21	
4L50L16-4	Cow	unidentified	1297	10.75	-22.50	4.90	3.28	
4L50K16-4	Cow	unidentified	1298	9.31	-16.20	7.44	3.29	
4L58K14-9	Cow	R rib	1299a	23.85	-21.90	5.06	3.20	
			1299b		-21.97	4.91	3.19	
55L28E16-4	Pig	atlas	501	10.89	-18.70	7.17	3.34	
4L52L12-12	Pig	R maxilla	1300	12.30	-14.56	11.01	3.29	
4L50M14-7	Pig	L mandible	1301	20.07	-19.96	7.29	3.25	
4L58K14-7	Pig	R maxilla	1302	18.24	-21.47	9.46	3.24	
4L50N15-10	Pig	R maxilla	1303	19.14	-21.22	5.02	3.24	
55L28E5-3	Sheep	metatarsal	493	0	-	-	-	*
4L58K14-8	Sheep	R humerus	1304	18.05	-20.70	4.73	3.22	
3L19D5-3	Sheep	L radius	1305	13.67	-21.15	4.40	3.24	
4L58K14-6	Sheep	R maxilla	1306	16.06	-21.46	7.39	3.28	
4L22C7-1	Sheep	L mandible	1307	14.92	-21.05	6.24	3.29	
3L22N1-6	Goat	R mandible	1308	7.69	-21.12	7.25	3.44	
3L17Y3-3	Goat	R mandible	1309	6.60	-20.65	5.68	3.39	
3L21E3-3	Cat	tibia	1315	18.94	-17.33	10.83	3.27	

Table 5. Continued.

Provenience	Animal	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
1L34D5-39	Cat	mandible	1316	24.00	-16.38	12.65	3.22	
55L28F6-13	Chicken	radius	497	13.70	-18.13	9.73	3.31	
55L28G7-1	Chicken	scapula	506	20.89	-14.97	14.14	3.33	
55L28G7-3	Chicken	tibiotarsus	508	20.39	-14.16	13.40	3.31	
55L28E10-7	Chicken	coracoid	510	20.86	-17.14	8.28	3.29	
55L28E10-4	Chicken	humerus	512	25.68	-17.79	14.99	3.23	
55L28E19-5	Chicken	coracoid	515	23.59	-13.95	13.83	3.30	
55L28F4-3	Chicken	tibiotarsus	522	11.93	-23.51	0.02	3.38	
55L28E20-51a	Chicken	tibiotarsus	526	20.88	-21.51	13.86	3.10	
55L28E10-11	Chicken	tibiotarsus	527	8.39	-23.51	15.22	4.09	*
55L28E20-51b	Chicken	tibiotarsus	538	14.30	-12.66	14.82	3.25	
55L38G7-5	Turkey	tarsometatarsus	489	14.40	-18.88	14.00	3.39	
55L28E10-8	Turkey	femur	503	9.38	-16.39	13.26	3.39	
55L28G7-6	Turkey	radius	507	18.57	-16.83	5.88	3.19	
4L50M14-5	Goose	L carpometacarpus	1310	21.69	-17.29	13.98	3.25	
3L6N13-1	Goose	sternum	1311	22.97	-15.80	6.85	3.28	
4L22C7-2	Duck	L ulna	1312	20.53	-19.26	7.11	3.23	
4L50M14-6	Eider	sternum	1313	20.55	-16.45	12.41	3.23	
4L51N12-10	Spruce Grouse	sternum	1314	20.25	-18.04	9.57	3.25	
55L28F16-3	Avian	radius	490	0	-	-	-	*
55L28E4-17	Avian	carpometacarpus	504	13.37	-16.30	15.10	3.37	

Table 5. Continued.

Provenience	Animal	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
55L28F13-1a	Dove/Robin	L pelvis	531	7.08	-16.03	13.73	3.24	
55L28E4-20a	Dove/Robin	R pelvis	532	10.50	-16.43	12.30	3.24	
55L28F13-1b	Dove/Robin	R pelvis	539	6.63	-15.87	14.57	3.32	
55L28E4-20b	Dove/Robin	L pelvis	540	6.29	-16.80	12.52	3.35	
55L28E7-3	Fish	vertebra	514	5.72	-13.98	15.31	3.36	
55L28E10-12a	Fish	vertebra	535	1.81	-15.72	16.00	3.68	*
55L28E10-12b	Fish	vertebra	541	6.78	-14.70	15.38	3.22	
55L28E10-12c	Fish	vertebra	542	6.83	-15.00	14.74	3.22	
55L28E10-12d	Fish	unidentified	543	9.50	-13.94	16.20	3.23	
55L28E10-12e	Fish	unidentified	544	12.17	-14.24	14.39	3.15	
55L28E10-12f	Fish	unidentified	545	5.31	-14.58	14.80	3.26	
55L28F6-9	Rat	humerus	495	7.40	-15.99	14.02	3.44	
55L28F6-11	Rat	ulna	496	17.14	-15.84	13.03	3.30	
55L28E4-21	Rat	humerus	500	8.59	-16.64	12.61	3.44	
55L28E4-16a	Rat	L mandible	509	6.16	-17.01	12.27	3.47	
55L28F6-12	Rat	femur	511	5.94	-16.16	13.72	3.38	
55L28E4-23a	Rat	L tibia	517	4.89	-17.58	10.69	3.41	
55L28E4-19	Rat	femur	524	7.54	-14.17	12.19	3.19	
55L28E4-16b	Rat	R mandible	536	13.64	-16.06	12.55	3.19	
55L28E4-23b	Rat	L tibia	537	3.84	-16.40	13.57	3.33	
17L45A4-12	Rat	skull	1317	19.60	-20.37	7.27	3.20	

Table 5. Continued.

Provenience	Animal	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
55L28E4-22	Mouse	ulna	499	18.11	-14.64	15.64	3.32	
55L28E10-5	Mouse	femur	502	2.97	-16.57	13.81	3.64	*
55L28F13-3	Mouse	scapula	518	7.23	-16.49	13.63	3.36	
55L28E4-18	Mouse	ulna	528	14.88	-16.47	12.08	3.24	
55L28F13-2	Mouse	atlas	533	7.48	-16.34	14.06	3.34	
55L28G7-2	Hare	humerus	519	8.72	-14.17	13.79	3.37	
55L28E10-9	Hare	vertebra	520	31.08	-15.93	13.49	3.25	
55L28E10-6	Hare	pelvis	521	15.83	-21.51	6.64	3.32	
55L28E24-4	Hare	vertebra	525	5.28	-15.93	11.92	3.71	*
55L28F6-10	Hare	calcaneus	534	7.91	-14.70	15.48	3.23	
55L28F4-2	Hare	scapula	546	13.33	-21.92	5.09	3.37	
4L55X99-2	Hare	mandible	1318	17.99	-23.87	1.27	3.27	
4L55X99-1	Hare	mandible	1319	8.50	-23.06	1.33	3.30	
3L17H1-1	Hare	R mandible	1320	8.03	-24.14	0.95	3.31	
55L28E23-25	Red squirrel	tibia	492	10.36	-15.32	15.60	3.39	
55L28E19-3	Red squirrel	ulna	494	15.65	-16.26	9.65	3.30	
55L28E19-4	Red squirrel	ulna	505	16.17	-15.17	16.13	3.37	
55L28F12-3	Red squirrel	radius	513	26.85	-13.93	9.48	3.23	
55L28E4-15	Red squirrel	tibia	523	29.37	-16.49	9.02	3.26	
55L28E10-10	Red squirrel	tibia	529a 529b	10.98	-18.33 -18.38	7.64 7.59	3.27 3.28	

Table 5. Continued.

Provenience	Animal	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
4L20F11-3	Red Fox	R humerus	1321	17.16	-14.37	14.82	3.23	
3L6N10-9	Red Fox	R mandible	1322	9.31	-18.02	12.16	3.57	
4L51M11-9	Lynx	R femur	1323	10.19	-17.09	12.00	3.28	
55L28G7-4	Deer	trapezoid magnum	491	11.49	-21.82	5.69	3.38	
55L28F6-8	Deer	ulna	498	8.24	-16.58	6.11	3.40	
55L28E9-3	Deer	metatarsal	516	11.22	-20.15	6.40	3.25	
55L28E9-4	Deer	metatarsal	530	3.61	-19.13	6.06	3.29	
4L51J12-3	Deer	L mandible	1324	9.39	-20.67	5.48	3.30	
4L19A5-7	Deer	L mandible	1325	8.80	-20.94	4.98	3.29	
4L20A2-14	Moose	phalanx	1326	7.09	-21.99	0.77	3.36	
3L33D3-55	Caribou	L radius distal end	1327	6.97	-20.37	2.80	3.30	

Table 6. Ste. Marie individuals' bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, % collagen yield and C/N atomic ratios. Rejected samples are positively indicated with a star (*).

Individual (55L28…)	Element	MARC	Yield (%)	$\delta^{13}C$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	C/N Atomic Ratio	Rejected Samples
A12	bone fragment	1139	2.92	-16.65	9.69	3.82	*
A13/F19	rib fragment, middle	1061	10.37	-15.78	9.44	3.14	
	rib fragment, middle	1062	30.00	-16.11	9.73	3.18	
A14	humerus fragment	1063	3.52	-18.38	8.17	4.11	*
	rib fragment	1064	7.49	-17.43	9.36	3.22	
A15/F23	rib fragment	1065	4.48	-17.32	13.61	3.29	
	R. humerus, mid-shaft, anterior	1066	14.68	-16.99	13.72	3.26	
A16	R. femur, mid-shaft, anterior	1067	16.47	-14.28	10.84	3.20	
	R. femur, mid-shaft, anterior	1068	15.50	-14.00	10.71	3.28	
A17	R. femur, mid-shaft	1069	18.44	-13.56	8.97	3.21	
	L femur, mid-shaft, anterior	1070	22.18	-13.52	8.93	3.15	
A18	clavicle fragment	1071	0	-	-	-	*
	clavicle fragment	1072	2.28	-18.50	7.91	3.82	*
A20/F20	R fibula, mid-shaft, posterior	1073	8.91	-20.71	9.52	3.07	
	R fibula, mid-shaft, posterior	1074	19.30	-20.79	9.80	3.10	
C7	unidentified bone fragment	1075	8.57	-17.35	12.33	3.18	
	unidentified bone fragment	1076	10.96	-17.55	12.21	3.16	
D3	unidentified bone fragment	1079	10.22	-19.62	9.55	3.14	
	unidentified bone fragment	1080	5.58	-16.79	7.89	3.00	

Table 6. Continued.

Individual (55L28…)	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
D4	unidentified bone fragment	1077	7.28	-15.12	8.84	3.25	
	unidentified bone fragment	1078	17.14	-16.24	8.43	3.44	
D5	R fibula, mid-shaft, anterior	1081a	11.67	-15.81	5.50	2.97	
		1081b		-15.91	9.47	3.35	
	R fibula, mid-shaft, anterior	1082a	6.54	-15.43	8.56	3.14	
		1082b		-15.21	9.41	3.29	
D6	rib fragment, middle posterior	1083	8.33	-19.38	11.28	3.08	
	rib fragment, middle posterior	1084	7.41	-19.50	11.01	3.10	
D7A/F8	rib fragment, middle posterior	1085	6.88	-18.60	8.17	3.12	
	rib fragment, middle posterior	1086	4.39	-18.67	7.89	3.07	
D7B	rib fragment, middle anterior	1288	10.37	-19.66	9.32	3.29	
	rib fragment, middle anterior	1088	14.58	-19.57	8.58	3.08	
D8	R femur, mid-shaft, anterior	1089	20.43	-17.38	10.77	3.17	
	R femur, mid-shaft, anterior	1090	14.23	-17.55	11.27	3.18	
D10	R fibula, mid-shaft, anterior	1091	11.62	-16.42	11.01	3.17	
	R fibula, mid-shaft, anterior	1092	7.87	-16.74	10.85	3.21	
D11/F11	rib fragment, middle posterior	1093	13.01	-19.79	8.15	3.20	
	rib fragment, middle posterior	1094	4.55	-19.81	7.66	3.16	
D12/F9	L humerus, mid-shaft, posterior	1095	2.71	-15.93	8.89	3.17	
	L humerus, mid-shaft, posterior	1096	7.17	-16.12	9.16	3.21	

Table 6. Continued.

Individual (55L28…)	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
D14	ulna shaft fragment, anterior	1097	4.07	-18.05	9.94	3.18	
	rib fragment	1098	8.52	-14.29	10.83	3.15	
E6	rib fragment, middle posterior	1099	5.20	-18.22	11.50	3.13	
	rib fragment, middle posterior	1100	9.43	-18.73	11.98	3.15	
E7	rib fragment, middle posterior	1101	12.45	-16.57	10.43	3.05	
	rib fragment, middle posterior	1102	13.75	-17.04	10.22	3.05	
E8/F22	rib fragment, middle posterior	1103	8.88	-17.97	8.31	3.11	
	rib fragment, middle posterior	1104	7.91	-18.11	8.69	3.14	
E9	L humerus mid-shaft, anterior	1109	13.82	-16.10	9.33	3.07	
	L humerus mid-shaft, anterior	1110	4.48	-15.96	9.99	3.15	
E12/F26	1st half of rib fragment	1105a	10.08	-17.72	6.94	3.13	
		1105b		-17.63	8.78	3.33	
	2nd half of rib fragment	1289a	9.16	-17.65	8.74	3.33	
		1289b		-17.62	8.64	3.29	
E13	rib fragment, middle posterior	1111a	14.34	-12.14	12.95	3.22	
		1111b		-12.32	13.72	3.26	
	rib fragment, middle posterior	1112a	8.85	-12.16	12.84	3.16	
		1112b		-12.47	13.22	3.23	
E15	1st half of rib fragment	1291	33.85	-15.42	8.99	3.22	
	2nd half of rib fragment	1114	19.03	-15.66	8.42	3.15	

Table 6. Continued.

Individual (55L28…)	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
E16	rib fragment, middle posterior	1107a	7.05	-18.96	10.25	3.13	
		1107b		-19.19	11.26	3.27	
	rib fragment, middle posterior	1292a	9.74	-18.38	11.38	3.29	
		1292b		-18.39	11.13	3.28	
E18	rib fragment, middle posterior	1115	5.45	-16.62	7.88	3.28	
	rib fragment, middle posterior	1116	5.17	-16.44	7.78	3.37	
F12	rib fragment, middle posterior	1117	8.43	-19.59	10.10	3.26	
	rib fragment, middle posterior	1118	4.82	-19.26	9.67	3.27	
F18	rib fragment, middle posterior	1119	7.48	-15.47	9.80	3.32	
	rib fragment, middle posterior	1120	3.13	-15.68	9.16	3.28	
F24	1st half of rib fragment	1121	18.97	-15.59	8.19	3.16	
	2nd half of rib fragment	1122	11.84	-15.93	8.05	3.20	
F25	R humerus, mid-shaft, anterior	1123a	17.12	-13.08	8.68	3.20	
		1123b		-13.02	8.49	3.21	
	R humerus, mid-shaft, anterior	1124a	21.27	-13.21	8.55	3.18	
		1124b		-13.11	8.60	3.21	
F28	1st half of R tibia fragment	1125a	10.68	-16.72	7.78	3.35	
		1125b		-17.00	8.76	3.38	
	2nd half of R tibia fragment	1126a	7.57	-16.10	9.32	3.32	
		1126b		-16.15	9.75	3.32	

Table 6. Continued.

Individual (55L28…)	Element	MARC	Yield (%)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	C/N Atomic Ratio	Rejected Samples
F29	rib fragment, middle posterior	1127	11.74	-14.88	7.80	3.26	
	rib fragment, middle posterior	1128	2.53	-15.03	7.45	3.20	
F30	rib fragment, middle posterior	1290a	11.64	-16.69	15.11	3.30	
		1290b		-16.96	14.86	3.29	
	rib fragment, middle posterior	1130a	6.73	-16.60	14.10	3.21	
		1130b		-16.63	14.88	3.25	
F32	rib fragment, end	1131	8.00	-14.08	8.51	3.26	
	rib fragment, end	1132	5.13	-14.20	7.94	3.25	
F33	1st half of rib fragment	1133	6.80	-19.48	8.99	3.29	
	2nd half of rib fragment	1134	4.76	-19.23	8.65	3.36	
F34	rib fragment	1135	10.76	-16.25	8.14	3.21	
	rib fragment, end	1136	13.12	-16.19	8.40	3.22	
H3	1st half of rib fragment	1293	10.37	-16.39	9.85	3.35	
	2nd half of rib fragment	1294	13.30	-16.53	9.82	3.42	

Table 7. Enamel and dentine carbonate $\delta^{13}C$ and $\delta^{18}O$ results of six faunal specimens.

Provenience	Animal	Enamel MARC	Dentine MARC	Enamel $\delta^{13}C$	Dentine $\delta^{13}C$	$\delta^{13}C_{E-D}$	Enamel $\delta^{18}O$	Dentine $\delta^{18}O$	$\delta^{18}O_{E-D}$
4L58K14-10	Cow	1333	1736	-12.11	-12.33	0.22	-7.71	-7.32	-0.39
3L17Y3-3	Goat	1342	1737	-9.62	-11.89	2.27	-9.13	-5.82	-3.31
3L22N1-5	Horse	1345	1738	-8.05	-8.84	0.79	-8.74	-7.85	-0.89
3L6N10-9	Fox	1356	1739	-11.24	-11.63	0.39	-6.15	-5.85	-0.30
3L22N1-4	Deer	1360	1740	-12.68	-13.42	0.74	-6.62	-6.60	-0.02
4L20A2-11	Moose	1363	1741	-11.06	-11.95	0.89	-7.04	-6.90	-0.14

Table 8. Enamel and dentine $^{87}Sr/^{86}Sr$ results of six faunal specimens.

Provenience	Animal	Enamel MARC	Dentine MARC	Enamel $^{87}Sr/^{86}Sr$	Dentine $^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr_{E-D}$
4L50K16-3	Cow	1365	1606	0.710683	0.710270	0.000413
4L52L12-12	Pig	1370	1607	0.709526	0.709655	-0.000130
3L22N1-7	Horse	1382	1608	0.710487	0.710436	0.000051
3L19C2-6	Beaver	1391	1609	0.709938	0.710257	-0.000319
3L19B4-3	Lynx	1393	1610	0.710061	0.710484	-0.000423
3L22N1-4	Deer	1396	1611	0.711345	0.710880	0.000465

Table 9. Enamel and dentine carbonate $\delta^{13}C$ and $\delta^{18}O$ results of 10 individuals.

Individual (55L28…)	Enamel MARC	Dentine MARC	Enamel $\delta^{13}C$	Dentine $\delta^{13}C$	$\delta^{13}C_{E-D}$	Enamel $\delta^{18}O$	Dentine $\delta^{18}O$	$\delta^{18}O_{E-D}$
A3	1424	1685	-9.29	-11.46	2.17	-5.40	-5.26	-0.14
C7	1430	1686	-14.11	-13.88	-0.23	-6.23	-5.69	-0.54
D13	1436	1693	-6.24	-7.18	0.94	-4.82	-5.80	0.98
E8/F22	1439	1696	-11.30	-11.77	0.47	-5.27	-5.45	0.18
E13	1443	1698	-3.20	-6.54	3.34	-5.06	-5.41	0.35
E18	1445	1702	-4.79	-7.37	2.58	-4.13	-4.65	0.52
F18	1447	1704	-6.47	-9.50	3.03	-4.90	-4.87	-0.03
F24	1448	1705	-7.75	-10.66	2.91	-5.02	-5.84	0.82
F25	1449	1706	-5.41	-8.78	3.37	-6.26	-6.18	-0.08
F28	1450	1707	-11.02	-12.32	1.30	-3.88	-5.07	1.19

Table 10. Enamel and dentine $^{87}Sr/^{86}Sr$ results of 10 individuals.

Individual (55L28…)	Enamel MARC	Dentine MARC	Enamel $^{87}Sr/^{86}Sr$	Dentine $^{87}Sr/^{86}Sr$	$^{87}Sr/^{86}Sr_{E-D}$
D12/F9	1663	1725	0.710335	0.710261	-0.000074
E7	1666	1726	0.709653	0.709849	0.000196
E8/F22	1667	1727	0.712269	0.711644	-0.000625
E13	1670	1728	0.709646	0.709649	0.000003
E18	1673	1729	0.710981	0.710410	-0.000571
F18	1675	1730	0.711469	0.711205	-0.000264
F25	1677	1731	0.710842	0.710222	-0.000620
F32	1681	1732	0.712567	0.711834	-0.000733
F34	1683	1733	0.710868	0.710478	-0.000391
H3	1684	1734	0.709741	0.709826	0.000085

Table 11. Ste. Marie individuals' intra-bone element carbon and nitrogen isotopic data.

Individual (55L28…)	Element	MARC	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$
A13/F19	rib fragment, middle	1061	-15.78	9.44	0.33	0.29
	rib fragment, middle	1062	-16.11	9.73		
A16	R. femur, mid-shaft, anterior	1067	-14.28	10.84	0.28	0.13
	R. femur, mid-shaft, anterior	1068	-14.00	10.71		
A17	R. femur, mid-shaft	1069	-13.56	8.97	0.04	0.04
	L femur, mid-shaft, anterior	1070	-13.52	8.93		
A20/F20	R fibula, mid-shaft, posterior	1073	-20.71	9.52	0.08	0.28
	R fibula, mid-shaft, posterior	1074	-20.79	9.80		
D5	R fibula, mid-shaft, anterior	1081	-15.81	5.50	0.38	3.06
	R fibula, mid-shaft, anterior	1082	-15.43	8.56		
D6	rib fragment, middle posterior	1083	-19.38	11.28	0.12	0.27
	rib fragment, middle posterior	1084	-19.50	11.01		
D7A/F8	rib fragment, middle posterior	1085	-18.60	8.17	0.07	0.28
	rib fragment, middle posterior	1086	-18.67	7.89		
D7B	rib fragment, middle posterior	1288	-19.66	9.32	0.09	0.74
	rib fragment, middle posterior	1088	-19.57	8.58		
D8	R femur, mid-shaft, anterior	1089	-17.38	10.77	0.17	0.50
	R femur, mid-shaft, anterior	1090	-17.55	11.27		
D10	R fibula, mid-shaft, anterior	1091	-16.42	11.01	0.32	0.16
	R fibula, mid-shaft, anterior	1092	-16.74	10.85		
D11/F11	rib fragment, middle posterior	1093	-19.79	8.15	0.02	0.49
	rib fragment, middle posterior	1094	-19.81	7.66		
D12/F9	L humerus, mid-shaft, posterior	1095	-15.93	8.89	0.19	0.27
	L humerus, mid-shaft, posterior	1096	-16.12	9.16		
E6	rib fragment, middle posterior	1099	-18.22	11.50	0.51	0.48
	rib fragment, middle posterior	1100	-18.73	11.98		
E7	rib fragment, middle posterior	1101	-16.57	10.43	0.47	0.21
	rib fragment, middle posterior	1102	-17.04	10.22		
E8/F22	rib fragment, middle posterior	1103	-17.97	8.31	0.14	0.38
	rib fragment, middle posterior	1104	-18.11	8.69		
E9	L humerus mid-shaft, anterior	1109	-16.10	9.33	0.14	0.66
	L humerus mid-shaft, anterior	1110	-15.96	9.99		

Table 11. Continued.

Individual (55L28…)	Element	MARC	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$
E12/F26	1st half of rib fragment	1105	-17.72	6.94	0.07	1.80
	2nd half of rib fragment	1289	-17.65	8.74		
E13	rib fragment, middle posterior	1111	-12.14	12.95	0.02	0.11
	rib fragment, middle posterior	1112	-12.16	12.84		
E15	1st half of rib fragment	1291	-15.42	8.99	0.24	0.57
	2nd half of rib fragment	1114	-15.66	8.42		
E16	rib fragment, middle posterior	1107	-18.96	10.25	0.58	1.13
	rib fragment, middle posterior	1292	-18.38	11.38		
E18	rib fragment, middle posterior	1115	-16.62	7.88	0.18	0.10
	rib fragment, middle posterior	1116	-16.44	7.78		
F12	rib fragment, middle posterior	1117	-19.59	10.10	0.33	0.43
	rib fragment, middle posterior	1118	-19.26	9.67		
F18	rib fragment, middle posterior	1119	-15.47	9.80	0.21	0.64
	rib fragment, middle posterior	1120	-15.68	9.16		
F24	1st half of rib fragment	1121	-15.59	8.19	0.34	0.14
	2nd half of rib fragment	1122	-15.93	8.05		
F25	R humerus, mid-shaft, anterior	1123	-13.08	8.68	0.13	0.13
	R humerus, mid-shaft, anterior	1124	-13.21	8.55		
F28	1st half of R tibia fragment	1125	-16.72	7.78	0.62	1.54
	2nd half of R tibia fragment	1126	-16.10	9.32		
F29	rib fragment, middle posterior	1127	-14.88	7.80	0.15	0.35
	rib fragment, middle posterior	1128	-15.03	7.45		
F30	rib fragment, middle posterior	1290	-16.69	15.11	0.09	1.01
	rib fragment, middle posterior	1130	-16.60	14.10		
F32	rib fragment, end	1131	-14.08	8.51	0.12	0.57
	rib fragment, end	1132	-14.20	7.94		
F33	1st half of rib fragment	1133	-19.48	8.99	0.25	0.34
	2nd half of rib fragment	1134	-19.23	8.65		
F34	rib fragment	1135	-16.25	8.14	0.06	0.26
	rib fragment, end	1136	-16.19	8.40		
H3	1^{st} half of rib fragment	1293	-16.39	9.85	0.14	0.03
	2^{nd} half of rib fragment	1294	-16.53	9.82		

Table 12. Isotopic values from the original analysis (Table 11) and reanalysis of samples with large $\Delta^{15}N$ values and control samples.

Individual (55L28…)	MARC	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$	MARC	$\delta^{13}C$	$\delta^{15}N$	$\Delta^{13}C$	$\Delta^{15}N$
D5	1081a 1082a	-15.81 -15.43	5.50 8.56	0.38	3.06	1081b 1082b	-15.91 -15.21	9.47 9.41	0.70	0.06
E12/F26	1105a 1289a	-17.72 -17.65	6.94 8.74	0.07	1.80	1105b 1289b	-17.63 -17.62	8.78 8.64	0.01	0.14
E16	1107a 1292a	-18.96 -18.38	10.25 11.38	0.58	1.13	1107b 1292b	-19.19 -18.39	11.26 11.13	0.80	0.13
F28	1125a 1126a	-16.72 -16.10	7.78 9.32	0.62	1.54	1125b 1126b	-17.00 -16.15	8.76 9.75	0.85	0.99
F30	1290a 1130a	-16.69 -16.60	15.11 14.10	0.09	1.01	1290b 1130b	-16.96 -16.63	14.86 14.88	0.33	0.02
E13	1111a 1112a	-12.14 -12.16	12.95 12.84	0.02	0.11	1111b 1112b	-12.32 -12.47	13.72 13.22	0.15	0.50
F25	1123a 1124a	-13.08 -13.21	8.68 8.55	0.13	0.13	1123b 1124b	-13.02 -13.11	8.49 8.60	0.09	0.11
Cow	1299a	-21.90	5.06	-	-	1299b	-21.97	4.91	0.07^{α}	0.15^{α}

$^{\alpha}$ $\Delta^{13}C$ and $\Delta^{15}N$ values not derived from the absolute differences between sample pairs but from the absolute differences between the isotopic values of the original analysis and the reanalysis.

Table 13. Peak amplitude (mV) and EA-IRMS sample weight (mg) of the Ste. Marie individuals' samples.

Individual (55L28…)	MARC	EA-IRMS Sample Weight (mg)	Carbon Peak Amplitude (mV)	Nitrogen Peak Amplitude (mV)
A12	1139	1.048	3473	3135
A13/F19	1061	1.055	4417	4712
	1062	1.095	4462	4701
A14	1063	1.060	3398	2758
	1064	1.041	4442	4659
A15/F23	1065	1.072	4439	4553
	1066	1.098	4594	4930
A16	1067	1.097	4958	5246
	1068	1.049	4547	4847
A17	1069	1.029	4472	4867
	1070	1.075	4503	4986
A18	1072	1.027	3357	2936
A20/F20	1073	1.049	4057	4445
	1074	1.086	4211	4543
C7	1075	1.021	4396	4678
	1076	1.047	4430	4712
D3	1079	1.065	4367	4686
	1080	1.076	2935	3236
D4	1077	1.062	4402	4548
	1078	1.077	4296	4210
D5	1081a	1.080	2413	2666
	1081b	0.975	1647	1849
	1082a	1.098	4037	4344
	1082b	1.003	2738	3225
D6	1083	1.101	4362	4768
	1084	1.039	4114	4458
D7A/F8	1085	1.059	4246	4580
	1086	1.051	4057	4438
D7B	1288	1.078	4433	4616
	1088	1.052	4296	4666

Table 13. Continued.

Individual (55L28…)	MARC	EA-IRMS Sample Weight (mg)	Carbon Peak Amplitude (mV)	Nitrogen Peak Amplitude (mV)
D8	1089	1.080	4771	5271
	1090	1.055	4640	5121
D10	1091	1.075	4030	4263
	1092	1.039	3823	4001
D11/F11	1093	1.021	3963	4137
	1094	1.002	3736	3950
D12/F9	1095	1.051	3686	3882
	1096	1.031	3447	3582
D14	1097	1.098	3966	4192
	1098	1.080	4676	5027
E6	1099	1.074	3972	4232
	1100	1.094	4066	4314
E7	1101	1.031	4143	4535
	1102	1.079	4306	4739
E8/F22	1103	1.089	4402	4775
	1104	1.080	4536	4864
E9	1109	1.055	4109	4511
	1110	1.075	4394	4689
E12/F26	1105a	1.070	3908	4195
	1105b	1.069	2885	3384
	1289a	1.017	3601	3675
	1289b	0.940	2706	3189
E13	1111a	1.048	4002	4261
	1111b	1.052	3108	3745
	1112a	1.055	4331	4728
	1112b	0.992	3174	3868
E15	1291	1.044	4409	4750
	1114	1.044	4391	4823
E16	1107a	1.047	4126	4425
	1107b	1.029	3071	3686
	1292a	1.046	4212	4390
	1292b	0.970	3037	3623

Table 13. Continued.

Individual (55L28…)	MARC	EA-IRMS Sample Weight (mg)	Carbon Peak Amplitude (mV)	Nitrogen Peak Amplitude (mV)
E18	1115	1.061	4447	4717
	1116	1.015	4183	4315
F12	1117	1.057	4147	4425
	1118	1.081	4490	4784
F18	1119	1.092	3954	4142
	1120	1.060	4462	4740
F24	1121	1.032	4388	4839
	1122	1.039	4476	4867
F25	1123a	1.069	4782	5238
	1123b	1.055	3631	4514
	1124a	1.056	4544	4952
	1124b	0.948	3188	3914
F28	1125a	1.063	4381	4559
	1125b	0.980	3113	3614
	1126a	1.048	4149	4351
	1126b	0.993	3062	3611
F29	1127	1.006	3764	3997
	1128	1.061	3780	4081
F30	1290a	1.036	4029	4168
	1290b	0.999	3193	3823
	1130a	1.034	4380	4749
	1130b	1.034	3301	4004
F32	1131	1.040	4309	4580
	1132	1.079	4484	4833
F33	1133	1.026	3946	4156
	1134	1.012	4001	4135
F34	1135	1.096	4636	5025
	1136	1.097	4632	5046
H3	1293	1.068	3871	3956
	1294	1.091	3945	3982

Table 14. Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of fauna (n=85) with accepted collagen yields and C/N atomic ratios (Table 5). For those specimens analysed from multiple bone samples, the isotopic values presented are averaged from all accepted samples.

Provenience	Animal	Element	MARC	$\delta^{13}C$ ‰ VPDB	$\delta^{15}N$ ‰ AIR
3L20E5-7	Cow	L radial carpal	1295	-20.77	5.24
4L50K12-8	Cow	R rib	1296	-16.93	5.23
4L50L16-4	Cow	unidentified	1297	-22.50	4.90
4L50K16-4	Cow	unidentified	1298	-16.20	7.44
4L58K14-9	Cow	R rib	1299	-21.94	4.99
55L28E16-4	Pig	atlas	501	-18.70	7.17
4L52L12-12	Pig	R maxilla	1300	-14.56	11.01
4L50M14-7	Pig	L mandible	1301	-19.96	7.29
4L58K14-7	Pig	R maxilla	1302	-21.47	9.46
4L50N15-10	Pig	R maxilla	1303	-21.22	5.02
4L58K14-8	Sheep	R humerus	1304	-20.70	4.73
3L19D5-3	Sheep	L radius	1305	-21.15	4.40
4L58K14-6	Sheep	R maxilla	1306	-21.46	7.39
4L22C7-1	Sheep	L mandible	1307	-21.05	6.24
3L22N1-6	Goat	R mandible	1308	-21.12	7.25
3L17Y3-3	Goat	R mandible	1309	-20.65	5.68
3L21E3-3	Cat	tibia	1315	-17.33	10.83
1L34D5-39	Cat	mandible	1316	-16.38	12.65
55L28F6-13	Chicken	radius	497	-18.13	9.73
55L28G7-1	Chicken	scapula	506	-14.97	14.14
55L28G7-3	Chicken	tibiotarsus	508	-14.16	13.40
55L28E10-7	Chicken	coracoid	510	-17.14	8.28
55L28E10-4	Chicken	humerus	512	-17.79	14.99
55L28E19-5	Chicken	coracoid	515	-13.95	13.83
55L28F4-3	Chicken	tibiotarsus	522	-23.51	0.02
55L28E20-51a	Chicken	tibiotarsus	526	-21.51	13.86
55L28E20-51b	Chicken	tibiotarsus	538	-12.66	14.82
55L38G7-5	Turkey	tarsometatarsus	489	-18.88	14.00
55L28E10-8	Turkey	femur	503	-16.39	13.26
55L28G7-6	Turkey	radius	507	-16.83	5.88
4L50M14-5	Goose	L carpometacarpus	1310	-17.29	13.98
3L6N13-1	Goose	sternum	1311	-15.80	6.85

Table 14. Continued.

Provenience	Animal	Element	MARC	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR
4L22C7-2	Duck	L ulna	1312	-19.26	7.11
4L50M14-6	Eider	sternum	1313	-16.45	12.41
4L51N12-10	Spruce Grouse	sternum	1314	-18.04	9.57
55L28E4-17	Avian	carpometacarpus	504	-16.30	15.10
55L28F13-1a	Dove/Robin	L pelvis	531	-16.03	13.73
55L28E4-20a	Dove/Robin	R pelvis	532	-16.43	12.30
55L28F13-1b	Dove/Robin	R pelvis	539	-15.87	14.57
55L28E4-20b	Dove/Robin	L pelvis	540	-16.80	12.52
55L28E7-3	Fish	vertebra	514	-13.98	15.31
55L28E10-12b	Fish	vertebra	541	-14.70	15.38
55L28E10-12c	Fish	vertebra	542	-15.00	14.74
55L28E10-12d	Fish	unidentified	543	-13.94	16.20
55L28E10-12e	Fish	unidentified	544	-14.24	14.39
55L28E10-12f	Fish	unidentified	545	-14.58	14.80
55L28F6-9	Rat	humerus	495	-15.99	14.02
55L28F6-11	Rat	ulna	496	-15.84	13.03
55L28E4-21	Rat	humerus	500	-16.64	12.61
55L28E4-16a	Rat	L mandible	509	-17.01	12.27
55L28F6-12	Rat	femur	511	-16.16	13.72
55L28E4-23b	Rat	L tibia	517	-17.58	10.69
55L28E4-19	Rat	femur	524	-14.17	12.19
55L28E4-16b	Rat	R mandible	536	-16.06	12.55
55L28E4-23a	Rat	L tibia	537	-16.40	13.57
17L45A4-12	Rat	skull	1317	-20.37	7.27
55L28E4-22	Mouse	ulna	499	-14.64	15.64
55L28F13-3	Mouse	scapula	518	-16.47	12.08
55L28E4-18	Mouse	ulna	528	-16.34	14.06
55L28F13-2	Mouse	atlas	533	-16.49	13.63
55L28G7-2	Hare	humerus	519	-14.17	13.79
55L28E10-9	Hare	vertebra	520	-15.93	13.49
55L28E10-6	Hare	pelvis	521	-21.51	6.64
55L28F6-10	Hare	calcaneus	534	-14.70	15.48
55L28F4-2	Hare	scapula	546	-21.92	5.09
4L55X99-2	Hare	mandible	1318	-23.87	1.27

Table 14. Continued.

Provenience	Animal	Element	MARC	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR
4L55X99-1	Hare	mandible	1319	-23.06	1.33
3L17H1-1	Hare	R mandible	1320	-24.14	0.95
55L28E23-25	Red squirrel	tibia	492	-15.32	15.60
55L28E19-3	Red squirrel	ulna	494	-16.26	9.65
55L28E19-4	Red squirrel	ulna	505	-15.17	16.13
55L28F12-3	Red squirrel	radius	513	-13.93	9.48
55L28E4-15	Red squirrel	tibia	523	-16.49	9.02
55L28E10-10	Red squirrel	tibia	529	-18.36	7.62
4L20F11-3	Red Fox	R humerus	1321	-14.37	14.82
3L6N10-9	Red Fox	R mandible	1322	-18.02	12.16
4L51M11-9	Lynx	R femur	1323	-17.09	12.00
55L28G7-4	Deer	trapezoid magnum	491	-21.82	5.69
55L28F6-8	Deer	ulna	498	-16.58	6.11
55L28E9-3	Deer	metatarsal	516	-20.15	6.40
55L28E9-4	Deer	metatarsal	530	-19.13	6.06
4L51J12-3	Deer	L mandible	1324	-20.67	5.48
4L19A5-7	Deer	L mandible	1325	-20.94	4.98
4L20A2-14	Moose	phalanx	1326	-21.99	0.77
3L33D3-55	Caribou	L radius, distal end	1327	-20.37	2.80
			Mean	-17.77	10.03
			Standard Deviation	2.84	4.35
			Range	11.48	16.18

Table 15. Descriptive statistics of faunal $\delta^{13}C$ and $\delta^{15}N$ values (n=85, Table 14).

		$\delta^{13}C$ ‰ VPDB			$\delta^{15}N$ ‰ AIR		
Animal Group	n=	Mean	Standard Deviation	Range	Mean	Standard Deviation	Range
Cow	5	-19.67	2.60	6.30	5.56	0.95	2.54
Pig	5	-19.18	2.51	6.91	7.99	2.06	5.99
Sheep	4	-21.09	0.27	0.76	5.69	1.20	2.99
Goat	2	-20.89	0.24	0.47	6.47	0.79	1.57
Cat	2	-16.86	0.48	0.95	11.74	0.91	1.82
Chicken	9	-17.09	3.41	10.85	11.45	4.60	14.97
Turkey	3	-17.37	1.09	2.49	11.05	3.67	8.12
Goose	2	-16.55	0.74	1.49	10.42	3.57	7.13
Duck	1	-19.26$^{\alpha}$	-	-	7.11$^{\alpha}$	-	-
Eider	1	-16.45$^{\alpha}$	-	-	12.41$^{\alpha}$	-	-
Spruce Grouse	1	-18.04$^{\alpha}$	-	-	9.57$^{\alpha}$	-	-
Avian	1	-16.30$^{\alpha}$	-	-	15.10$^{\alpha}$	-	-
Dove/Robin	4	-16.28	0.36	0.93	13.28	0.92	2.27
Fish	6	-14.41	0.39	1.06	15.14	0.58	1.81
Rat	10	-16.62	1.51	6.20	12.19	1.87	6.75
Mouse	4	-15.99	0.78	1.85	13.85	1.27	3.56
Hare	8	-19.91	3.97	9.97	7.26	5.76	14.53
Red Squirrel	6	-15.92	1.37	4.43	11.25	3.33	8.52
Red fox	2	-16.20	1.83	3.65	13.49	1.33	2.66
Lynx	1	-17.09$^{\alpha}$	-	-	12.00$^{\alpha}$	-	-
Deer	6	-19.88	1.69	5.24	5.79	0.47	1.42
Moose	1	-21.99$^{\alpha}$	-	-	0.77$^{\alpha}$	-	-
Caribou	1	-20.37$^{\alpha}$	-	-	2.80$^{\alpha}$	-	-

$^{\alpha}$ Value does not represent the animal group's mean value but the single isotopic value for the animal type.

Table 16. Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of the Ste. Marie individuals (n=38) with accepted collagen yields and C/N atomic ratios (Table 6). For those individuals analysed from multiple bone samples, the isotopic values presented are averaged from all accepted samples.

Individual (55L28…)	Sex	Age	$\delta^{13}C$ ‰ VPDB	$\delta^{15}N$ ‰ AIR
A13/F19	Male	Adult	-15.95	9.59
A14	Male	Adult	-17.43	9.36
A15/F23	Male	Adult	-17.16	13.67
A16	?	?	-14.14	10.78
A17	?	?	-13.54	8.95
A20/F20	?	?	-20.75	9.66
C7	Male	?	-17.45	12.27
D3	?	?	-18.21	8.72
D4	?	?	-15.68	8.64
D5	?	Adult	-15.52	9.15
D6	Male	Adult	-19.44	11.15
D7A/F8	Female	Adult	-18.64	8.03
D7B	?	Sub-adult	-19.62	8.95
D8	?	?	-17.47	11.02
D10	?	?	-16.58	10.93
D11/F11	Male	Adult	-19.80	7.91
D12/F9	Male	Adult	-16.03	9.03
D14	?	Adult	-16.17	10.39
E6	Male	Adult	-18.48	11.74
E7	Male	Adult	-16.81	10.33
E8/F22	Male	Adult	-18.04	8.50
E9	Male	Adult	-16.03	9.66
E12/F26	Male	Adult	-17.63	8.72
E13	Male	Adult	-12.27	13.18
E15	Male	Adult	-15.54	8.71
E16	?	Adult	-18.65	11.26
E18	Male	Adult	-16.53	7.83
F12	Female	Adult	-19.43	9.89
F18	Male	Adult	-15.58	9.48
F24	Male	Adult	-15.76	8.12
F25	Male	Adult	-13.11	8.58

Table 16. Continued.

Individual (55L28…)	Sex	Age	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR
F28	Male	Adult	-16.42	9.28
F29	Male	Adult	-14.96	7.63
F30	?	Adult	-16.76	14.95
F32	?	Sub-adult	-14.14	8.23
F33	Male	Adult	-19.36	8.82
F34	Male	Adult	-16.22	8.27
H3	Male	Adult	-16.46	9.84
		Mean	-16.78	9.77
		Standard Deviation	1.92	1.67
		Range	8.48	7.32

Table 17. Osteological information (Parish 2006, 2007) and $\delta^{13}C_{Col}$, $\delta^{15}N$, $\delta^{13}C_{Carb}$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ data for the Ste. Marie Individuals. Dental pathologies reported include carious lesions, abscesses, and periodontal disease. Bone pathologies include porotic hyperostosis, periostitis, myositis ossificans, and cribra orbitalia. Indications of muscular strain include bone loss, bone buildup, and woven bone at muscle attachment/insertion sites. Indications of smoking were based on the appearance of pipe wear on teeth. The presence of dental and bone pathologies and indications of muscular strain and smoking for each individual is positively indicated by a star (*).

Individual (55L28…)	Sex	Age	Dental Pathology	Bone Pathology	Muscular Strain	Smoker	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
X99	?	?					-	-	-	-	-
A3	?	Sub-adult	*				-15.95	9.59	-9.29	-5.40	0.712529
A12	?	?					-	-	-6.67	-5.96	0.711672
A13/F19	Male	Adult					-15.95	9.59	-	-	-
A14	Male	Adult					-17.43	9.36	-	-	-
A15/F23	Male	Adult	*				-17.16	13.67	-14.17	-5.11	0.709257
A16	?	?					-14.14	10.78	-	-	-
A17	?	?	*	*			-13.54	8.95	-6.29	-5.73	0.711164
A18	Female	?				*	-	-	-6.21	-7.06	0.710610
A19	Male	?	*			*	-	-	-4.24	-6.07	0.710140
A20/F20	?	?					-20.75	9.66	-	-	-
C7	Male	?					-17.45	12.27	-14.11	-6.23	0.710195
D3	?	?					-18.21	8.72	-	-	-
D4	?	?					-15.68	8.64	-	-	-
D5	?	Adult		*			-15.52	9.15	-	-	-
D6	Male	Adult	*				-19.44	11.15	-13.71	-5.42	0.709956
D7A/F8	Female	Adult	*				-18.64	8.03	-13.80	-3.95	0.712987

Table 17. Continued.

Individual (55L28…)	Sex	Age	Dental Pathology	Bone Pathology	Muscular Strain	Smoker	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
D7B	?	Sub-adult					-19.62	8.95	-	-	-
D8	?	?		*			-17.47	11.02	-	-	-
D9	?	Adult	*				-	-	-7.65	-5.60	0.709574
D10	?	?					-16.58	10.93	-	-	-
D11/F11	Male	Adult	*	*			-19.80	7.91	-13.44	-4.72	0.713716
D12/F9	Male	Adult	*				-16.03	9.03	-8.60	-5.67	0.710335
D13	?	?					-	-	-6.24	-4.82	0.710770
D14	?	Adult		*			-16.17	10.39	-	-	-
E6	Male	Adult	*				-18.48	11.74	-13.93	-5.97	0.710295
E7	Male	Adult	*			*	-16.81	10.33	-13.86	-4.90	0.709653
E8/F22	Male	Adult				*	-18.04	8.50	-11.30	-5.27	0.712269
E9	Male	Adult	*	*			-16.03	9.66	-9.06	-5.35	0.712546
E11	?	?					-	-	-	-	-
E12/F26	Male	Adult	*	*	*		-17.63	8.72	-11.08	-5.03	0.713015
E13	Male	Adult	*	*			-12.27	13.18	-3.20	-5.06	0.709646
E15	Male	Adult	*	*		*	-15.54	8.71	-14.54	-4.39	0.710135
E16	?	Adult	*	*		*	-18.65	11.26	-13.12	-4.98	0.709159
E18	Male	Adult	*	*			-16.53	7.83	-4.79	-4.13	0.710981
F12	Female	Adult	*				-19.43	9.89	-14.02	-4.58	0.708560
F18	Male	Adult	*	*			-15.58	9.48	-6.47	-4.90	0.711469
F24	Male	Adult	*	*			-15.76	8.12	-7.75	-5.02	0.710985

Table 17. Continued.

Individual (55L28…)	Sex	Age	Dental Pathology	Bone Pathology	Muscular Strain	Smoker	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
F25	Male	Adult		*			-13.11	8.58	-5.41	-6.26	0.710842
F28	Male	Adult	*			*	-16.42	9.28	-11.02	-3.88	0.710467
F29	Male	Adult	*	*	*	*	-14.96	7.63	-6.26	-5.23	0.711344
F30	?	Adult	*	*		*	-16.76	14.95	-13.24	-3.20	0.709219
F32	?	Sub-adult			*		-14.14	8.23	-7.43	-5.79	0.712567
F33	Male	Adult	*				-19.36	8.82	-13.96	-4.99	0.709208
F34	Male	Adult					-16.22	8.27	-9.16	-5.38	0.710868
H3	Male	Adult	*	*			-16.46	9.84	-11.43	-5.57	0.709741

Table 18. Faunal $\delta^{13}C$ and $\delta^{18}O$ bioapatite values and $^{87}Sr/^{86}Sr$ values (n=35).

Provenience	Animal	Tooth	MARC	$\delta^{13}C$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	Tooth	MARC	$^{87}Sr/^{86}Sr$
4L50K16-3	Cow	LI^1	1329	-8.85	-7.12	LI^1	1365	0.710683
4L18B9-1	Cow	RM^1	1330	-11.04	-8.27	RM^1	1366	0.712368
3L18D3-1	Cow	RM^3	1331	-13.05	-9.48	RM^3	1367	0.709491
1L36B3-1	Cow	RM^2	1332	-9.59	-8.73	RM^2	1368	0.714752
4L58K14-10	Cow	LM^1	1333	-12.11	-7.71	LM^1	1369	0.713552
4L52L12-12	Pig	RM^2	1334	-5.19	-6.72	RM^2	1370	0.709526
4L50M14-7	Pig	LM_3	1335	-12.64	-8.59	LM_3	1371	0.712540
4L58K14-7	Pig	RM^3	1336	-12.95	-6.67	RM^3	1372	0.710128
4L50N15-10	Pig	RM^2	1337	-13.79	-9.05	RM^2	1373	0.710960
4L58K14-6	Sheep	LM^2	1338	-14.95	-9.16	LM^2	1374	0.709883
4L22C7-1	Sheep	LP_4	1339	-13.06	-6.89	LP_4	1375	0.711099
3L20C2-4	Sheep	M^2	1340	-9.87	-6.99	M^2	1376	0.709329
3L22N1-6	Goat	$RM_?$	1341	-15.39	-7.92	$RM_?$	1377	0.709418
3L17Y3-3	Goat	$RM_?$	1342	-9.62	-9.13	$RM_?$	1378	0.712082
4L20F11-4	Goat	LM_2	1343	-12.66	-7.36	LM_2	1379	0.709329
3L17Y3-4	Goat	LM_3	1344	-11.96	-5.85	LM_3	1380	0.709329
3L22N1-5	Horse	RI^1	1345	-8.05	-8.74	RI^1	1381	0.711021
3L22N1-7	Horse	LI^1	1346	-11.93	-7.50	LI^1	1382	0.710487
1L34D5-39	Cat	LP^4 & LM^1	1347	-11.34	-5.85	LM^1	1383	0.709801
17L45A4-12	Rat	RI^1	1348	-13.06	-6.45	LI^1	1384	0.709888
4L19D7-1	Rat	I^1	1349	-13.24	-5.77	I^1	1385	0.710679
55L28E4-16b	Rat	RI^1	1350	-8.92	-6.42	LI_1	1386	0.710487

Table 18. Continued.

Provenience	Animal	Tooth	MARC	$\delta^{13}C$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	Tooth	MARC	$^{87}Sr/^{86}Sr$
4L55X99-2	Hare	many	1351	-16.37	-8.76	many	1387	0.710613
4L55X99-1	Hare	many	1352	-15.50	-8.86	many	1388	0.711220
3L17H1-1	Hare	many	1353	-15.72	-8.22	many	1389	0.708759
3L17F2-7	Beaver	RP_4	1354	-14.26	-7.24	RP_4	1390	0.709701
3L19C2-6	Beaver	many	1355	-14.10	-8.91	many	1391	0.709938
3L6N10-9	Fox	RM_1	1356	-11.24	-6.15	RM_1	1392	0.709070
3L19B4-3	Lynx	C	1357	-9.99	-6.21	C	1393	0.710061
4L51J12-3	Deer	LP_4	1358	-12.45	-7.14	LP_4	1394	0.709401
4L19A5-7	Deer	LP_3	1359	-12.89	-6.46	LP_3	1395	0.713583
3L22N1-4	Deer	RM_3	1360	-12.68	-6.62	RM_3	1396	0.711345
4L58K11-7	Deer	RM^2	1361	-4.65	-12.18	RM^2	1397	0.709917
3L22N1-8	Deer	LM^1 or ^{2}	1362	-10.87	-4.95	LM^1 or ^{2}	1398	0.713730
4L20A2-11	Moose	LP_2	1363	-11.06	-7.04	LP_2	1399	0.709133
			Mean	-11.86	-7.57			0.710666
			Standard Deviation	2.65	1.50			0.001483
			Range	11.72	7.23			0.005992

Table 19. Descriptive statistics of faunal $\delta^{13}C$ and $\delta^{18}O$ bioapatite values and $^{87}Sr/^{86}Sr$ values (n=35, Table 18).

		$\delta^{13}C$ ‰ VPDB			$\delta^{18}O$ ‰ VPDB			$^{87}Sr/^{86}Sr$		
Animal Group	n=	Mean	Standard Deviation	Range	Mean	Standard Deviation	Range	Mean	Standard Deviation	Range
Cow	5	-10.93	1.55	4.20	-8.26	0.81	2.36	0.712169	0.001897	0.005260
Pig	4	-11.14	3.46	8.60	-7.76	1.08	2.38	0.710788	0.001132	0.003014
Sheep	3	-12.63	2.10	5.08	-7.68	1.05	2.27	0.710104	0.000739	0.001770
Goat	4	-12.41	2.06	5.77	-7.57	1.18	3.28	0.710039	0.001180	0.002754
Horse	2	-9.99	1.94	3.88	-8.12	0.62	1.24	0.710754	0.000267	0.000534
Cat	1	-11.34$^{\alpha}$	-	-	-5.85$^{\alpha}$	-	-	0.709801$^{\alpha}$	-	-
Rat	3	-11.74	2.00	4.32	-6.21	0.31	0.68	0.710351	0.000337	0.000790
Hare	3	-15.86	0.37	0.87	-8.61	0.28	0.64	0.710197	0.001047	0.002460
Beaver	2	-14.18	0.08	0.16	-8.08	0.84	1.67	0.709819	0.000118	0.000237
Fox	1	-11.24$^{\alpha}$	-	-	-6.15$^{\alpha}$	-	-	0.709070$^{\alpha}$	-	-
Lynx	1	-9.99$^{\alpha}$	-	-	-6.21$^{\alpha}$	-	-	0.710061$^{\alpha}$	-	-
Deer	5	-10.71	3.11	8.24	-7.14	-7.47	2.47	0.711595	0.001800	0.004329
Moose	1	-11.06$^{\alpha}$	-	-	-7.04$^{\alpha}$	-	-	0.709133$^{\alpha}$	-	-

$^{\alpha}$ Value does not represent the animal group's mean but the single isotopic value for the animal type.

Table 20. $\delta^{13}C$ and $\delta^{18}O$ bioapatite values and $^{87}Sr/^{86}Sr$ values of the Ste. Marie individuals (n=33).

Individual (55L28…)	Tooth	MARC	$\delta^{13}C$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	Tooth	MARC	$^{87}Sr/^{86}Sr$
A3	LM^1	1424	-9.29	-5.40	LC^1	1652	0.712529
A12	$M_{2\ OR\ 3}$	1425	-6.67	-5.96	LM_3	1653	0.711672
A15/F23	RM^3	1426	-14.17	-5.11	RM^3	1654	0.709257
A17	RM^3	1427	-6.29	-5.73	RM^1	1655	0.711164
A18	RM_1	1428	-6.21	-7.06	LM^2	1656	0.710610
A19	RM_1	1429	-4.24	-6.07	RM_2	1657	0.710140
C7	RI^1	1430	-14.11	-6.23	RI^1	1658	0.710195
D6	LM_1	1431	-13.71	-5.42	LP_3	1659	0.709956
D7A/F8	LM_1	1432	-13.80	-3.95	LM_1	1660	0.712987
D9	RI^1	1433	-7.65	-5.60	RM^1	1661	0.709574
D11/F11	RI^1	1434	-13.44	-4.72	RM_3	1662	0.713716
D12/F9	RM_3	1435	-8.60	-5.67	RM_2	1663	0.710335
D13	RC^1	1436	-6.24	-4.82	RM^1	1664	0.710770
E6	RM_1	1437	-13.93	-5.97	RM_1	1665	0.710295
E7	RM_2	1438	-13.86	-4.90	RM_2	1666	0.709653
E8/F22	LP^4	1439	-11.30	-5.27	RM^2	1667	0.712269
E9	RM^3	1442	-9.06	-5.35	LM^3	1668	0.712546
E12/F26	LM^2	1440	-11.08	-5.03	LM^2	1669	0.713015
E13	LM_2	1443	-3.20	-5.06	LM_2	1670	0.709646
E15	LP_3	1444	-14.54	-4.39	RM_3	1671	0.710135
E16	RM_2	1441	-13.12	-4.98	LM^1	1672	0.709159
E18	LM_1	1445	-4.79	-4.13	RM^1	1673	0.710981

Table 20. Continued.

Individual (55L28…)	Tooth	MARC	δ^{13}C ‰ VPDB	δ^{18}O ‰ VPDB	Tooth	MARC	^{87}Sr/^{86}Sr
F12	LI_1	1446	-14.02	-4.58	RI^1	1674	0.708560
F18	RP_4	1447	-6.47	-4.90	LM_3	1675	0.711469
F24	RM_2	1448	-7.75	-5.02	RM_2	1676	0.710985
F25	LM_1	1449	-5.41	-6.26	LM^2	1677	0.710842
F28	RM^3	1450	-11.02	-3.88	LM^1	1678	0.710467
F29	RC_1	1451	-6.26	-5.23	$LM_{1\ or\ 2}$	1679	0.711344
F30	RI^1	1452	-13.24	-3.20	LM^3	1680	0.709219
F32	RM^1	1453	-7.43	-5.79	RM^1	1681	0.712567
F33	RM^3	1454	-13.96	-4.99	RM^2	1682	0.709208
F34	RM^2	1455	-9.16	-5.38	RM^2	1683	0.710868
H3	RM^1	1456	-11.43	-5.57	RM^1	1684	0.709741
		Mean	-9.86	-5.20			0.710784
		Standard Deviation	3.53	0.76			0.001281
		Range	11.34	3.86			0.005157

Table 21. $\delta^{13}C_{Col}$, $\delta^{15}N$, $\delta^{13}C_{Carb}$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ data and date associations of all faunal specimens (n=102, Tables 14 and 18).

Provenience	Animal	Date Association	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
3L20E5-7	Cow	1720 - 1724	-20.77	5.24	-	-	-
4L50K12-8	Cow	1744	-16.93	5.23	-	-	-
4L50L16-4	Cow	1744	-22.50	4.90	-	-	-
4L50K16-4	Cow	1744	-16.20	7.44	-	-	-
4L58K14-9	Cow	1713-1728	-21.94	4.99	-	-	-
4L50K16-3	Cow	1744	-	-	-8.85	-7.12	0.710683
4L18B9-1	Cow	1713 - 1731	-	-	-11.04	-8.27	0.712368
3L18D3-1	Cow	1725 - 1734	-	-	-13.05	-9.48	0.709491
1L36B3-1	Cow	1713 - 1745	-	-	-9.59	-8.73	0.714752
4L58K14-10	Cow	1713 - 1728	-	-	-12.11	-7.71	0.713552
55L28E16-4	Pig	<1745	-18.70	7.17	-	-	-
4L52L12-12	Pig	1744	-14.56	11.01	-5.19	-6.72	0.709526
4L50M14-7	Pig	1715 - 1718	-19.96	7.29	-12.64	-8.59	0.712540
4L58K14-7	Pig	1713 - 1728	-21.47	9.46	-12.95	-6.67	0.710128
4L50N15-10	Pig	1715 - 1724	-21.22	5.02	-13.79	-9.05	0.710960
4L58K14-8	Sheep	1713 - 1728	-20.70	4.73	-	-	-
3L19D5-3	Sheep	1723-1724	-21.15	4.40	-	-	-
4L58K14-6	Sheep	1713-1718	-21.46	7.39	-14.95	-9.16	0.709883
4L22C7-1	Sheep	1713	-21.05	6.24	-13.06	-6.89	0.711099
3L20C2-4	Sheep	1719 - 1725	-	-	-9.87	-6.99	0.709329

Table 21. Continued.

Provenience	Animal	Date Association	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
3L22N1-6	Goat	1725-1767	-21.12	7.25	-15.39	-7.92	0.709418
3L17Y3-3	Goat	1725-1767	-20.65	5.68	-9.62	-9.13	0.712082
4L20F11-4	Goat	1713 - 1731	-	-	-12.66	-7.36	0.709329
3L17Y3-4	Goat	1725 - 1767	-	-	-11.96	-5.85	0.709329
3L22N1-5	Horse	1725 - 1767	-	-	-8.05	-8.74	0.711021
3L22N1-7	Horse	1725 - 1767	-	-	-11.93	-7.50	0.710487
3L21E3-3	Cat	1713 - 1725	-17.33	10.83	-	-	-
1L34D5-39	Cat	-	-16.38	12.65	-11.34	-5.85	0.709801
55L28F6-13	Chicken	<1745	-18.13	9.73	-	-	-
55L28G7-1	Chicken	<1745	-14.97	14.14	-	-	-
55L28G7-3	Chicken	<1745	-14.16	13.40	-	-	-
55L28E10-7	Chicken	<1745	-17.14	8.28	-	-	-
55L28E19-5	Chicken	<1745	-13.95	13.83	-	-	-
55L28F4-3	Chicken	<1745	-23.51	0.02	-	-	-
55L28E20-51a	Chicken	<1745	-21.51	13.86	-	-	-
55L28E10-4	Chicken	<1745	-17.79	14.99	-	-	-
55L38G7-5	Turkey	<1745	-18.88	14.00	-	-	-
55L28E10-8	Turkey	<1745	-16.39	13.26	-	-	-
55L28G7-6	Turkey	<1745	-16.83	5.88	-	-	-
4L50M14-5	Goose	1715 - 1718	-17.29	13.98	-	-	-
3L6N13-1	Goose	1725 - 1758	-15.80	6.85	-	-	-

Table 21. Continued.

Provenience	Animal	Date Association	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
4L22C7-2	Duck	1713	-19.26	7.11	-	-	-
4L50M14-6	Eider	1715 - 1718	-16.45	12.41	-	-	-
4L51N12-10	Spruce Grouse	1715 - 1718	-18.04	9.57	-	-	-
55L28E4-17	Avian	<1745	-16.30	15.10	-	-	-
55L28F13-1a	Dove/Robin	<1745	-16.03	13.73	-	-	-
55L28E4-20a	Dove/Robin	<1745	-16.43	12.30	-	-	-
55L28F13-1b	Dove/Robin	<1745	-15.87	14.57	-	-	-
55L28E4-20b	Dove/Robin	<1745	-16.80	12.52	-	-	-
55L28E7-3	Fish	<1745	-13.98	15.31	-	-	-
55L28E10-12b	Fish	<1745	-14.70	15.38	-	-	-
55L28E10-12c	Fish	<1745	-15.00	14.74	-	-	-
55L28E10-12d	Fish	<1745	-13.94	16.20	-	-	-
55L28E10-12e	Fish	<1745	-14.24	14.39	-	-	-
55L28E10-12f	Fish	<1745	-14.58	14.80	-	-	-
55L28F6-9	Rat	~<1745	-15.99	14.02	-	-	-
55L28F6-11	Rat	~<1745	-15.84	13.03	-	-	-
55L28E4-21	Rat	~<1745	-16.64	12.61	-	-	-
55L28E4-16a	Rat	~<1745	-17.01	12.27	-	-	-
55L28F6-12	Rat	~<1745	-16.16	13.72	-	-	-
55L28E4-19	Rat	~<1745	-14.17	12.19	-	-	-
55L28E4-16b	Rat	~<1745	-16.06	12.55	-8.92	-6.42	0.710487

Table 21. Continued.

Provenience	Animal	Date Association	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
55L28E4-23a	Rat	~<1745	-16.40	13.57	-	-	-
55L28E4-23b	Rat	~<1745	-17.58	10.69	-	-	-
17L45A4-12	Rat	1751 - 1784	-20.37	7.27	-13.06	-6.45	0.709888
4L19D7-1	Rat	-	-	-	-13.24	-5.77	0.710679
55L28E4-22	Mouse	~<1745	-14.64	15.64	-	-	-
55L28F13-3	Mouse	~<1745	-16.47	12.08	-	-	-
55L28E4-18	Mouse	~<1745	-16.34	14.06	-	-	-
55L28F13-2	Mouse	~<1745	-16.49	13.63	-	-	-
55L28G7-2	Hare	<1745	-14.17	13.79	-	-	-
55L28E10-9	Hare	<1745	-15.93	13.49	-	-	-
55L28E10-6	Hare	<1745	-21.51	6.64	-	-	-
55L28F6-10	Hare	<1745	-14.70	15.48	-	-	-
55L28F4-2	Hare	<1745	-21.92	5.09	-	-	-
4L55X99-2	Hare	1713 - 1787	-23.87	1.27	-16.37	-8.76	0.710613
4L55X99-1	Hare	1713 - 1787	-23.06	1.33	-15.50	-8.86	0.711220
3L17H1-1	Hare	1784 - 1974	-24.14	0.95	-15.72	-8.22	0.708759
3L17F2-7	Beaver	1784 - 1974	-	-	-14.26	-7.24	0.709701
3L19C2-6	Beaver	1774 - 1778	-	-	-14.10	-8.91	0.709938
55L28E23-25	Red squirrel	<1745	-15.32	15.60	-	-	-
55L28E19-3	Red squirrel	<1745	-16.26	9.65	-	-	-
55L28E19-4	Red squirrel	<1745	-15.17	16.13	-	-	-

Table 21. Continued.

Provenience	Animal	Date Association	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
55L28F12-3	Red squirrel	<1745	-13.93	9.48	-	-	-
55L28E4-15	Red squirrel	<1745	-16.49	9.02	-	-	-
55L28E10-10	Red squirrel	<1745	-18.36	7.62	-	-	-
4L20F11-3	Red Fox	1713 - 1731	-14.37	14.82	-	-	-
3L6N10-9	Red Fox	1774 - 1784	-18.02	12.16	-11.24	-6.15	0.709070
4L51M11-9	Lynx	<1745	-17.09	12.00	-	-	-
3L19B4-3	Lynx	1758 - 1785	-	-	-9.99	-6.21	0.710061
55L28G7-4	Deer	<1745	-21.82	5.69	-	-	-
55L28F6-8	Deer	<1745	-16.58	6.11	-	-	-
55L28E9-4	Deer	<1745	-19.13	6.06	-	-	-
55L28E9-3	Deer	<1745	-20.15	6.40	-	-	-
4L51J12-3	Deer	1744	-20.67	5.48	-12.45	-7.14	0.709401
4L19A5-7	Deer	1758 - 1784	-20.94	4.98	-12.89	-6.46	0.713583
3L22N1-4	Deer	1725 - 1767	-	-	-12.68	-6.62	0.711345
4L58K11-7	Deer	1744 - 1758	-	-	-4.65	-12.18	0.709917
3L22N1-8	Deer	1725 - 1767	-	-	-10.87	-4.95	0.713730
4L20A2-14	Moose	1745 - 1784	-21.99	0.77	-	-	-
4L20A2-11	Moose	1745 - 1784	-	-	-11.06	-7.04	0.709133
3L33D3-55	Caribou	1758 - 1784	-20.37	2.80	-	-	-

Table 22. $\delta^{13}C_{Col}$, $\delta^{15}N$, $\delta^{13}C_{Carb}$, $\delta^{18}O$, and $^{87}Sr/^{86}Sr$ values of all individuals sampled (n=44, Tables 16 and 20).

Individual (55L28…)	Sex	Age Group	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
A3	?	Sub-adult	-	-	-9.29	-5.40	0.712529
A12	?	?	-	-	-6.67	-5.96	0.711672
A13/F19	Male	Adult	-15.95	9.59	-	-	-
A14	Male	Adult	-17.43	9.36	-	-	-
A15/F23	Male	Adult	-17.16	13.67	-14.17	-5.11	0.709257
A16	?	?	-14.14	10.78	-	-	-
A17	?	?	-13.54	8.95	-6.29	-5.73	0.711164
A18	Female	?	-	-	-6.21	-7.06	0.710610
A19	Male	?	-	-	-4.24	-6.07	0.710140
A20/F20	?	?	-20.75	9.66	-	-	-
C7	Male	?	-17.45	12.27	-14.11	-6.23	0.710195
D3	?	?	-18.21	8.72	-	-	-
D4	?	?	-15.68	8.64	-	-	-
D5	?	Adult	-15.52	9.15	-	-	-
D6	Male	Adult	-19.44	11.15	-13.71	-5.42	0.709956
D7A/F8	Female	Adult	-18.64	8.03	-13.80	-3.95	0.712987
D7B	?	Sub-adult	-19.62	8.95	-	-	-
D8	?	?	-17.47	11.02	-	-	-
D9	?	Adult	-	-	-7.65	-5.60	0.709574
D10	?	?	-16.58	10.93	-	-	-
D11/F11	Male	Adult	-19.80	7.91	-13.44	-4.72	0.713716
D12/F9	Male	Adult	-16.03	9.03	-8.60	-5.67	0.710335
D13	?	?	-	-	-6.24	-4.82	0.710770
D14	?	Adult	-16.17	10.39	-	-	-
E6	Male	Adult	-18.48	11.74	-13.93	-5.97	0.710295
E7	Male	Adult	-16.81	10.33	-13.86	-4.90	0.709653
E8/F22	Male	Adult	-18.04	8.50	-11.30	-5.27	0.712269
E9	Male	Adult	-16.03	9.66	-9.06	-5.35	0.709646
E12/F26	Male	Adult	-17.63	8.72	-11.08	-5.03	0.712546
E13	Male	Adult	-12.27	13.18	-3.20	-5.06	0.710135
E15	Male	Adult	-15.54	8.71	-14.54	-4.39	0.709159
E16	?	Adult	-18.65	11.26	-13.12	-4.98	0.713015

Table 22. Continued.

Individual (55L28…)	Sex	Age Group	$\delta^{13}C_{Col}$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	$\delta^{13}C_{Carb}$ ‰ VPDB	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
E18	Male	Adult	-16.53	7.83	-4.79	-4.13	0.710981
F12	Female	Adult	-19.43	9.89	-14.02	-4.58	0.708560
F18	Male	Adult	-15.58	9.48	-6.47	-4.90	0.711469
F24	Male	Adult	-15.76	8.12	-7.75	-5.02	0.710985
F25	Male	Adult	-13.11	8.58	-5.41	-6.26	0.710842
F28	Male	Adult	-16.42	9.28	-11.02	-3.88	0.710467
F29	Male	Adult	-14.96	7.63	-6.26	-5.23	0.711344
F30	?	Adult	-16.76	14.95	-13.24	-3.20	0.709219
F32	?	Sub-adult	-14.14	8.23	-7.43	-5.79	0.712567
F33	Male	Adult	-19.36	8.82	-13.96	-4.99	0.709208
F34	Male	Adult	-16.22	8.27	-9.16	-5.38	0.710868
H3	Male	Adult	-16.46	9.84	-11.43	-5.57	0.709741

Table 23. $\delta^{13}C$ and $\delta^{15}N$ values of the Ste. Marie individuals (n=38) and the sample pair bone elements analysed (Table 11). The bone elements analysed are positively indicated with a star (*).

			Sample Pair Bone Elements			
Individual (55L28…)	$\delta^{13}C$ ‰ VPDB	$\delta^{15}N$ ‰ AIR	Ribs	Long Bones of Arm and/or Leg	Rib and Arm/Leg Long Bone	Unidentified Fragments
A13/F19	-15.95	9.59	*			
A14	-17.43	9.36	*			
A15/F23	-17.16	13.67			*	
A16	-14.14	10.78		*		
A17	-13.54	8.95		*		
A20/F20	-20.75	9.66		*		
C7	-17.45	12.27				*
D3	-18.21	8.72				*
D4	-15.68	8.64				*
D5	-15.52	9.15		*		
D6	-19.44	11.15	*			
D7A/F8	-18.64	8.03	*			
D7B	-19.62	8.95	*			
D8	-17.47	11.02		*		
D10	-16.58	10.93		*		
D11/F11	-19.80	7.91	*			
D12/F9	-16.03	9.03		*		
D14	-16.17	10.39			*	
E6	-18.48	11.74	*			
E7	-16.81	10.33	*			
E8/F22	-18.04	8.50	*			
E9	-16.03	9.66		*		
E12/F26	-17.63	8.72	*			
E13	-12.27	13.18	*			
E15	-15.54	8.71	*			
E16	-18.65	11.26	*			
E18	-16.53	7.83	*			
F12	-19.43	9.89	*			
F18	-15.58	9.48	*			

Table 23. Continued.

			Sample Pair Bone Elements			
Individual (55L28…)	δ^{13}C ‰ VPDB	δ^{15}N ‰ AIR	Ribs	Long Bones of Arm and/or Leg	Rib and Arm/Leg Long Bone	Unidentified Fragments
F24	-15.76	8.12	*			
F25	-13.11	8.58		*		
F28	-16.42	9.28		*		
F29	-14.96	7.63	*			
F30	-16.76	14.95	*			
F32	-14.14	8.23	*			
F33	-19.36	8.82	*			
F34	-16.22	8.27	*			
H3	-16.46	9.84	*			
		n=	23	10	2	3
		%	61	26	5	8

Table 24. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of wild fauna (n=9, Table 21) used to define the Louisbourg oxygen and strontium ranges. Also shown are the descriptive statistics including the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges.

Provenience	Animal	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$
17L45A4-12	Rat	-6.45	0.709888
4L19D7-1	Rat	-5.77	0.710679
55L28E4-16b	Rat	-6.42	0.710487
4L55X99-2	Hare	-8.76	0.710613
4L55X99-1	Hare	-8.86	0.711220
3L17H1-1	Hare	-8.22	0.708759
3L17F2-7	Beaver	-7.24	0.709701
3L19C2-6	Beaver	-8.91	0.709938
3L6N10-9	Fox	-6.15	0.709070
	Mean	-7.42	0.710039
	2σ	2.41	0.001499
	2σ range	4.81	0.002999
	2σ minimum	-9.83	0.708540
	2σ maximum	-5.01	0.711539

Table 25. Faunal $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values (n=35, Table 21) and their isotopic orientation relative to the oxygen and strontium 2σ ranges (Figure 40 and Table 24). Specimens within the 2σ ranges vs. outside the 2σ ranges are indicated with a star (*). Also shown are those specimens with A: $^{87}Sr/^{86}Sr$ values within the strontium 2σ range but with $\delta^{18}O$ values lower than the oxygen 2σ range, B: $\delta^{18}O$ values within the oxygen 2σ range but with $^{87}Sr/^{86}Sr$ values higher than the strontium 2σ range and, C: $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values higher than the oxygen and strontium 2σ ranges.

Provenience	Animal	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$	Within 2σ Ranges	Outside 2σ Ranges	A	B	C
4L50K16-3	Cow	-7.12	0.710683	*				
4L18B9-1	Cow	-8.27	0.712368		*		*	
3L18D3-1	Cow	-9.48	0.709491	*				
1L36B3-1	Cow	-8.73	0.714752		*		*	
4L58K14-10	Cow	-7.71	0.713552		*		*	
4L52L12-12	Pig	-6.72	0.709526	*				
4L50M14-7	Pig	-8.59	0.712540		*		*	
4L58K14-7	Pig	-6.67	0.710128	*				
4L50N15-10	Pig	-9.05	0.710960	*				
4L58K14-6	Sheep	-9.16	0.709883	*				
4L22C7-1	Sheep	-6.89	0.711099	*				
3L20C2-4	Sheep	-6.99	0.709329	*				
3L22N1-6	Goat	-7.92	0.709418	*				
3L17Y3-3	Goat	-9.13	0.712082		*		*	
4L20F11-4	Goat	-7.36	0.709329	*				
3L17Y3-4	Goat	-5.85	0.709329	*				
3L22N1-5	Horse	-8.74	0.711021	*				
3L22N1-7	Horse	-7.50	0.710487	*				
1L34D5-39	Cat	-5.85	0.709801	*				
17L45A4-12	Rat	-6.45	0.709888	*				
4L19D7-1	Rat	-5.77	0.710679	*				
55L28E4-16b	Rat	-6.42	0.710487	*				
4L55X99-2	Hare	-8.76	0.710613	*				
4L55X99-1	Hare	-8.86	0.711220	*				
3L17H1-1	Hare	-8.22	0.708759	*				
3L17F2-7	Beaver	-7.24	0.709701	*				
3L19C2-6	Beaver	-8.91	0.709938	*				

Table 25. Continued.

Provenience	Animal	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$	Within 2σ Ranges	Outside 2σ Ranges	A	B	C
3L6N10-9	Fox	-6.15	0.709070	*				
3L19B4-3	Lynx	-6.21	0.710061	*				
4L51J12-3	Deer	-7.14	0.709401	*				
4L19A5-7	Deer	-6.46	0.713583		*		*	
3L22N1-4	Deer	-6.62	0.711345	*				
4L58K11-7	Deer	-12.18	0.709917		*	*		
3L22N1-8	Deer	-4.95	0.713730		*			*
4L20A2-11	Moose	-7.04	0.709133	*				
			n=	27	8	1	6	1
			%	77	23	3	17	3

Table 26. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (n=33, Table 22) and their isotopic orientation relative to the oxygen and strontium 2σ ranges (Figure 41 and Table 24). Individuals within the 2σ ranges vs. outside the 2σ ranges are indicated with a star (*). Also shown are those individuals with A: $^{87}Sr/^{86}Sr$ values within the strontium 2σ range but with $\delta^{18}O$ values lower than the oxygen 2σ range, B: $\delta^{18}O$ values within the oxygen 2σ range but with $^{87}Sr/^{86}Sr$ values higher than the strontium 2σ range and, C: $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values higher than the oxygen and strontium 2σ ranges.

Individual (55L28…)	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$	Within 2σ Ranges	Outside 2σ Ranges	A	B	C
A3	1424	0.712529		*	*		
A12	1425	0.711672		*	*		
A15/F23	1426	0.709257	*				
A17	1427	0.711164	*				
A18	1428	0.710610	*				
A19	1429	0.710140	*				
C7	1430	0.710195	*				
D6	1431	0.709956	*				
D7A/F8	1432	0.712987		*		*	
D9	1433	0.709574	*				
D11/F11	1434	0.713716		*		*	
D12/F9	1435	0.710335	*				
D13	1436	0.710770		*			*
E6	1437	0.710295	*				
E7	1438	0.709653		*			*
E8/F22	1439	0.712269		*	*		
E9	1442	0.712546	*				
E12/F26	1440	0.713015		*	*		
E13	1443	0.709646	*				
E15	1444	0.710135		*			*
E16	1441	0.709159		*		*	
E18	1445	0.710981		*			*
F12	1446	0.708560		*			*
F18	1447	0.711469		*			*
F24	1448	0.710985	*				
F25	1449	0.710842	*				

Table 26. Continued.

Individual (55L28…)	$\delta^{18}O$ ‰ VPDB	$^{87}Sr/^{86}Sr$	Within 2σ Ranges	Outside 2σ Ranges	A	B	C
F28	1450	0.710467		*			*
F29	1451	0.711344	*				
F30	1452	0.709219		*			*
F32	1453	0.712567		*	*		
F33	1454	0.709208		*			*
F34	1455	0.710868	*				
H3	1456	0.709741	*				
		n=	16	17	5	3	9
		%	48	52	15	9	27

Table 27. Calculated drinking water $\delta^{18}O$ values of the Ste. Marie individuals (n=33, Table 22).

Individual (55L28…)	$^{87}Sr/^{86}Sr$	$\delta^{18}O_E$ ‰ VPDB	$\delta^{18}O_{DW}$ ‰ VSMOW
A3	0.712529	-5.40	-8.34
A12	0.711672	-5.96	-9.26
A15/F23	0.709257	-5.11	-7.86
A17	0.711164	-5.73	-8.88
A18	0.710610	-7.06	-11.06
A19	0.710140	-6.07	-9.44
C7	0.710195	-6.23	-9.70
D6	0.709956	-5.42	-8.37
D7A/F8	0.712987	-3.95	-5.96
D9	0.709574	-5.60	-8.67
D11/F11	0.713716	-4.72	-7.22
D12/F9	0.710335	-5.67	-8.78
D13	0.710770	-4.82	-7.39
E6	0.710295	-5.97	-9.27
E7	0.709653	-4.90	-7.52
E8/F22	0.712269	-5.27	-8.13
E9	0.712546	-5.35	-8.26
E12/F26	0.713015	-5.03	-7.73
E13	0.709646	-5.06	-7.78
E15	0.710135	-4.39	-6.68
E16	0.709159	-4.98	-7.65
E18	0.710981	-4.13	-6.26
F12	0.708560	-4.58	-6.99
F18	0.711469	-4.90	-7.52
F24	0.710985	-5.02	-7.72
F25	0.710842	-6.26	-9.75
F28	0.710467	-3.88	-5.85
F29	0.711344	-5.23	-8.06
F30	0.709219	-3.20	-4.73
F32	0.712567	-5.79	-8.98
F33	0.709208	-4.99	-7.67
F34	0.710868	-5.38	-8.31
H3	0.709741	-5.57	-8.62

Table 28. Precipitation $\delta^{18}O$ values for areas of Canada, France, Switzerland, Germany, USA, England, and Scotland. Cited from the IAEA/WMO (2013) database unless otherwise indicated.

Site Location	$\delta^{18}O_{PPT}$ ‰ VSMOW	Sampling Period
Truro, Nova Scotia, Canada	-9.23	1975 – 1983
Dax, France	-4.92	1999 – 2005
Breast, France	-4.84	1996 – 2002
Orléans, France	-6.17	1996 – 2005
Bern, Switzerland	-9.94	1969 – 2008
Berlin, Germany	-7.97	1978 – 2005
Ste. Agathe, Quebec, Canada	-12.66	1975 – 1982
St. John's, Newfoundland, Canada[1]	-8.38	1994 – 1995
Hanover, New Hampshire, USA	-8.83	1997 – 1998
New Haven, Connecticut, USA[2]	-7.63	2003 – 2004
Wallingford, England	-6.67	1979 – 2007
Inchnadamph, Scotland	-6.53	2003 – 2005

[1] Jamieson and Wadleigh 1999. [2] Lee et al. 2006.

Figures

Figure 1. The location of the Fortress of Louisbourg on Cape Breton Island, Nova Scotia, Canada. Adapted from Google™ Earth by the author.

Figure 2. Aerial photograph of the Fortress of Louisbourg and Rochefort Point showing the location of the feature. (Duggan 2010).

Figure 3. Exposed corner of dry laid stone feature on Rochefort Point. Trowel indicates north. (Duggan 2010).

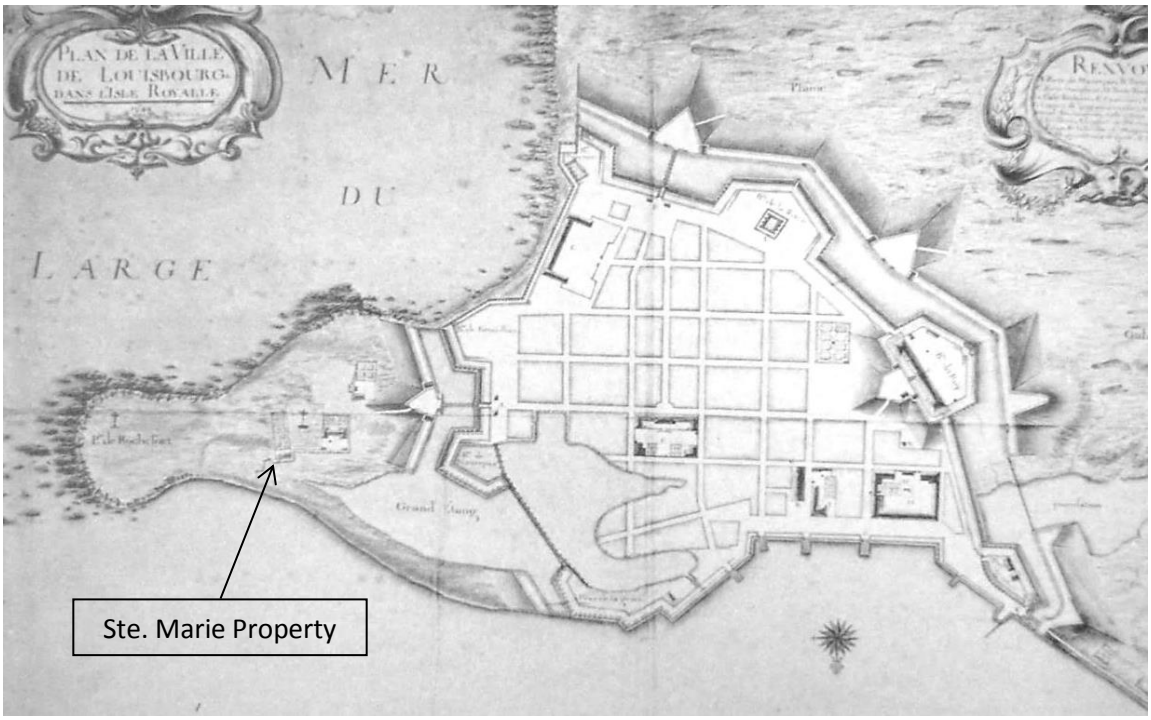


Figure 4. Plan of Louisbourg in 1744 (Fry 1984) with the Ste. Marie property indicated.

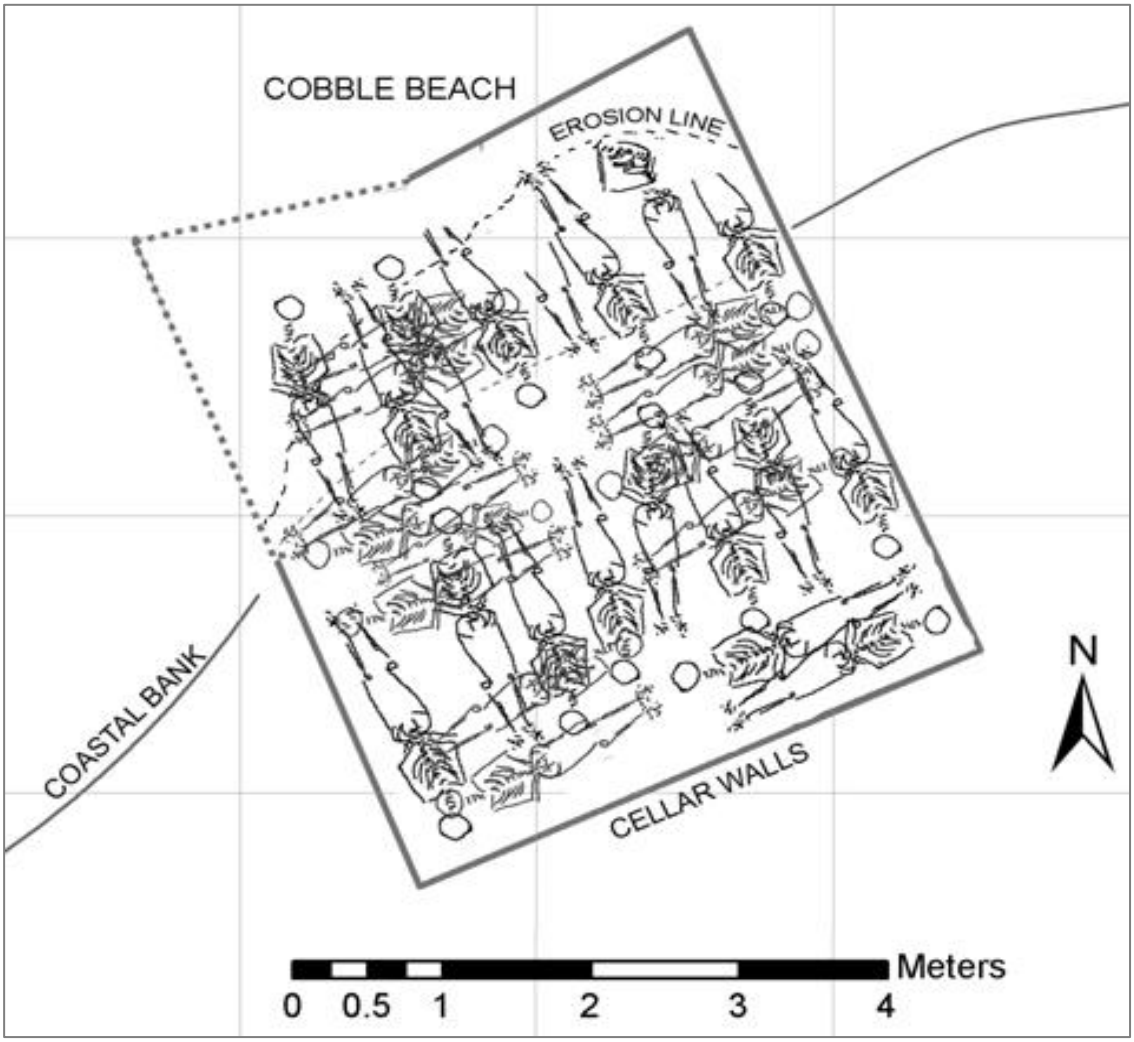


Figure 5. Plan view drawing of skeletal remains within the root cellar (Duggan 2007).

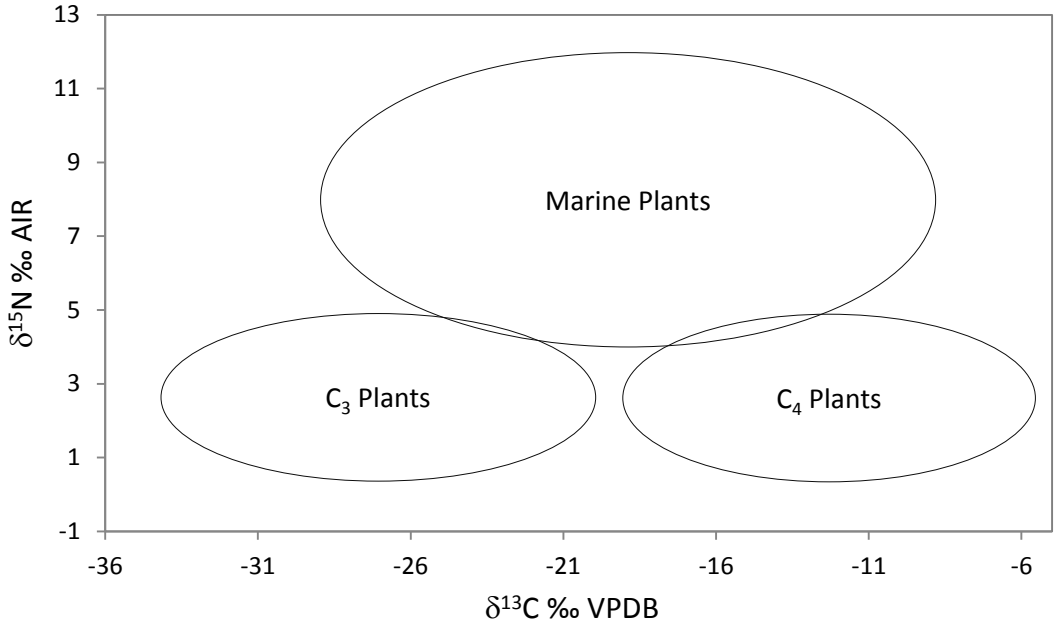


Figure 6. Approximate $\delta^{13}C$ and $\delta^{15}N$ values for C_3, C_4, and marine plants.

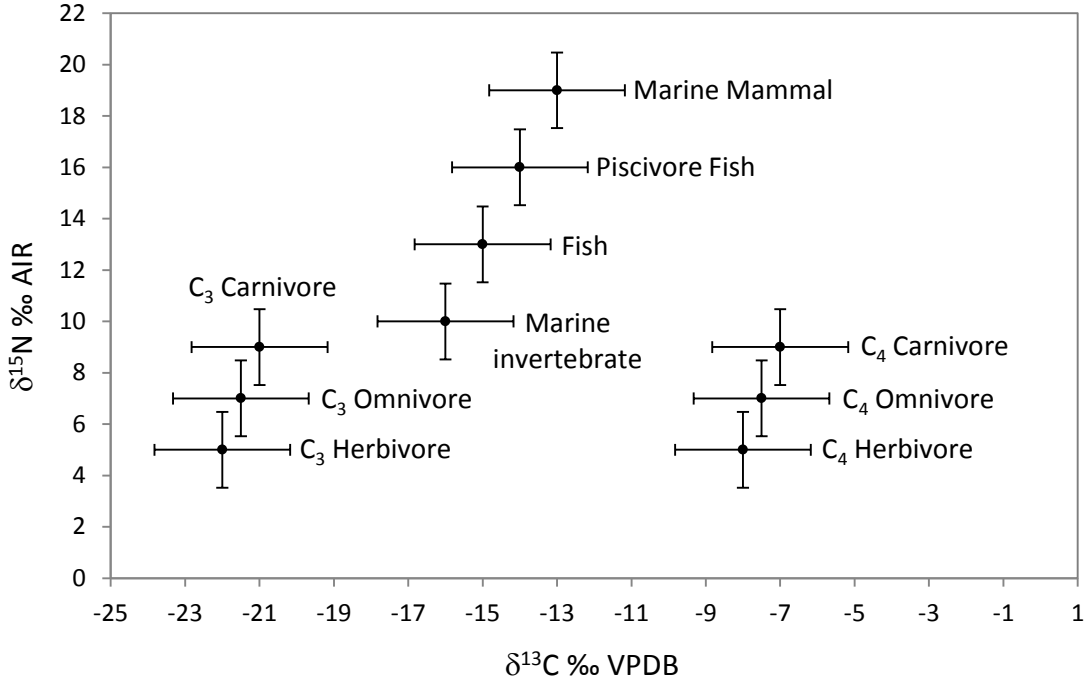


Figure 7. Theoretical trophic levels for C_3, C_4, and marine environments.

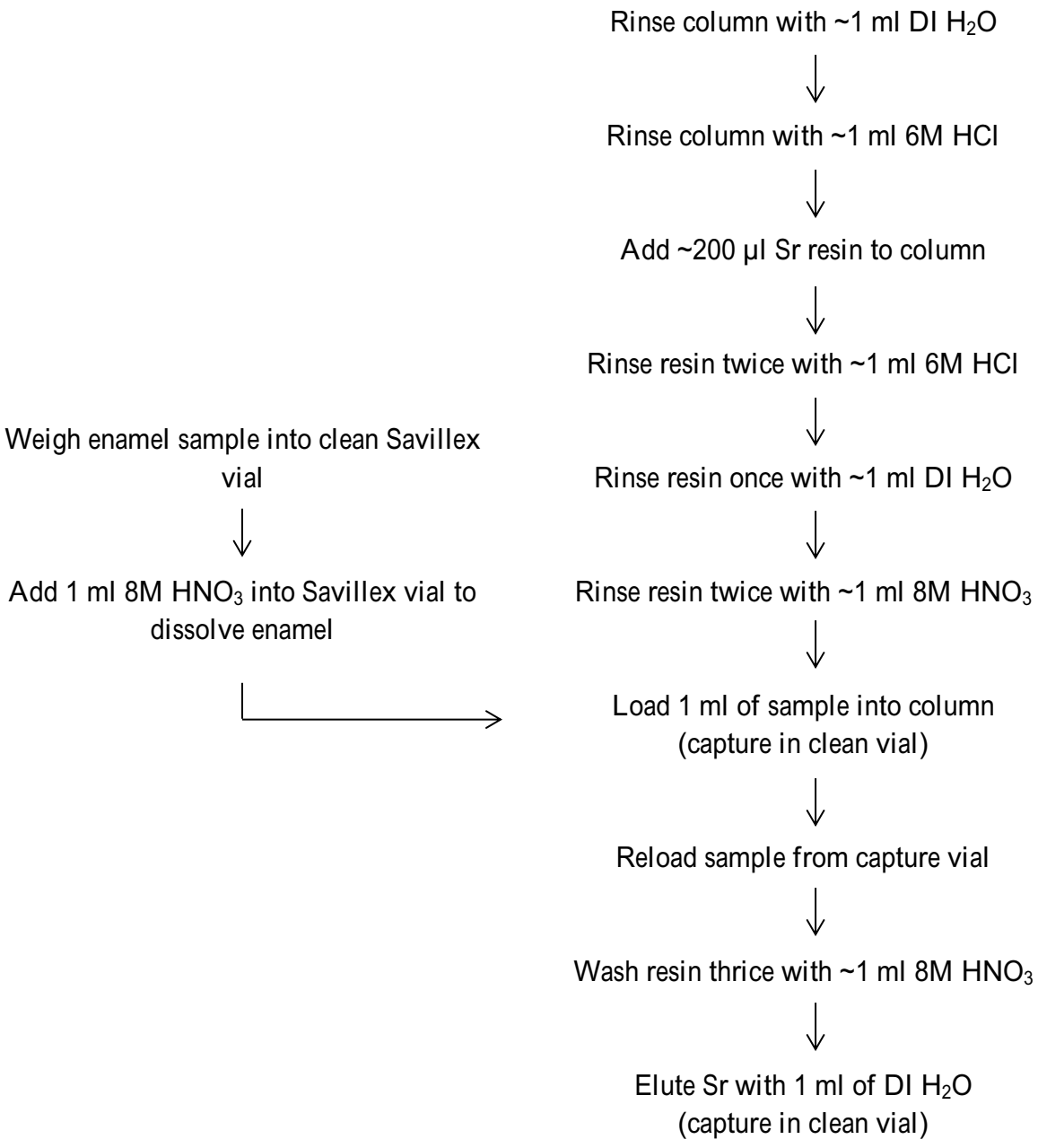
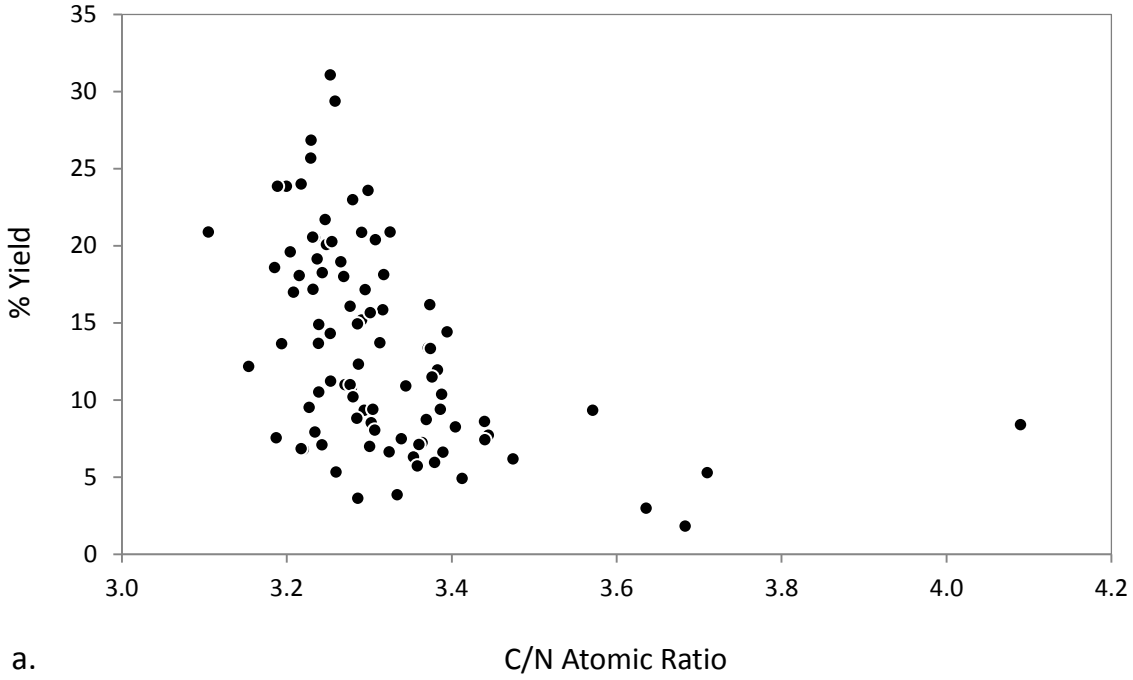
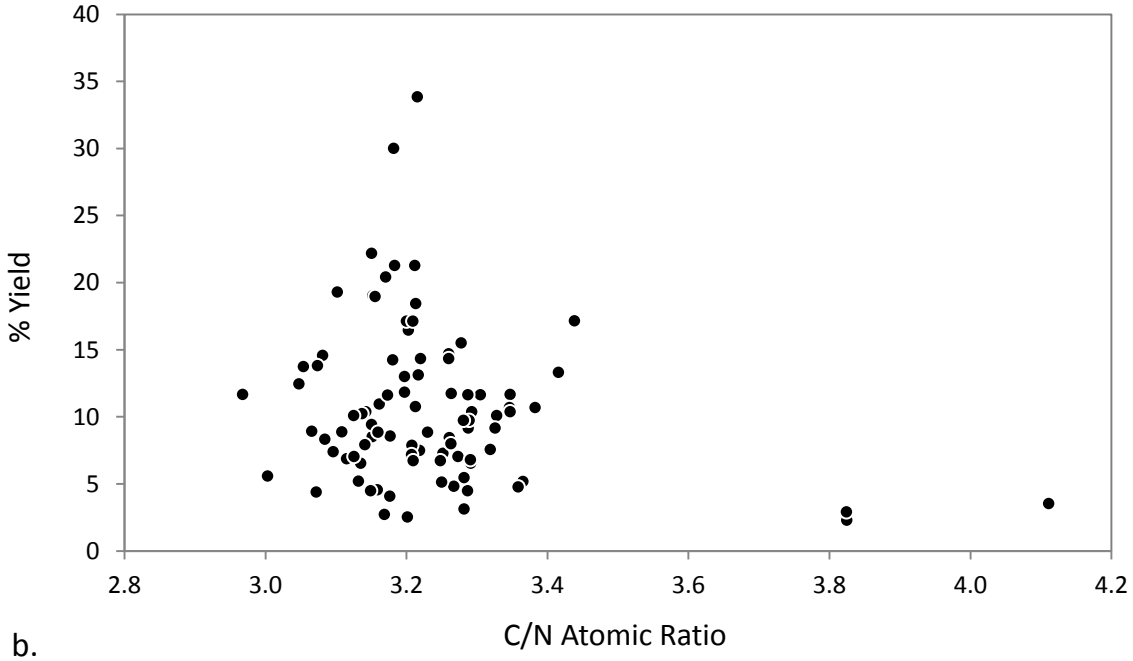


Figure 8. Flow chart of the procedure for extracting strontium from tooth enamel.



a.



b.

Figure 9. Percent collagen yield and C/N atomic ratio of (a) all faunal samples (Table 5) and (b) of all individuals sampled (Table 6).

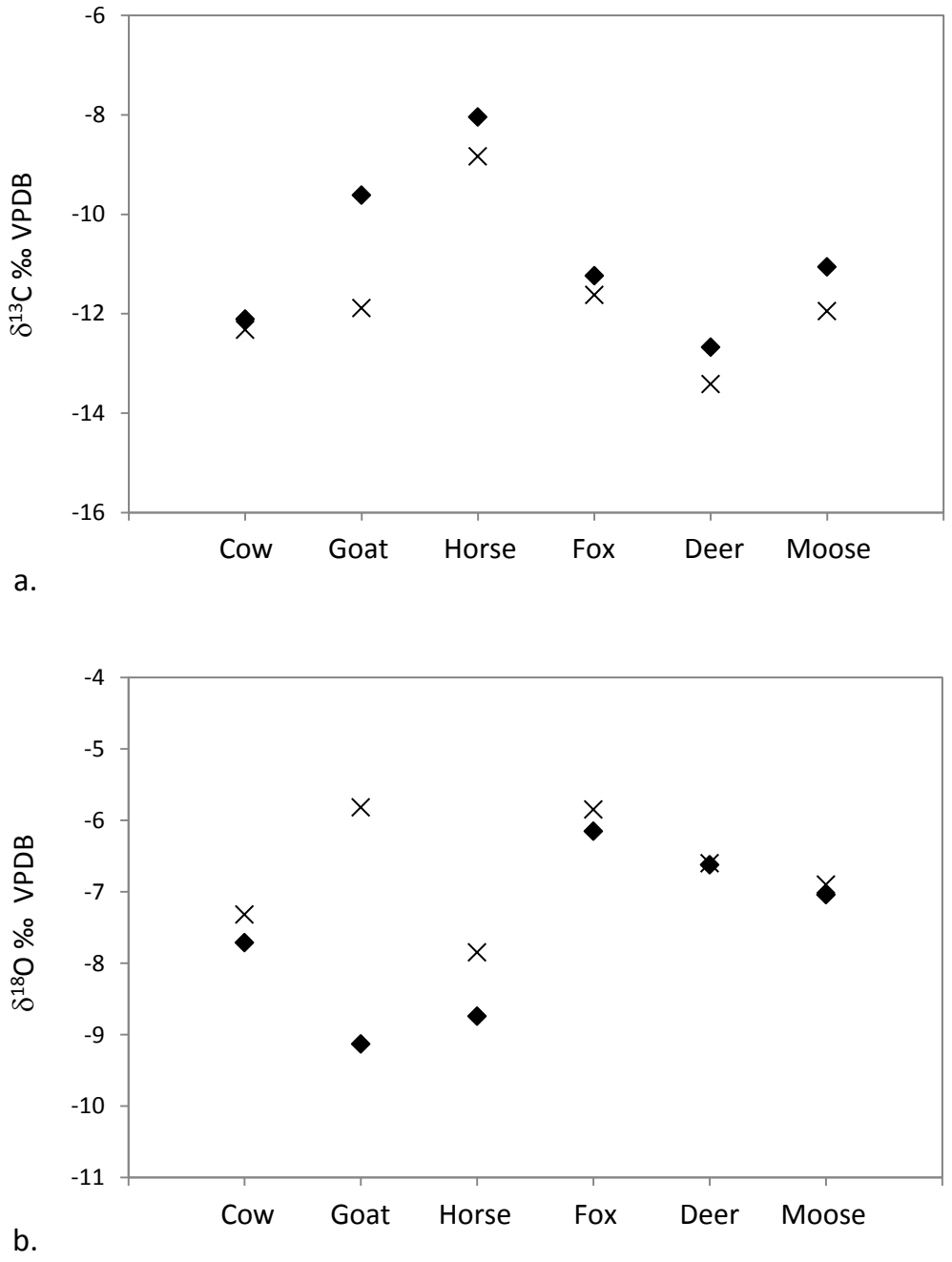


Figure 10. Enamel and dentine (a) $\delta^{13}C$ values and (b) $\delta^{18}O$ values of six faunal specimens (Table 7). Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).

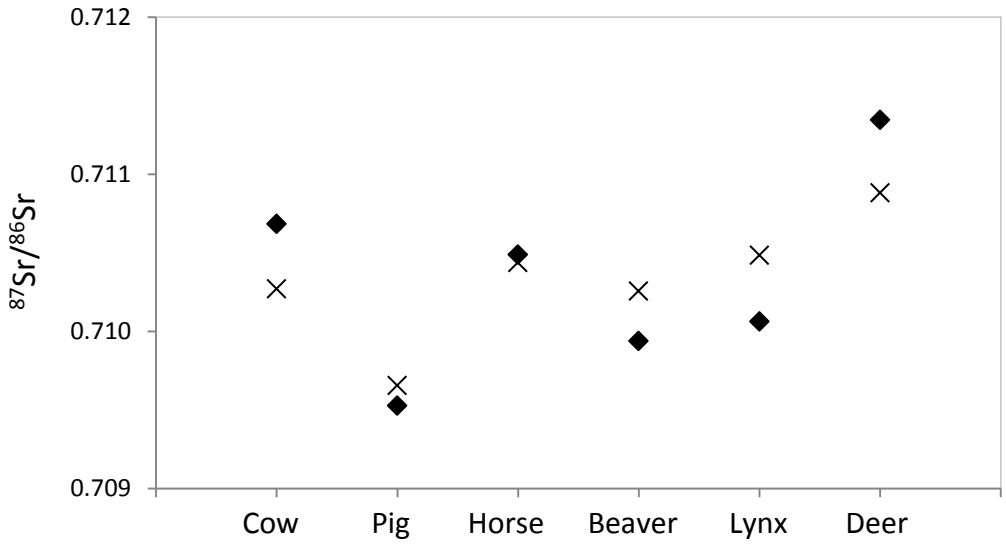
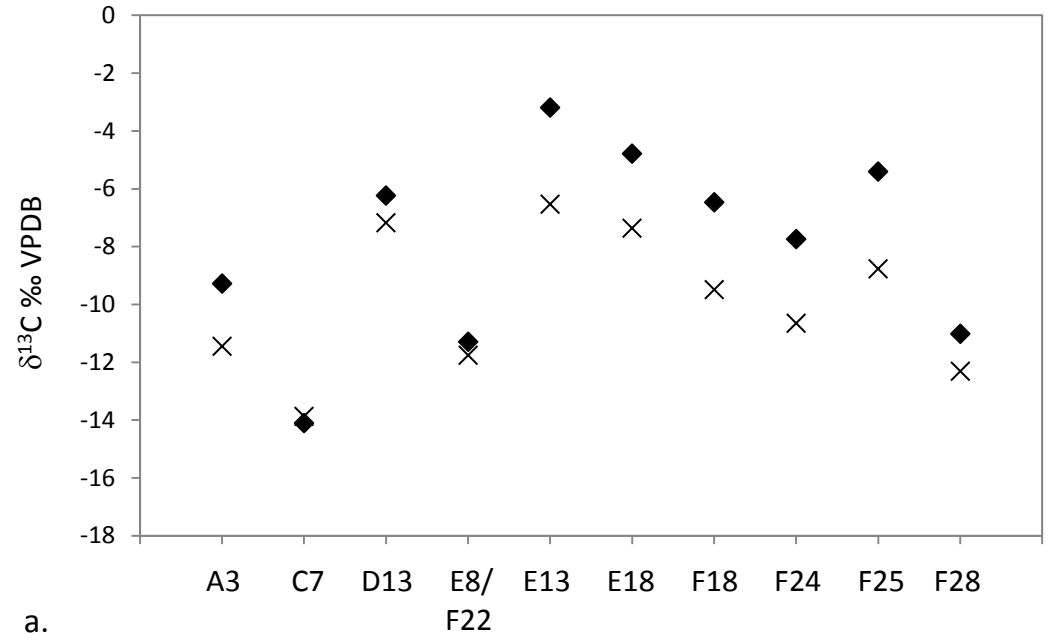
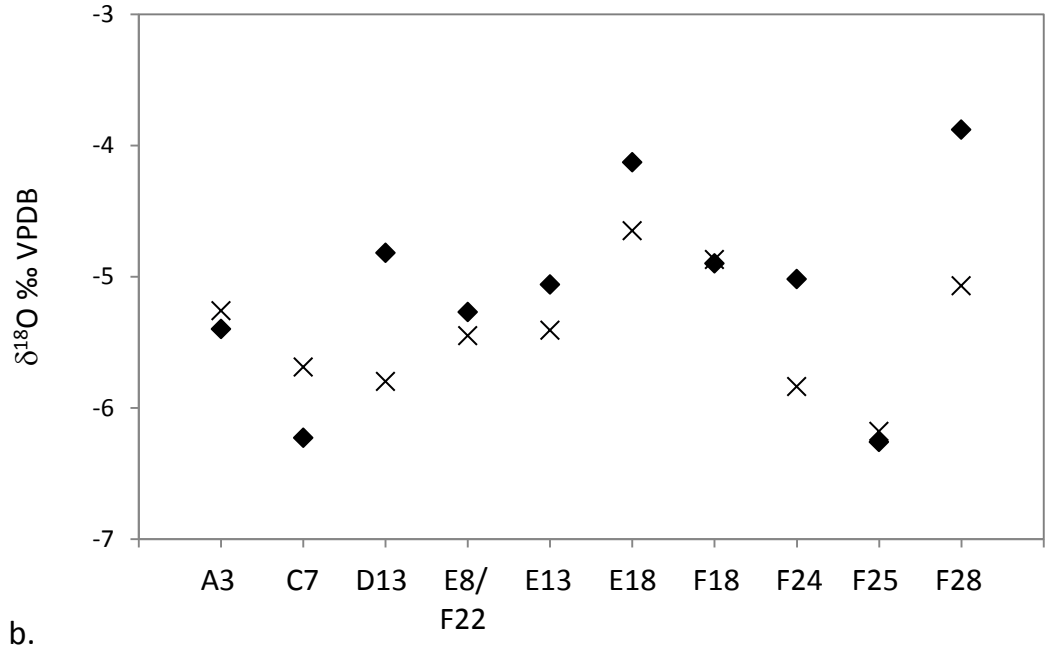


Figure 11. Enamel and dentine $^{87}Sr/^{86}Sr$ values from six fauna specimens (Table 8). Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).



a.



b.

Figure 12. Enamel and dentine (a) $\delta^{13}C$ values and (b) $\delta^{18}O$ values from 10 individuals (Table 9). Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).

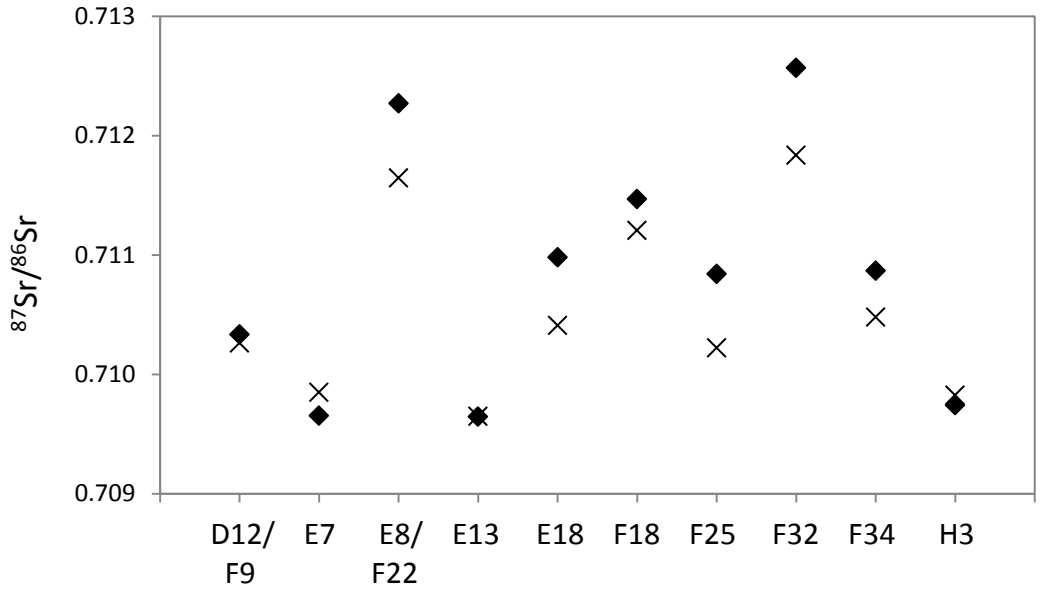


Figure 13. Enamel and dentine $^{87}Sr/^{86}Sr$ values from 10 individuals (Table 10). Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).

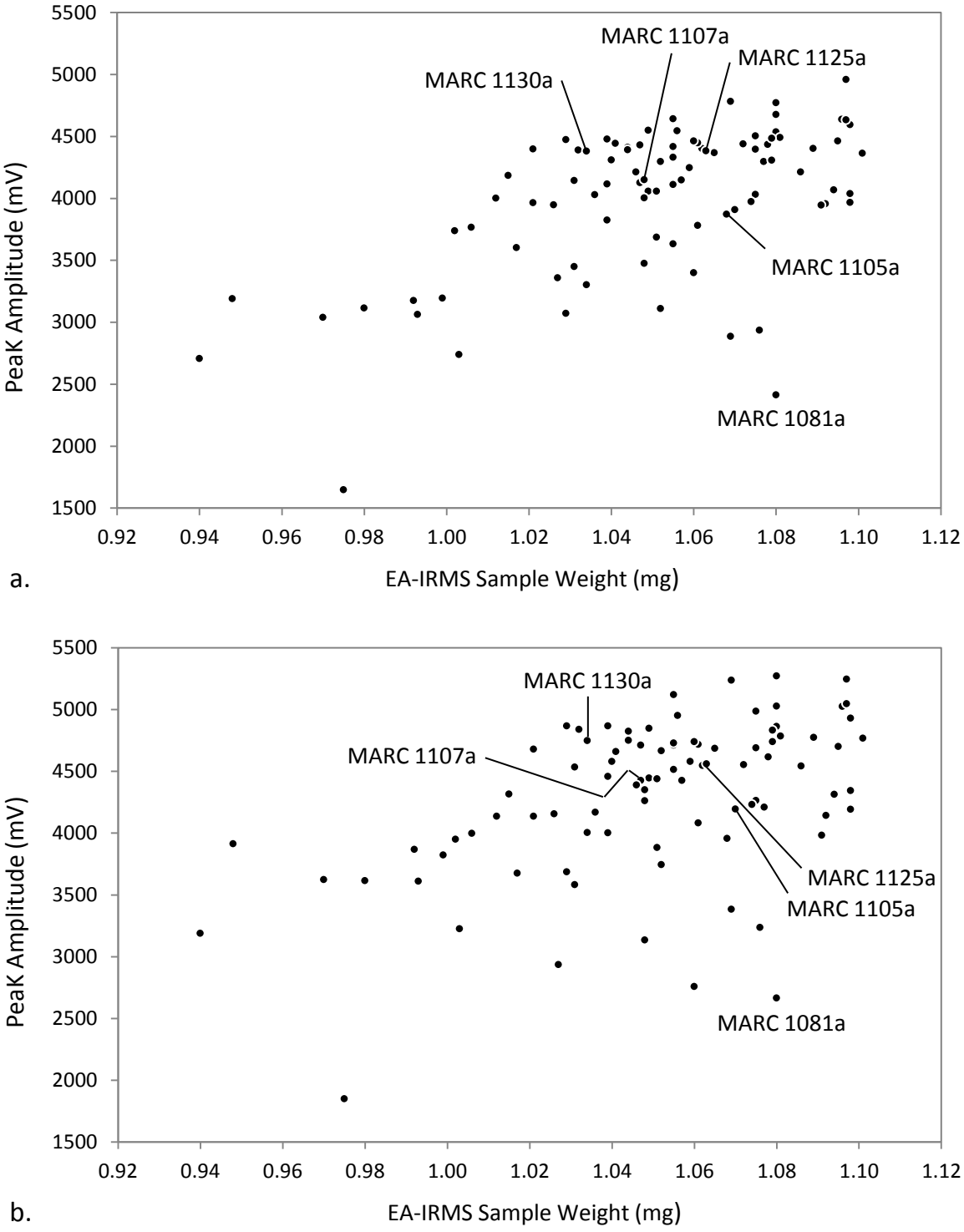


Figure 14. Peak amplitude (mV) and EA-IRMS sample weight (mg) for (a) carbon isotopic analysis and (b) nitrogen isotopic analysis of all individuals sampled (Table 13).

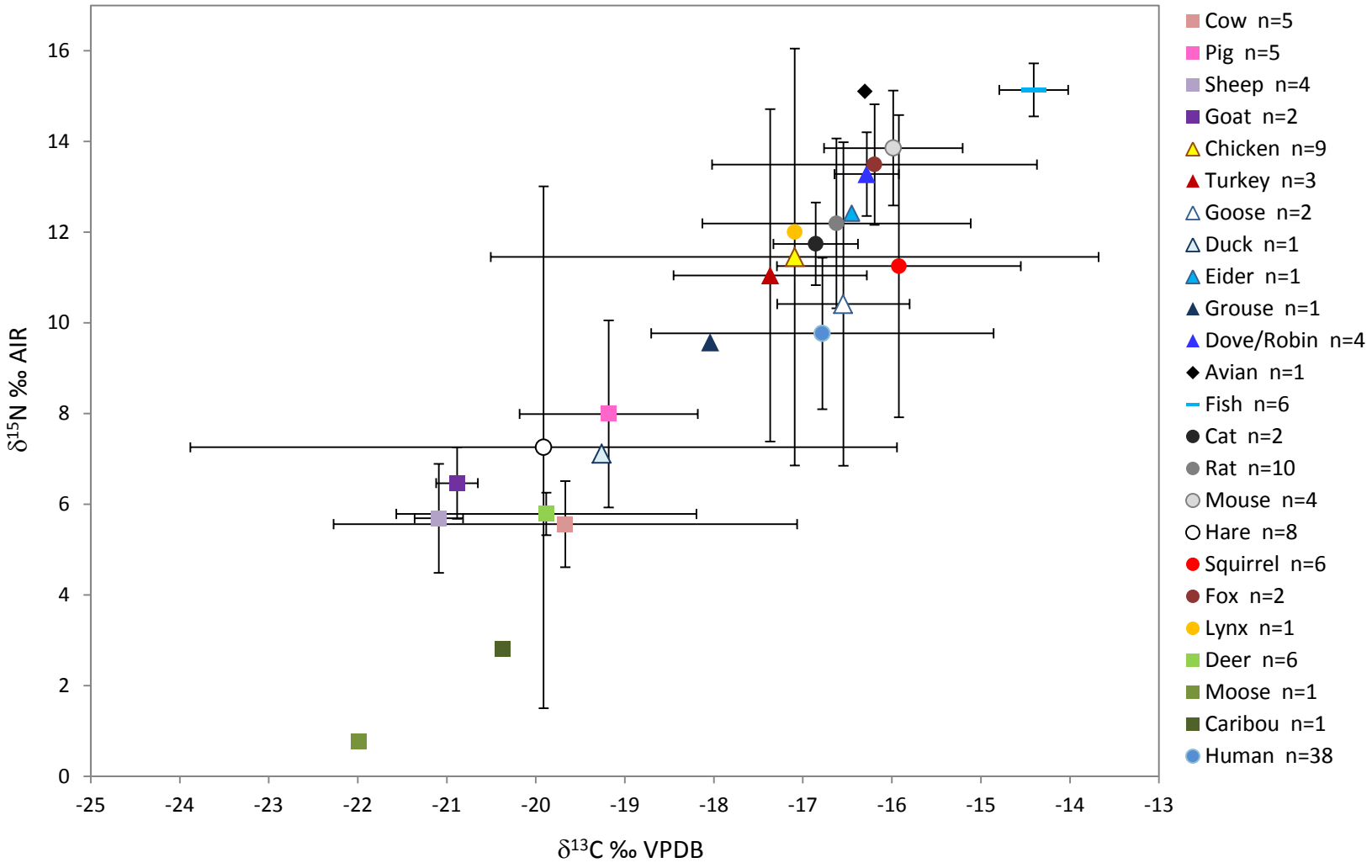


Figure 15. The mean $\delta^{13}C$ and $\delta^{15}N$ values ± 1σ of faunal groups (Table 15) and the Ste. Marie individuals (n=38, Table 16).

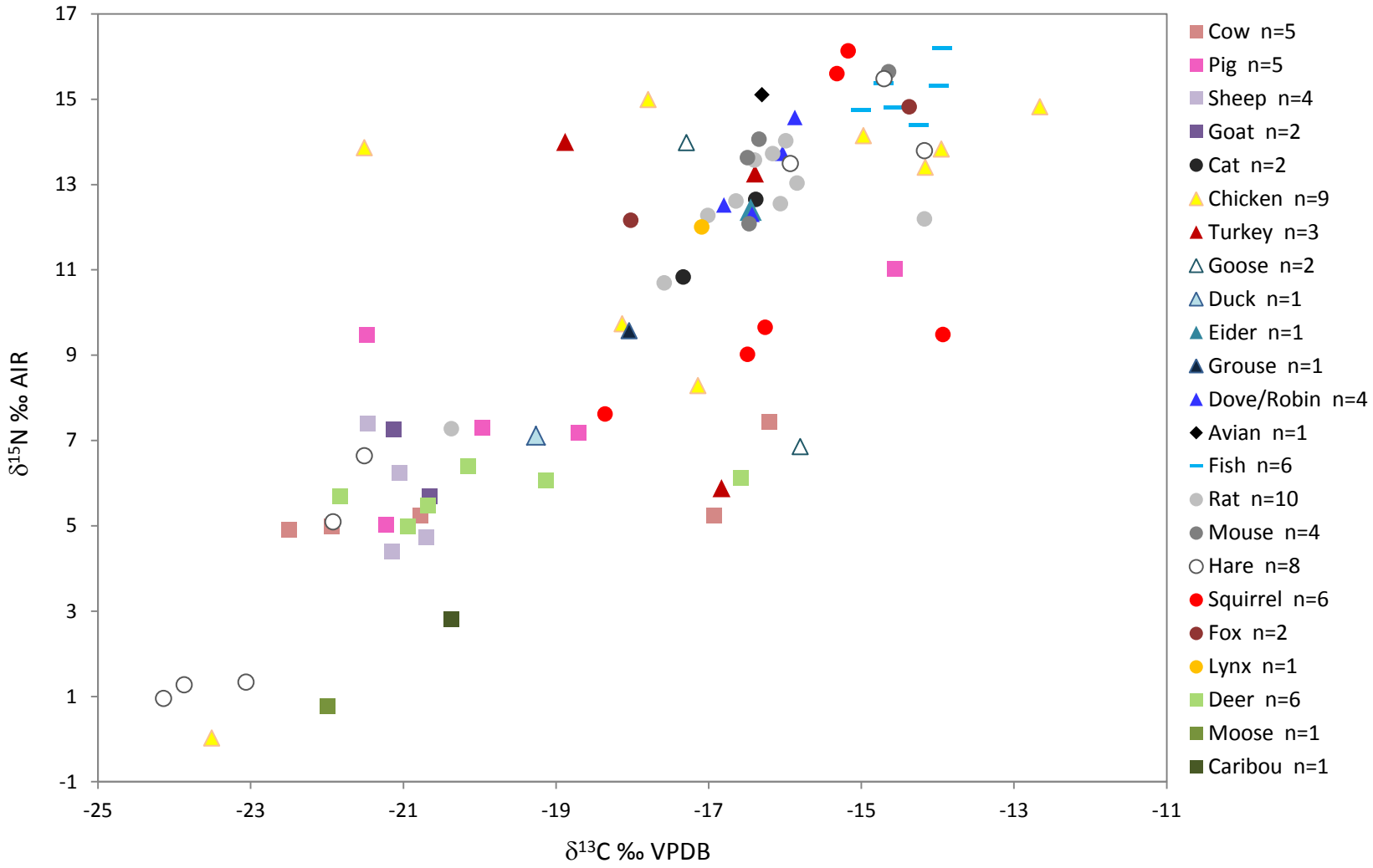


Figure 16. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of faunal specimens (n=85, Table 14).

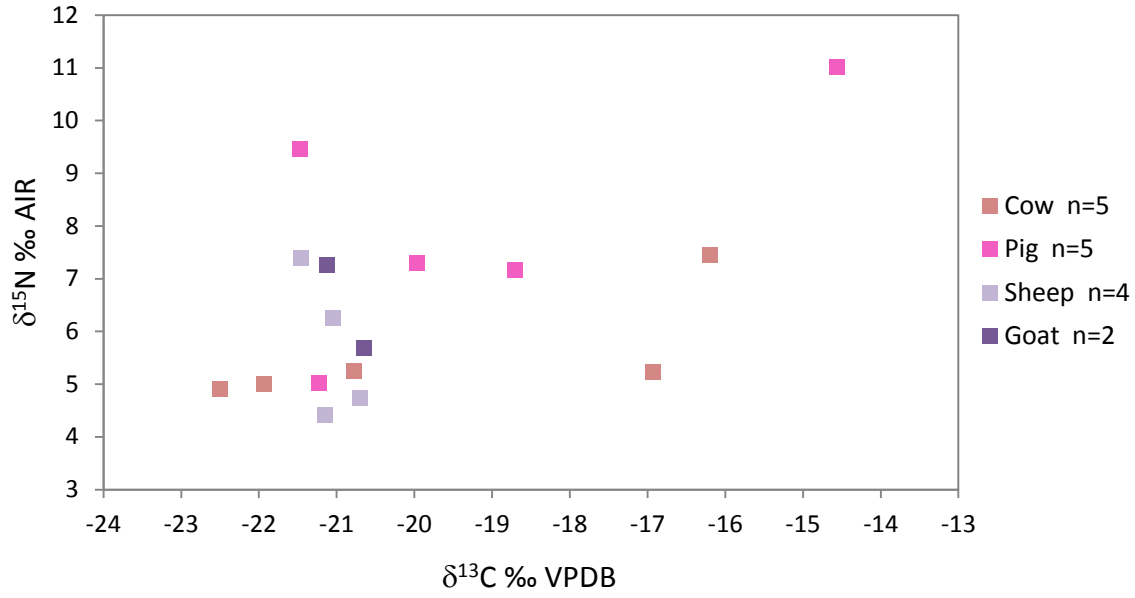


Figure 17. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of domestic mammals (Table 14).

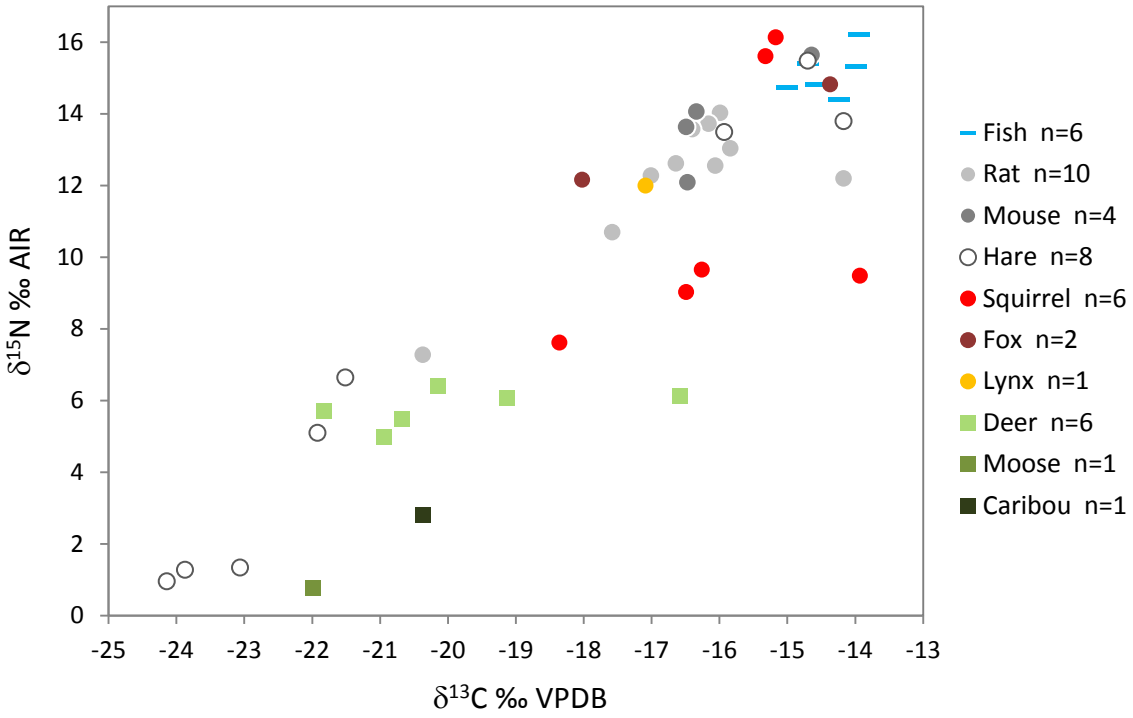


Figure 18. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of wild fauna (Table 14).

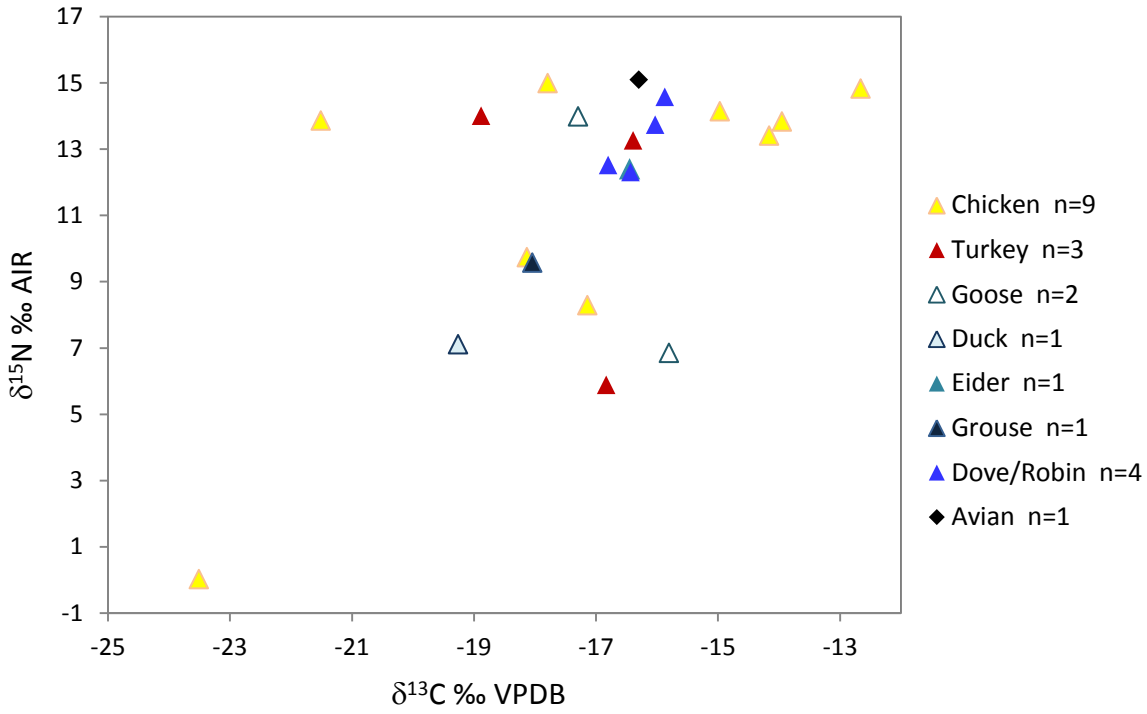


Figure 19. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of all bird specimens (Table 14).

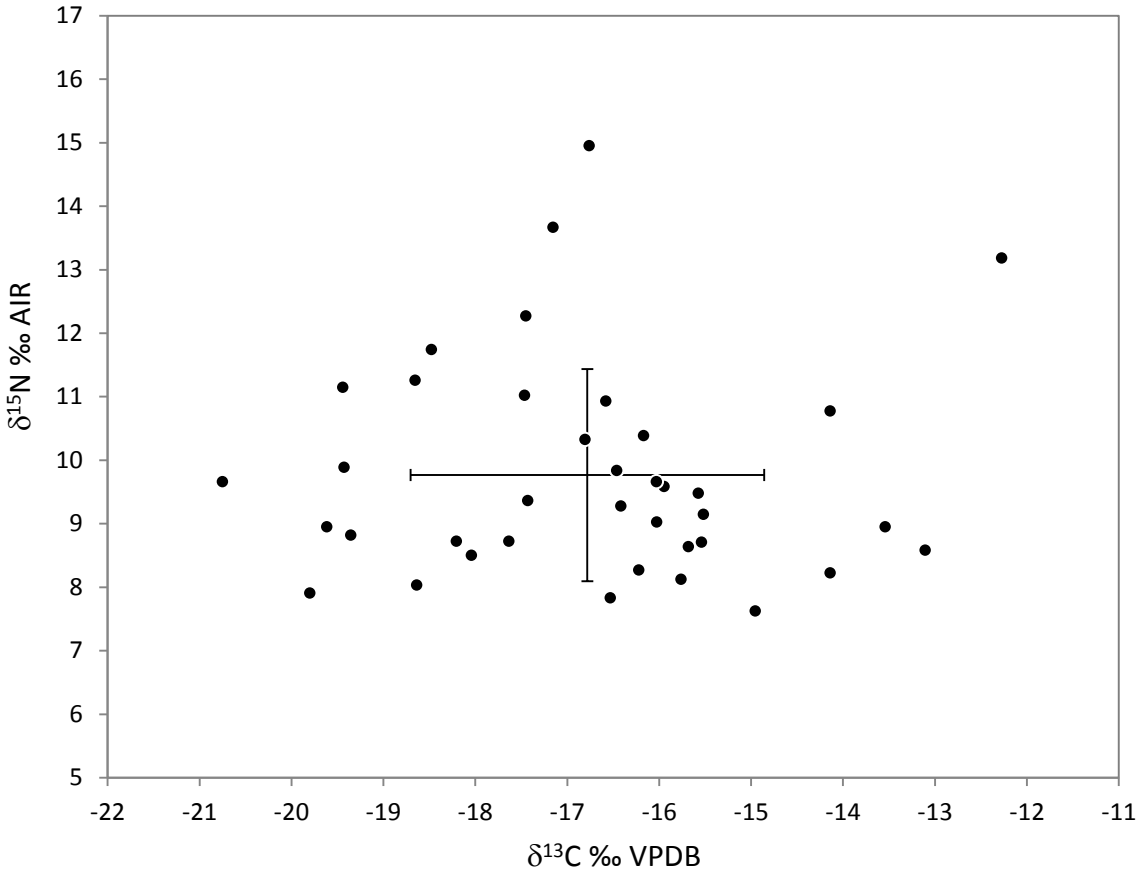


Figure 20. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values and the mean ± 1σ of the Ste. Marie individuals (n=38, Table 16).

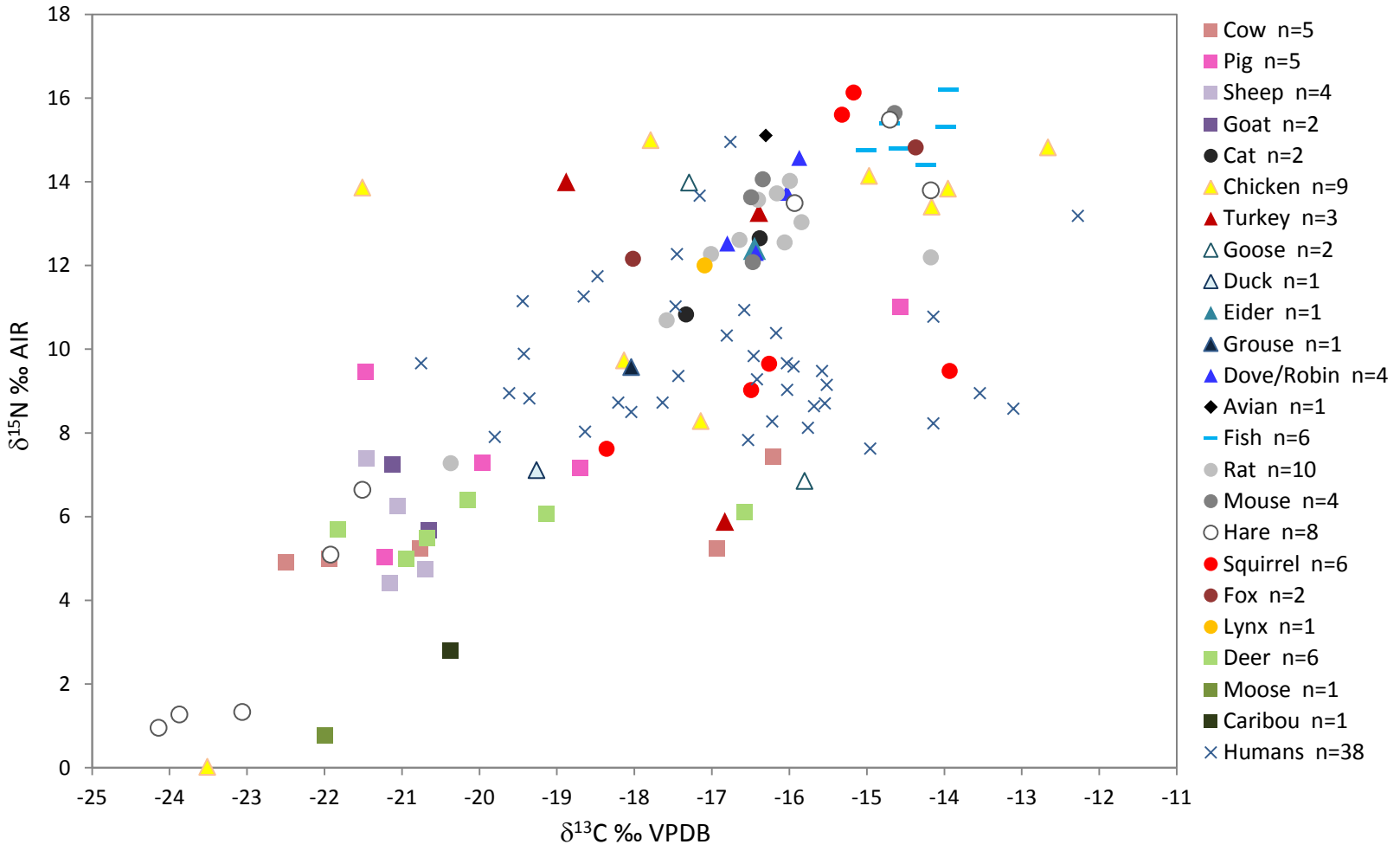


Figure 21. Scatter plot of $\delta^{13}C$ and $\delta^{15}N$ values of fauna (n=85, Table 14) and the Ste. Marie individuals (n=38, Table 16).

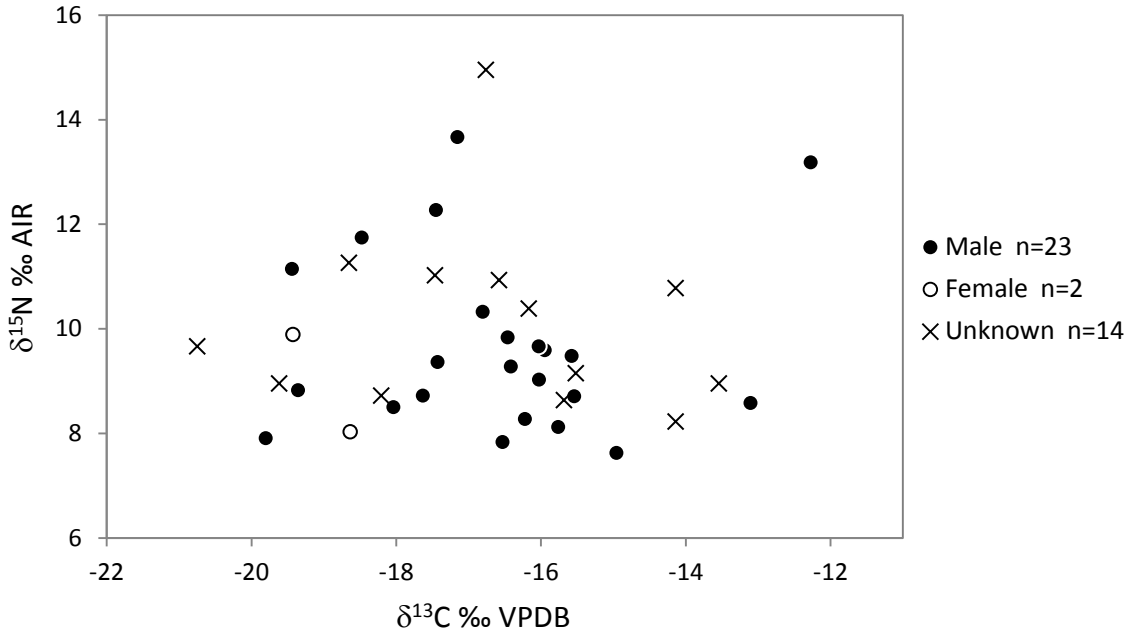


Figure 22. $\delta^{13}C$ and $\delta^{15}N$ values of males (n=23), females (n=2), and individuals of unknown sex (n=14, Table 17).

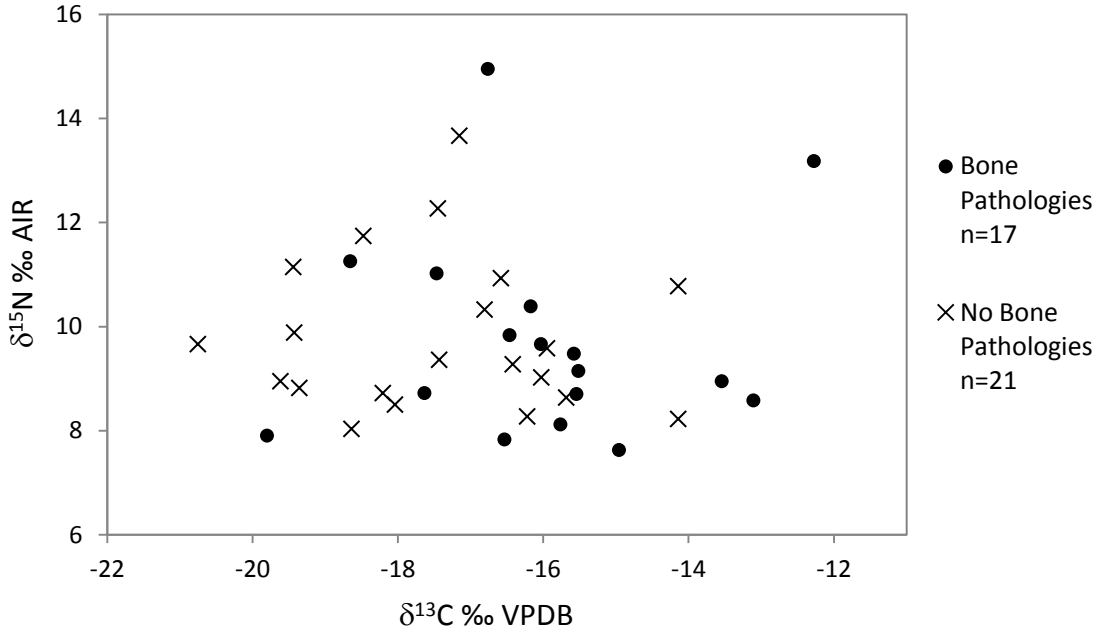


Figure 23. $\delta^{13}C$ and $\delta^{15}N$ values of individuals exhibiting bone pathologies (n=17) and individuals exhibiting no bone pathologies (n=21, Table 17).

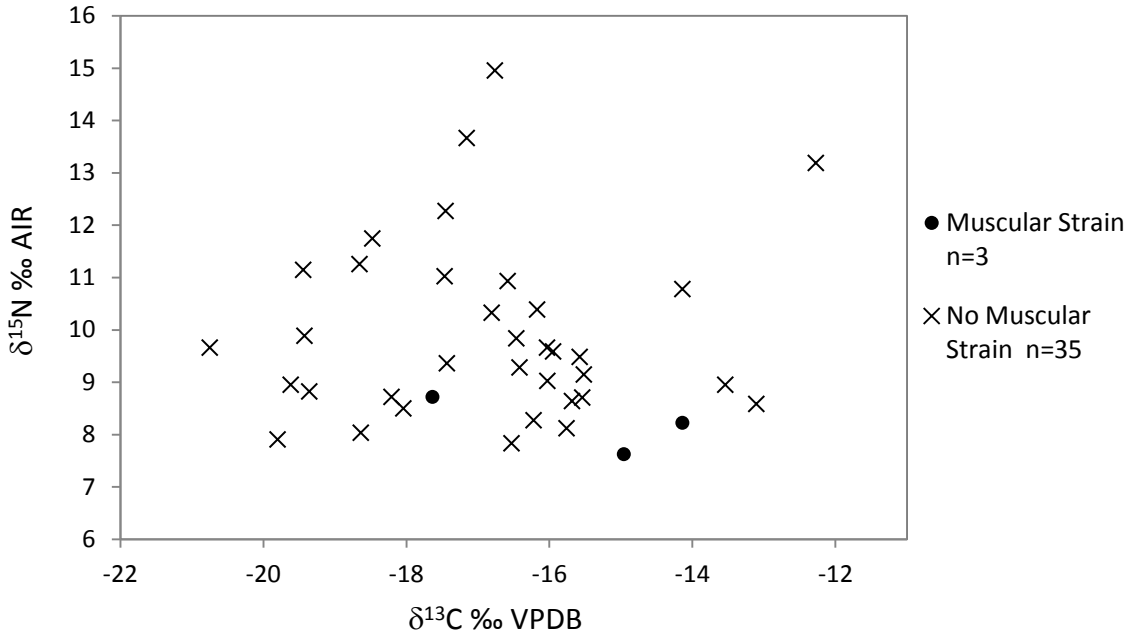


Figure 24. $\delta^{13}C$ and $\delta^{15}N$ values of individuals exhibiting evidence of muscular strain (n=3) and individuals not showing evidence of muscular strain (n=35, Table 17).

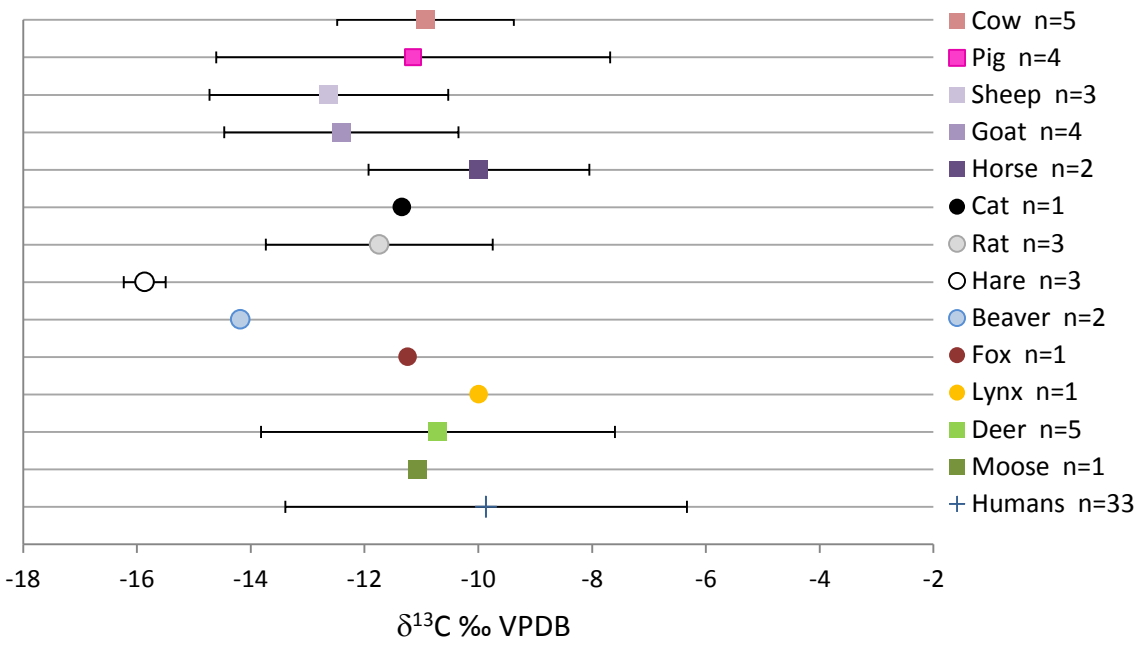


Figure 25. Mean $\delta^{13}C$ bioapatite values $\pm$ 1σ of fauna (n=35, Table 19) and the Ste. Marie individuals (n=33, Table 20).

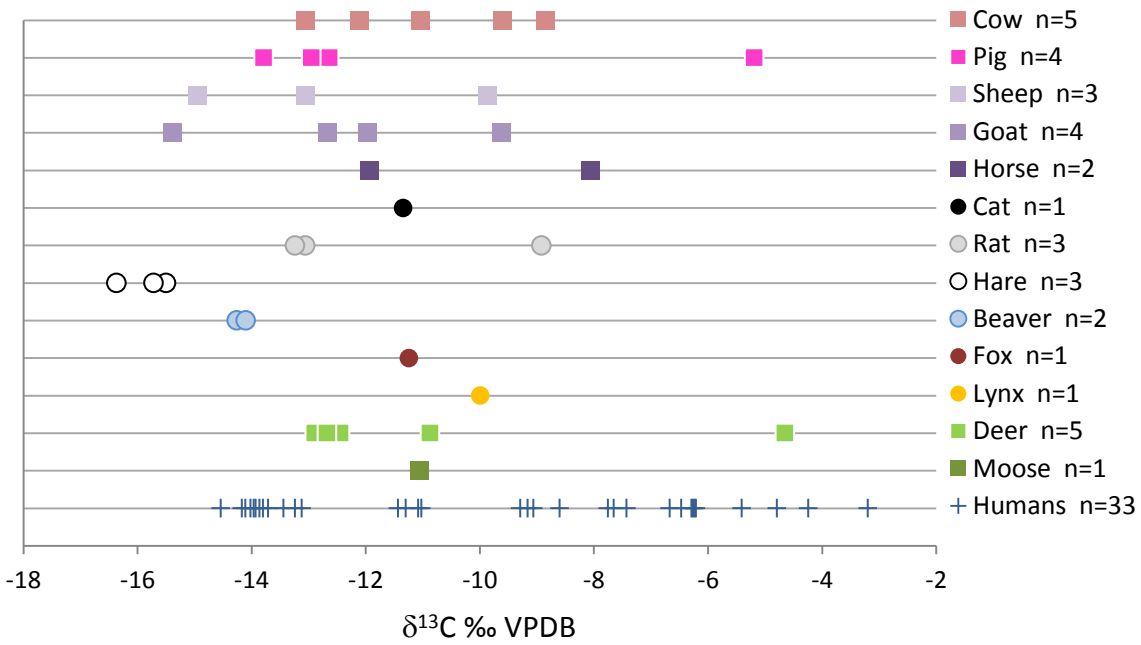


Figure 26. Scatter plot of $\delta^{13}C$ bioapatite values of fauna (n=35, Table 18) and the Ste. Marie individuals (n=33, Table 20).

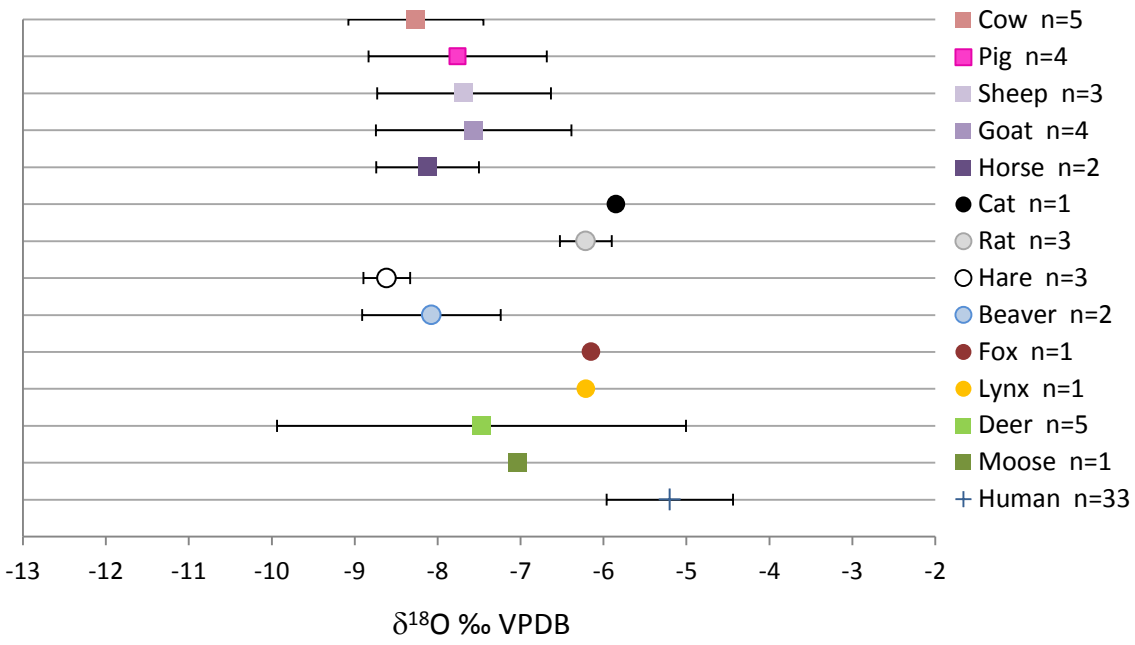


Figure 27. Mean $\delta^{18}O$ bioapatite values ± 1σ of fauna (n=35, Table 19) and the Ste. Marie individuals (n=33, Table 20).

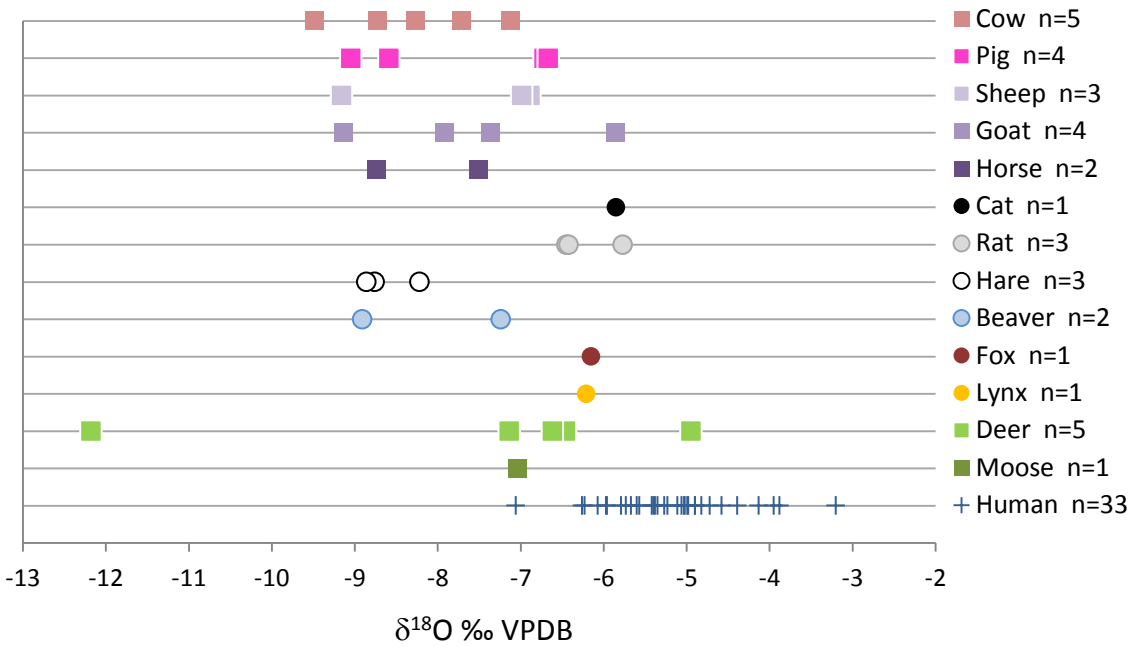


Figure 28. Scatter plot of $\delta^{18}O$ bioapatite of fauna (n=35, Table 18) and the Ste. Marie individuals (n=33, Table 20).

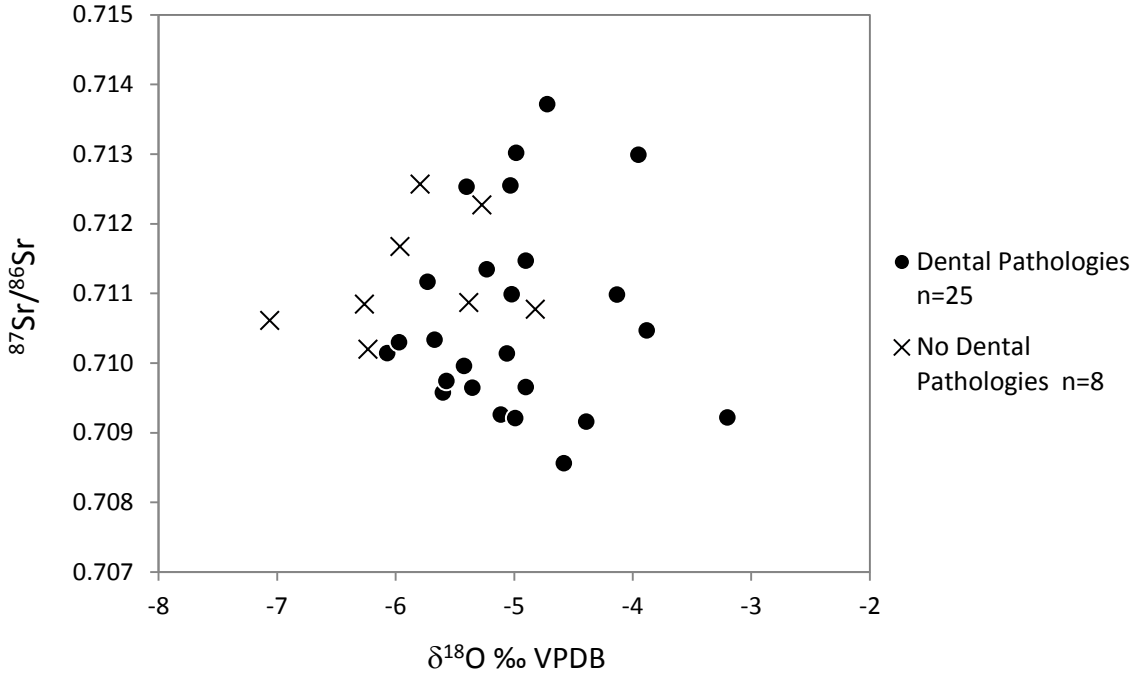


Figure 29. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of individuals with dental pathologies (n=25) and individuals with no dental pathologies (n=8, Table 17).

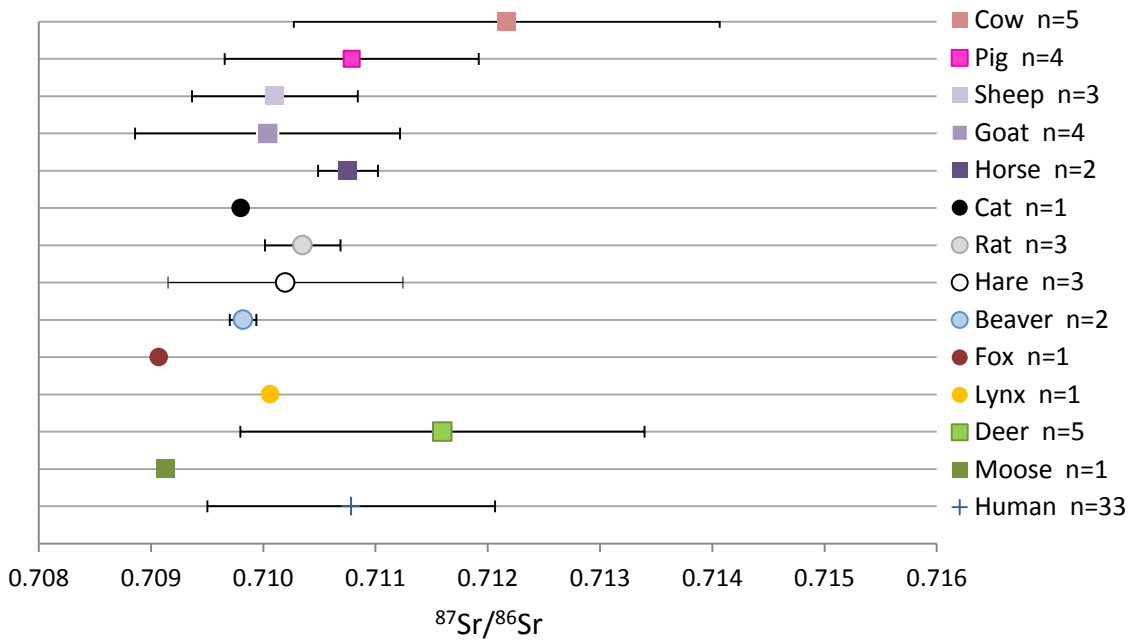


Figure 30. Mean $^{87}Sr/^{86}Sr$ values ± 1σ of fauna (n=35, Table 19) and the Ste. Marie individuals (n=33, Table 20).

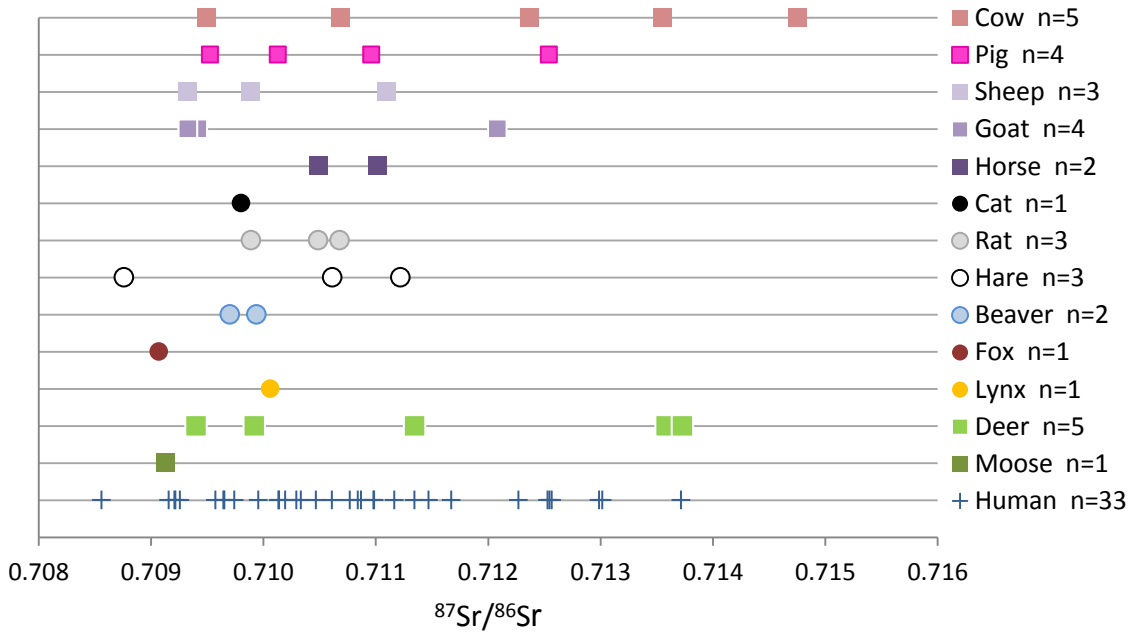


Figure 31. Scatter plot of $^{87}Sr/^{86}Sr$ of fauna (n=35, Table 18) and the Ste. Marie individuals (n=33, Table 20).

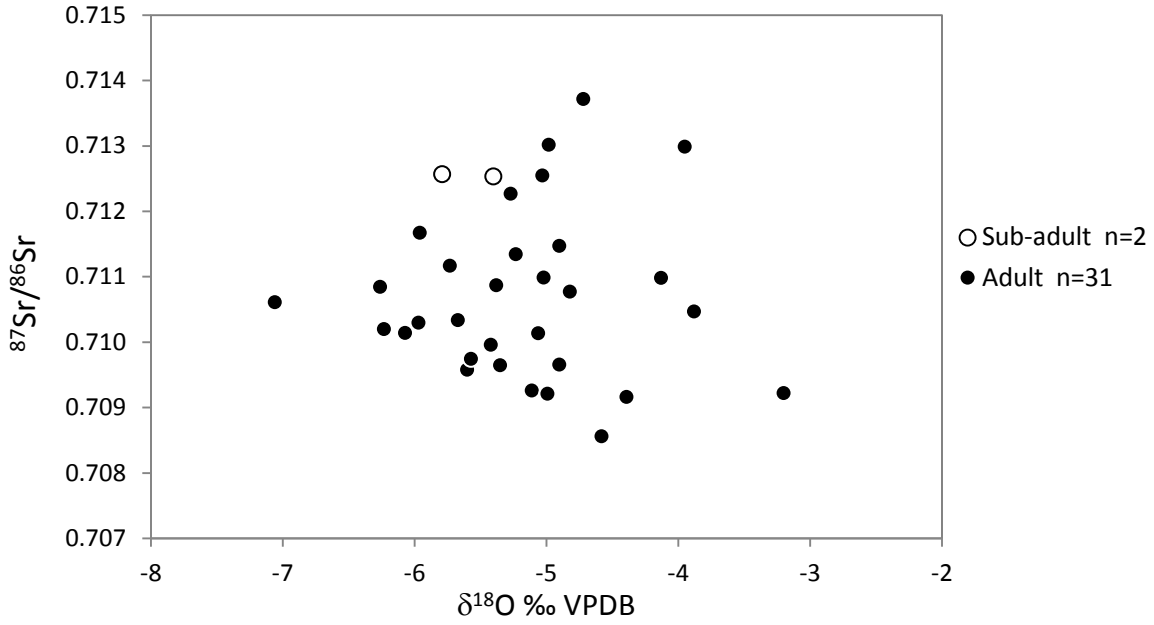


Figure 32. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of adults (n=31) and sub-adults (n=2, Table 17).

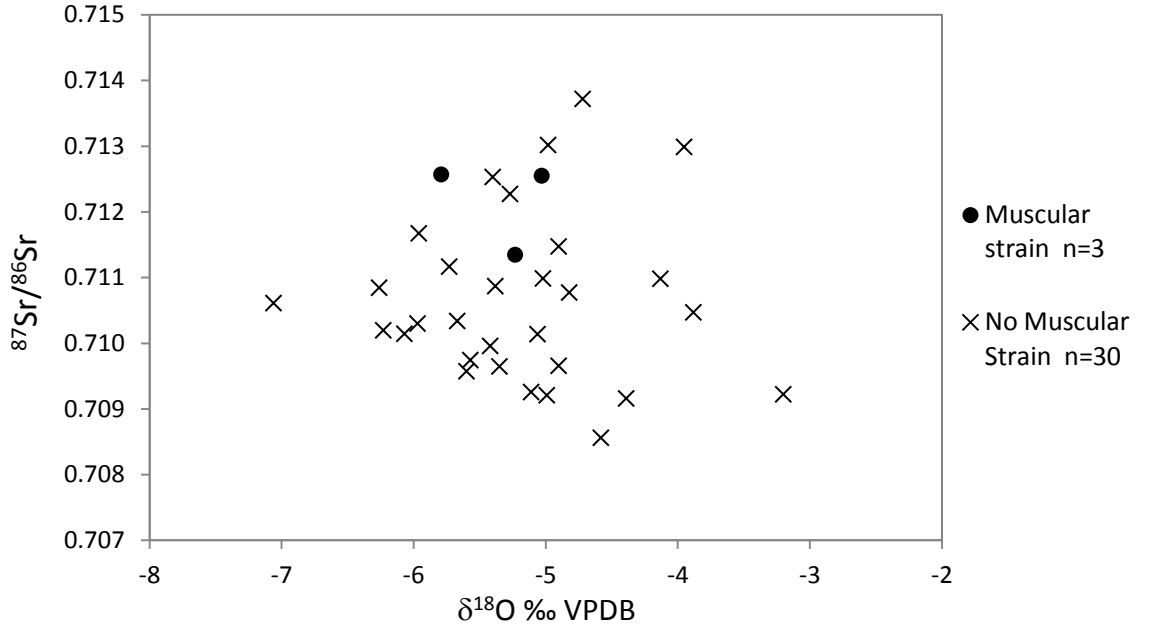


Figure 33. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values of individuals with evidence of muscular strain (n=3) and individuals with no evidence of muscular strain (n=30, Table 17).

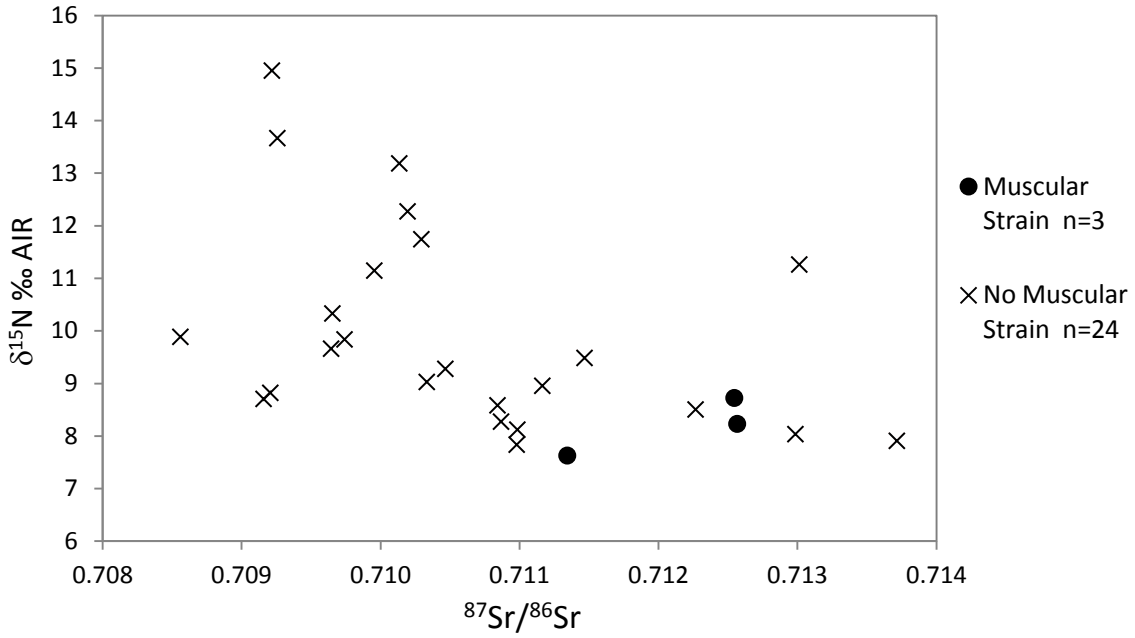


Figure 34. $\delta^{15}N$ and $^{87}Sr/^{86}Sr$ values of individuals with evidence of muscular strain (n=3) and individuals with no evidence of muscular strain (n=24, Table 17).

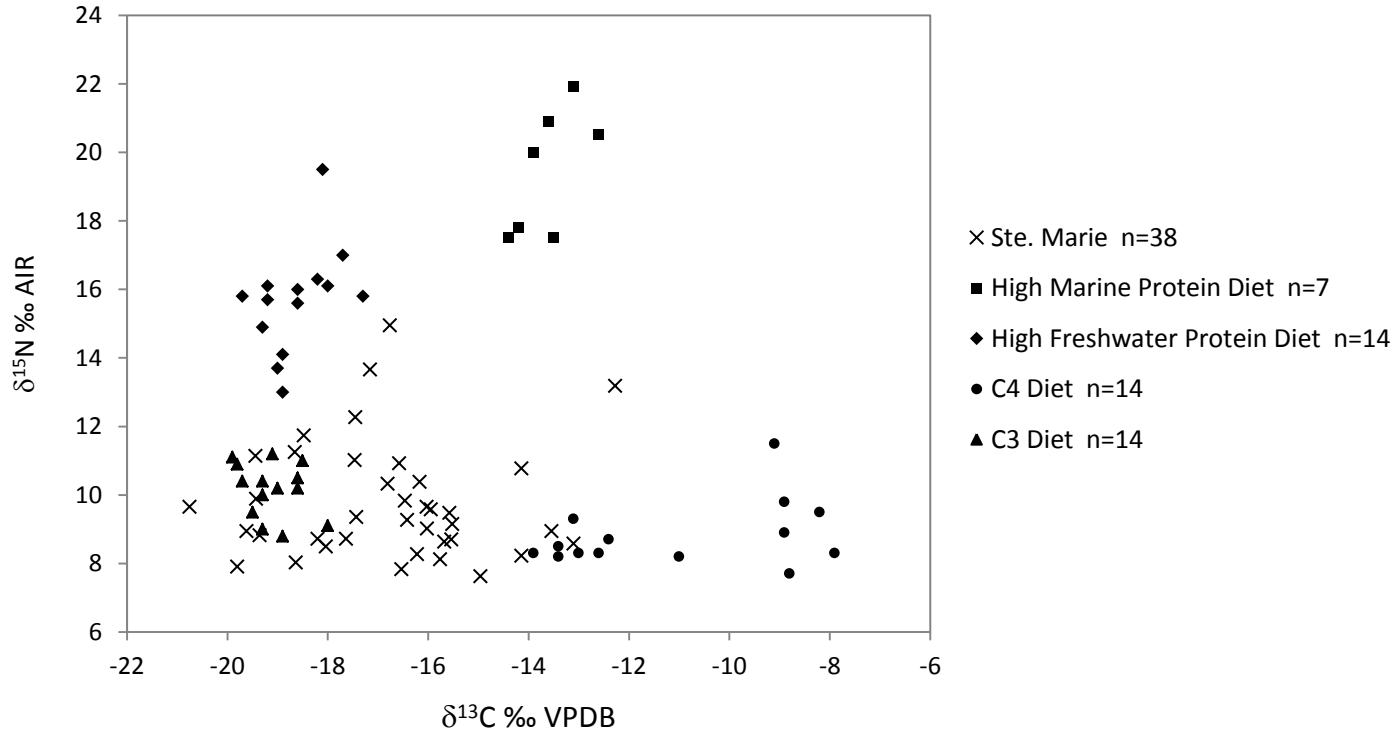


Figure 35. $\delta^{13}C$ and $\delta^{15}N$ values of the Ste. Marie individuals (Table 16) and human groups from the Honch et al. (2012) study.

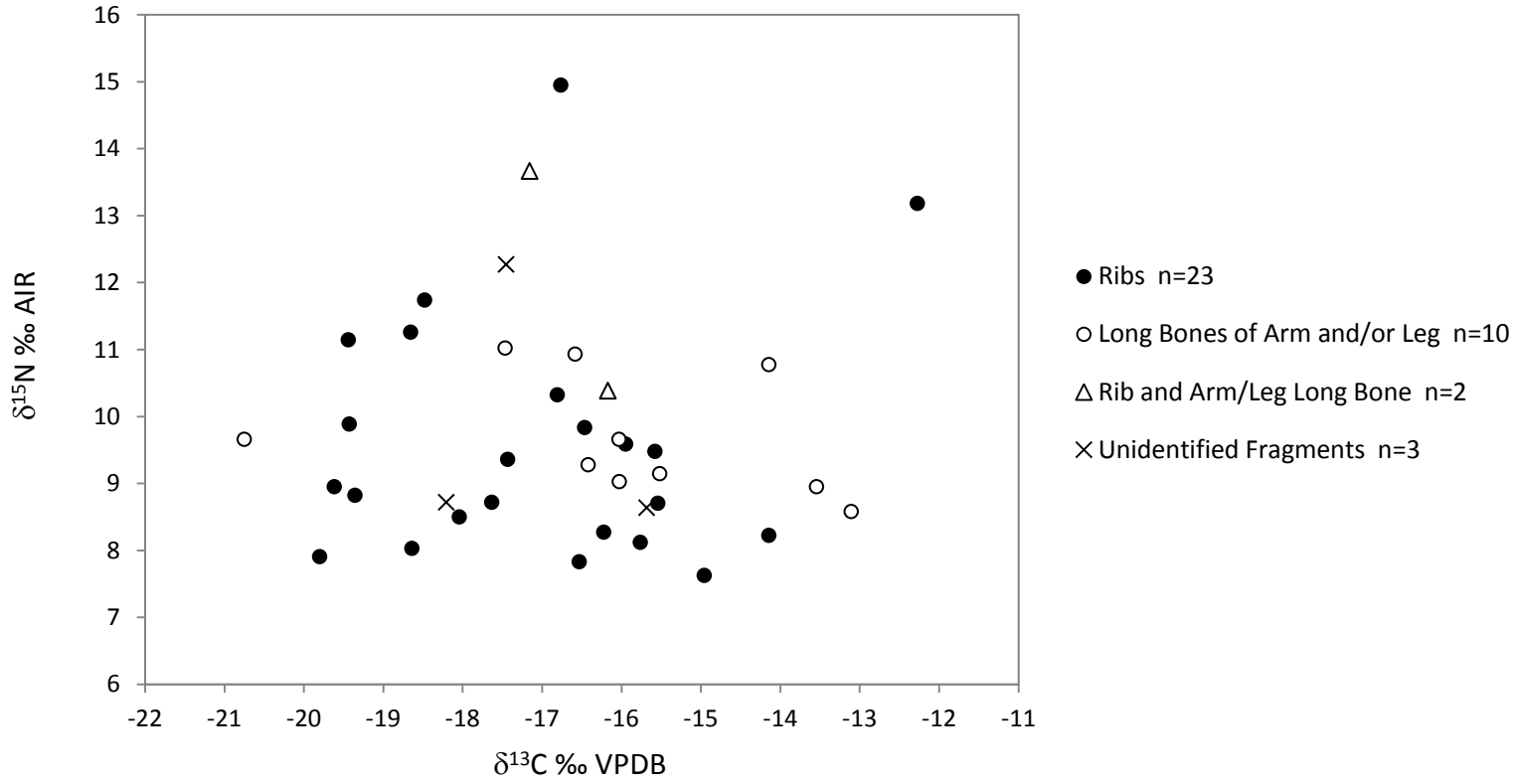
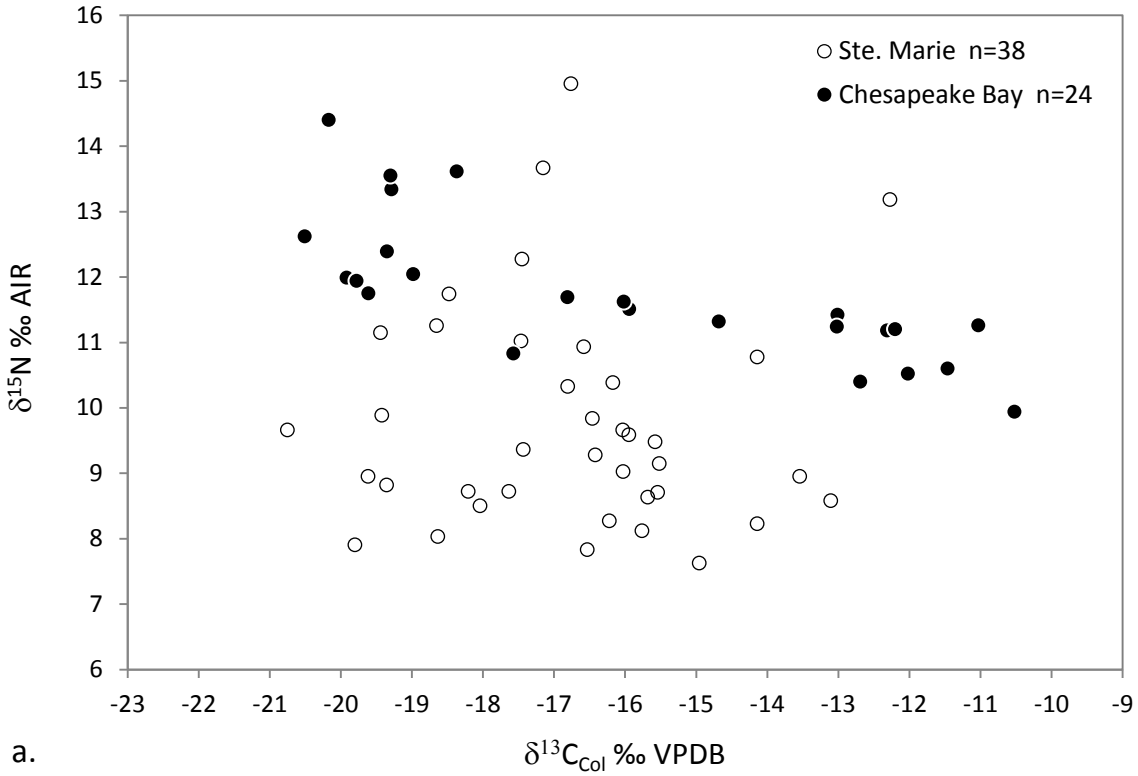


Figure 36. Scatter plot of the $\delta^{13}C$ and $\delta^{15}N$ values of the Ste. Marie individuals (n=38) by bone element(s) analysed (Table 23).



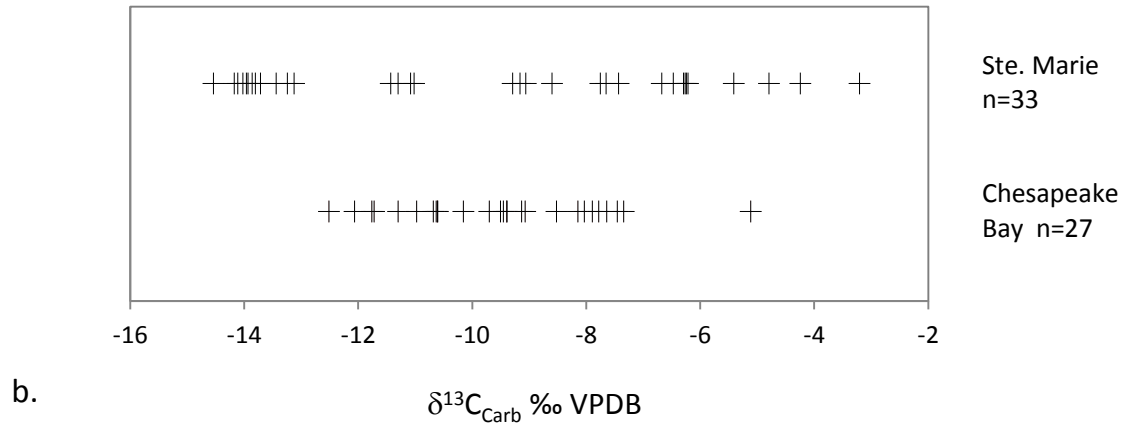


Figure 37. Scatter plot of (a) $\delta^{13}C$ and $\delta^{15}N$ bone collagen values and (b) $\delta^{13}C$ enamel bioapatite values of the Ste. Marie individuals and the Chesapeake Bay individuals (Ubelaker and Owsley 2003).

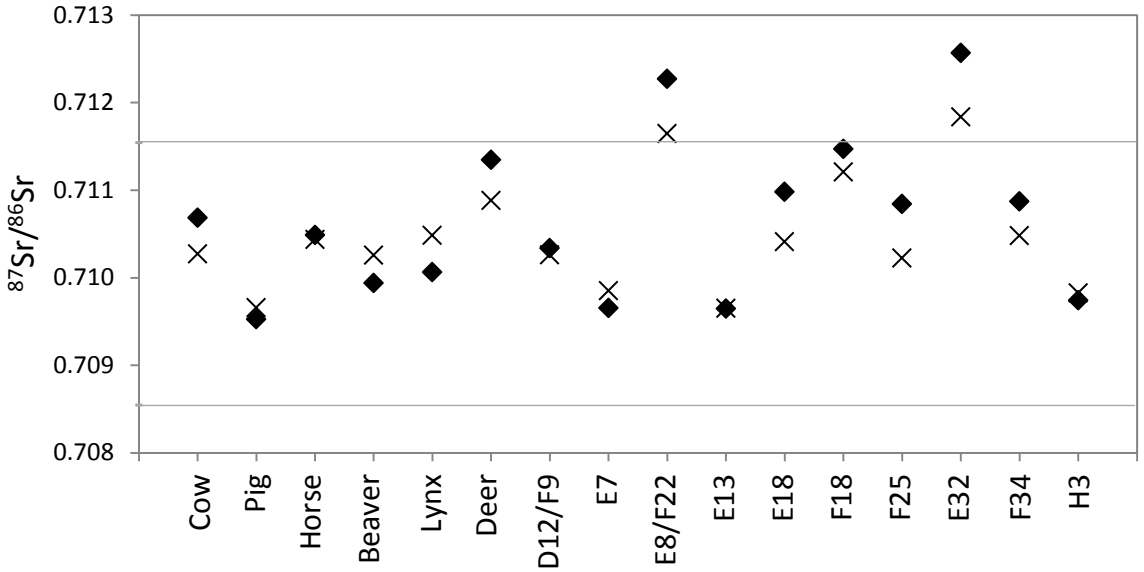


Figure 38. Enamel and dentine $^{87}Sr/^{86}Sr$ values of six faunal specimens (Table 8) and 10 Ste. Marie individuals (Table 10) in comparison to the strontium 2σ range. Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).

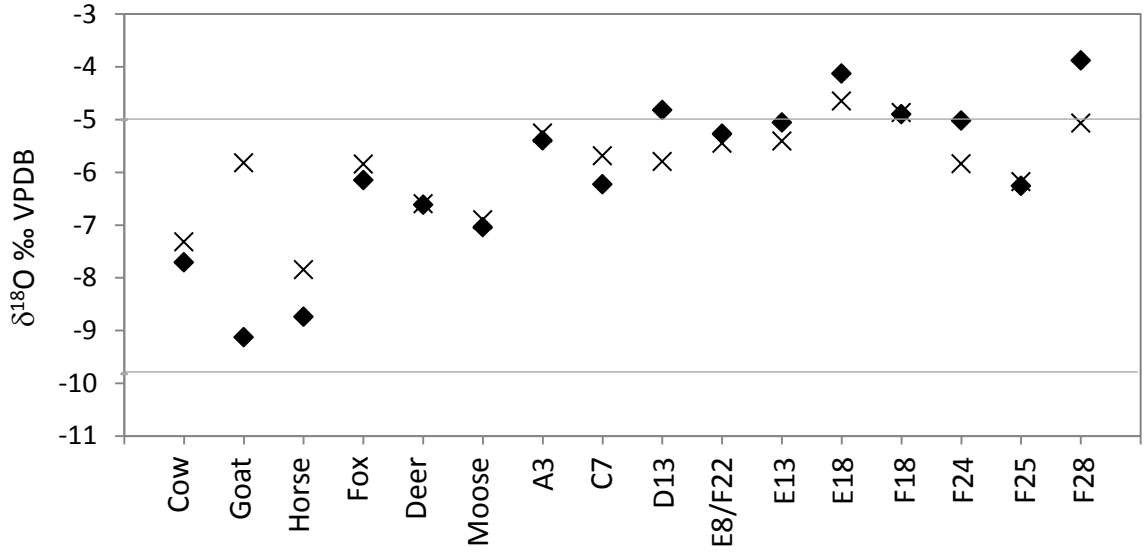


Figure 39. Enamel and dentine $\delta^{18}O$ values of six faunal specimens (Table 7) and 10 Ste. Marie individuals (Table 9) in comparison to the oxygen 2σ range. Enamel is represented by a diamond (♦), and dentine is represented by an x mark (x).

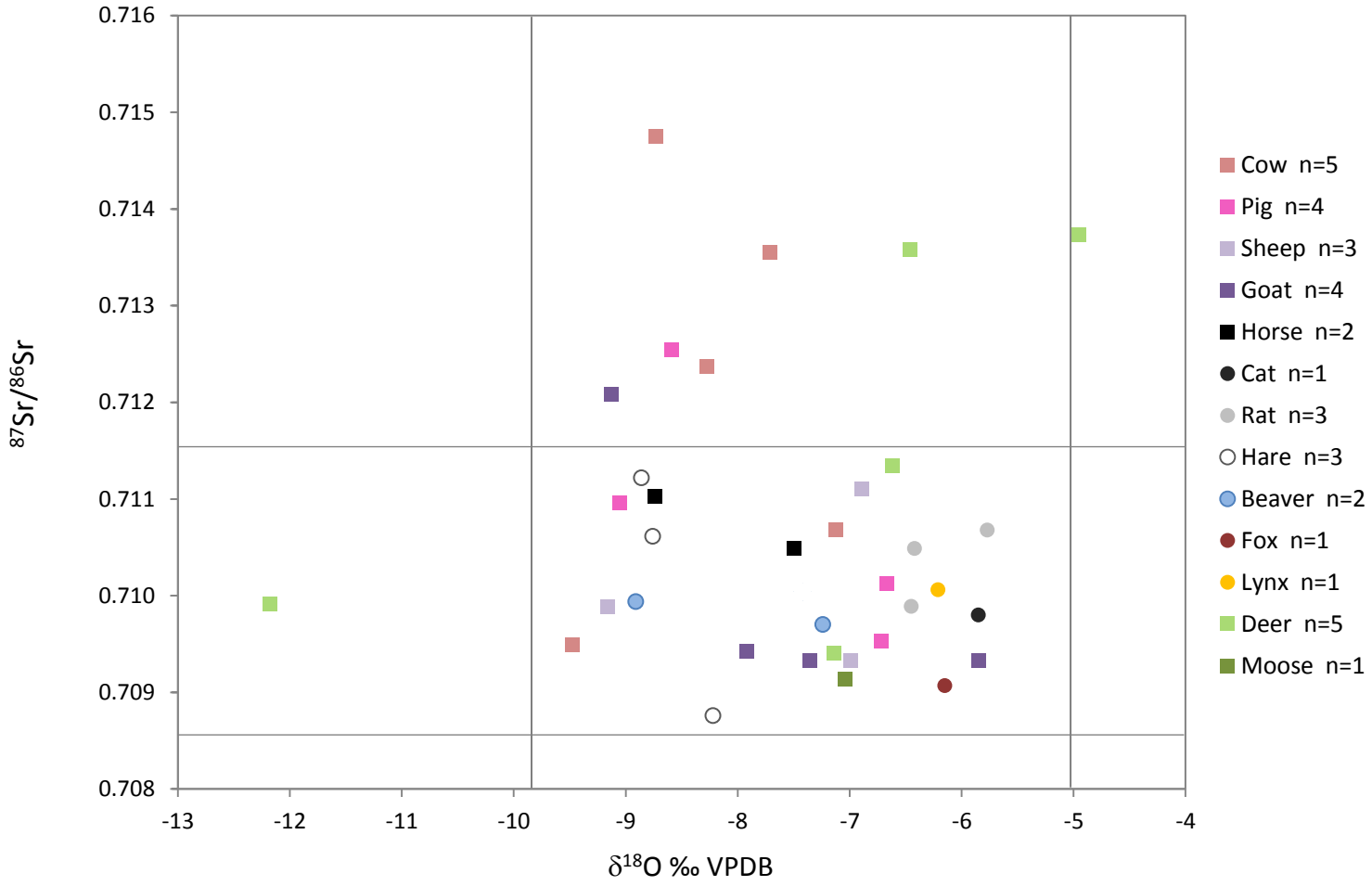
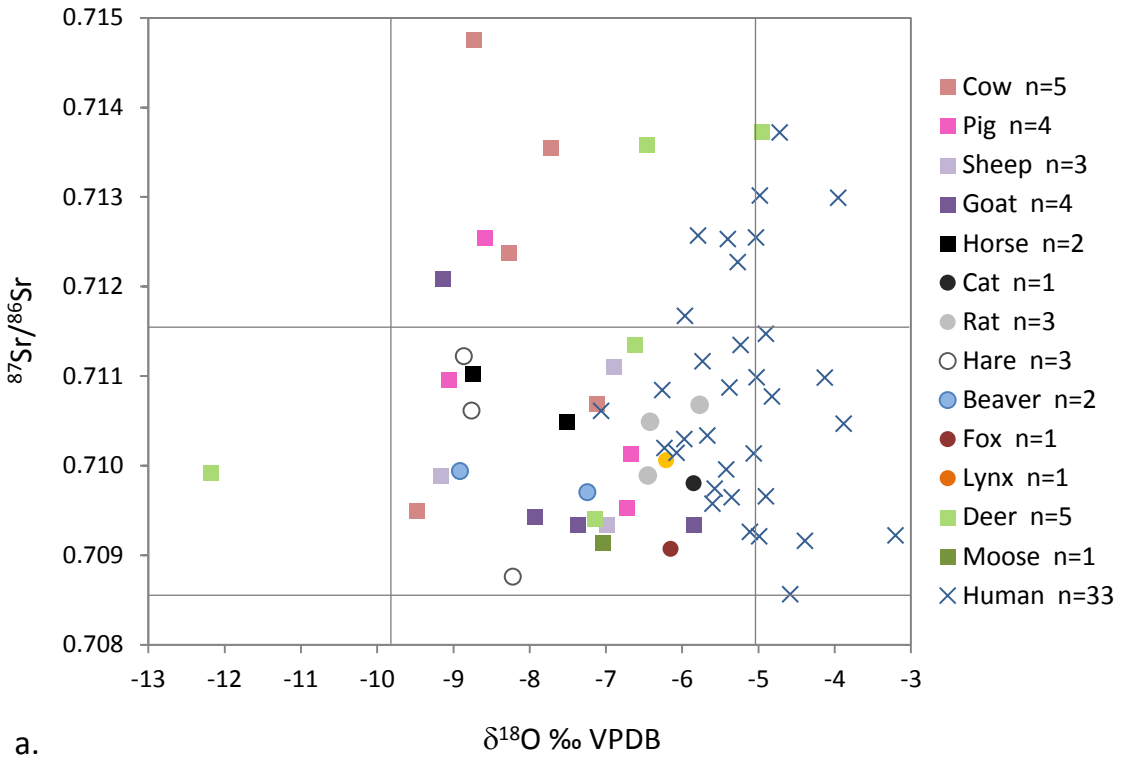
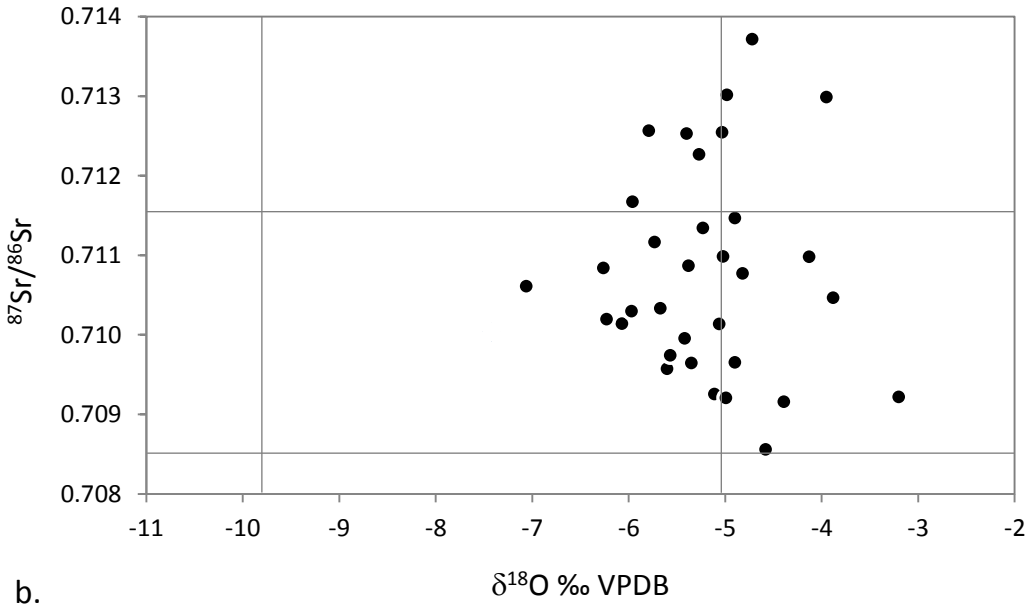


Figure 40. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for fauna (n=35, Table 21) and the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges.



a.



b.

Figure 41. $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (n=33, Table 22) with (a) the fauna from this study (n=35, Table 21) and the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges and (b) with the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges only.

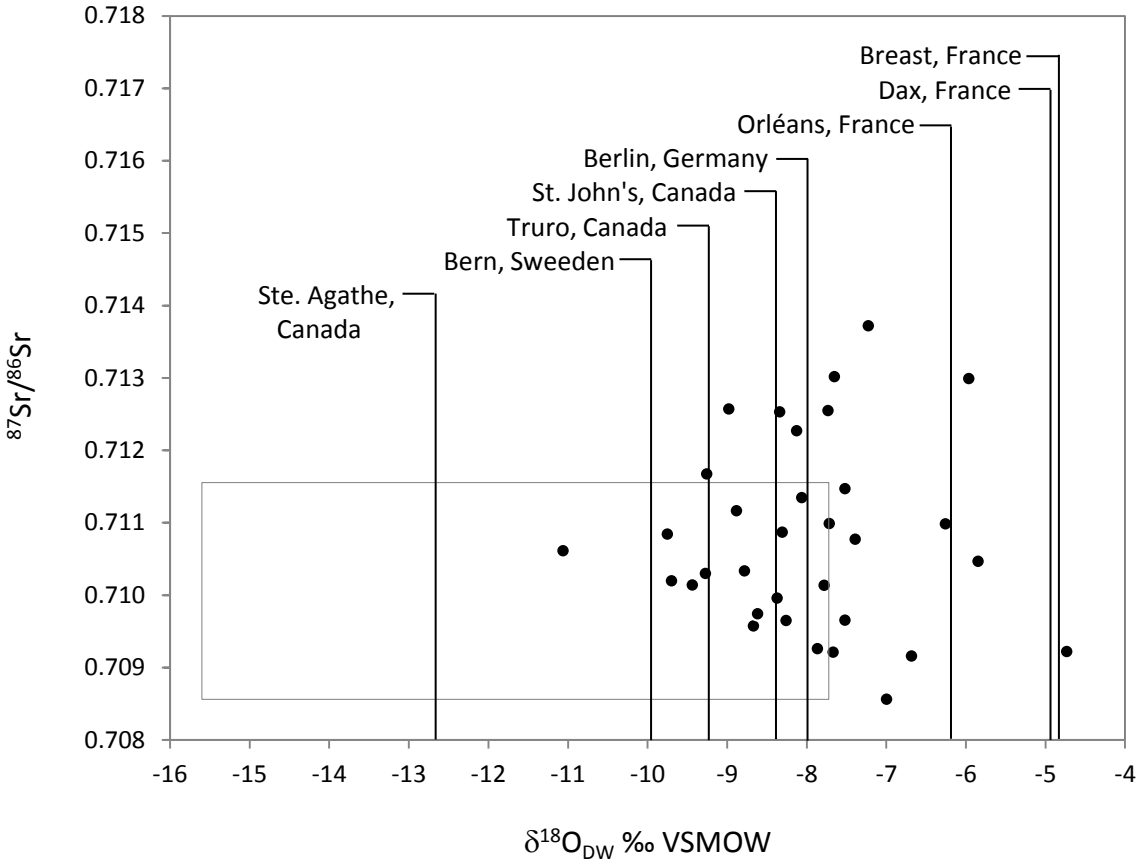


Figure 42. $\delta^{18}O_{DW}$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (n=33, Table 27) and $\delta^{18}O_{PPT}$ values for areas of Canada, France, Switzerland, and Germany (Table 28). Also shown are the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges.

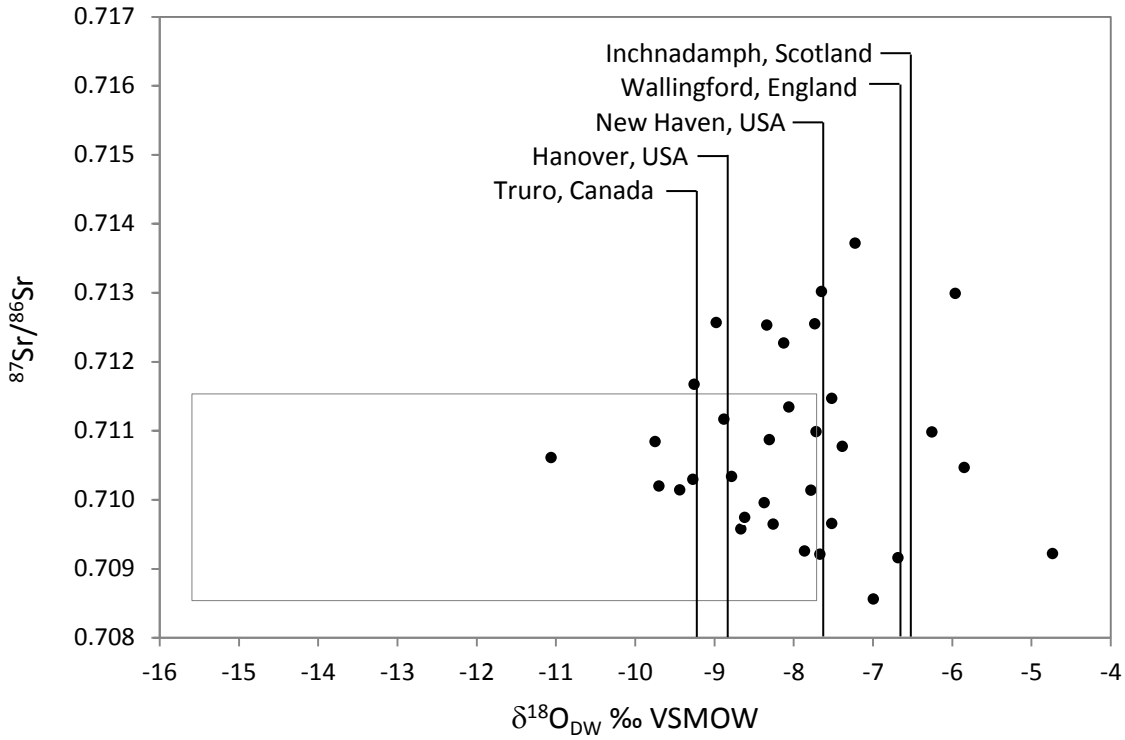


Figure 43. $\delta^{18}O_{DW}$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (n=33, Table 27) and $\delta^{18}O_{PPT}$ values for areas of Canada, New England, and Britain (Table 28). Also shown are the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges.

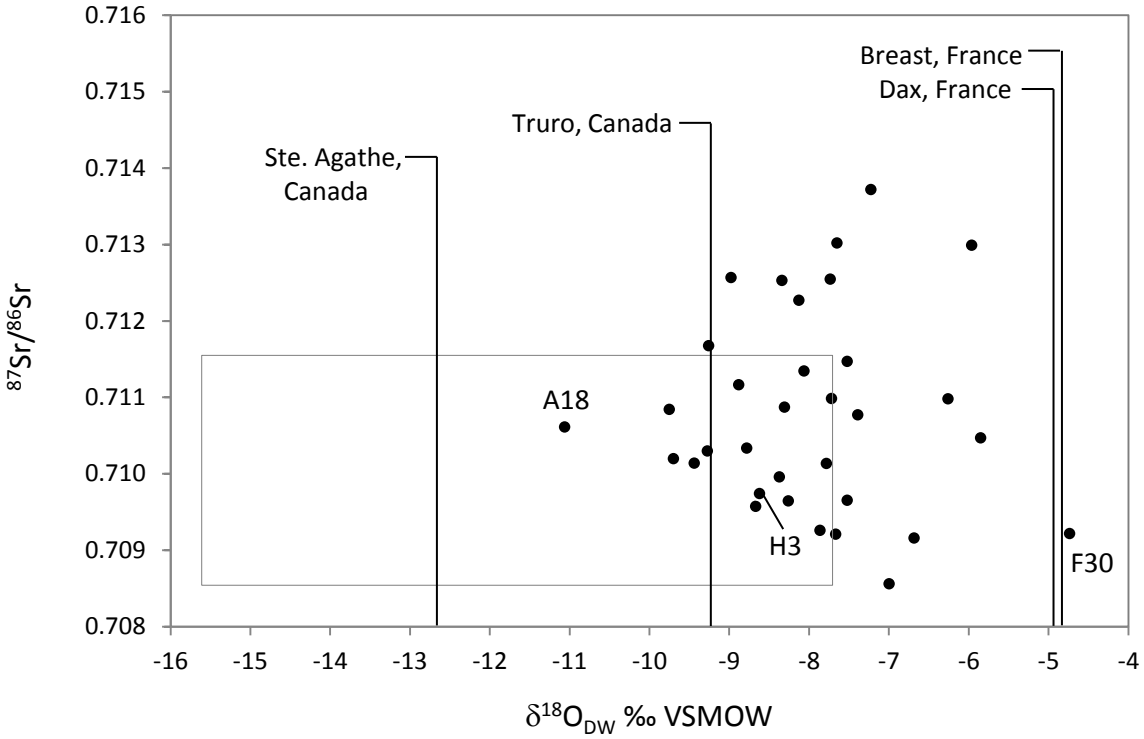
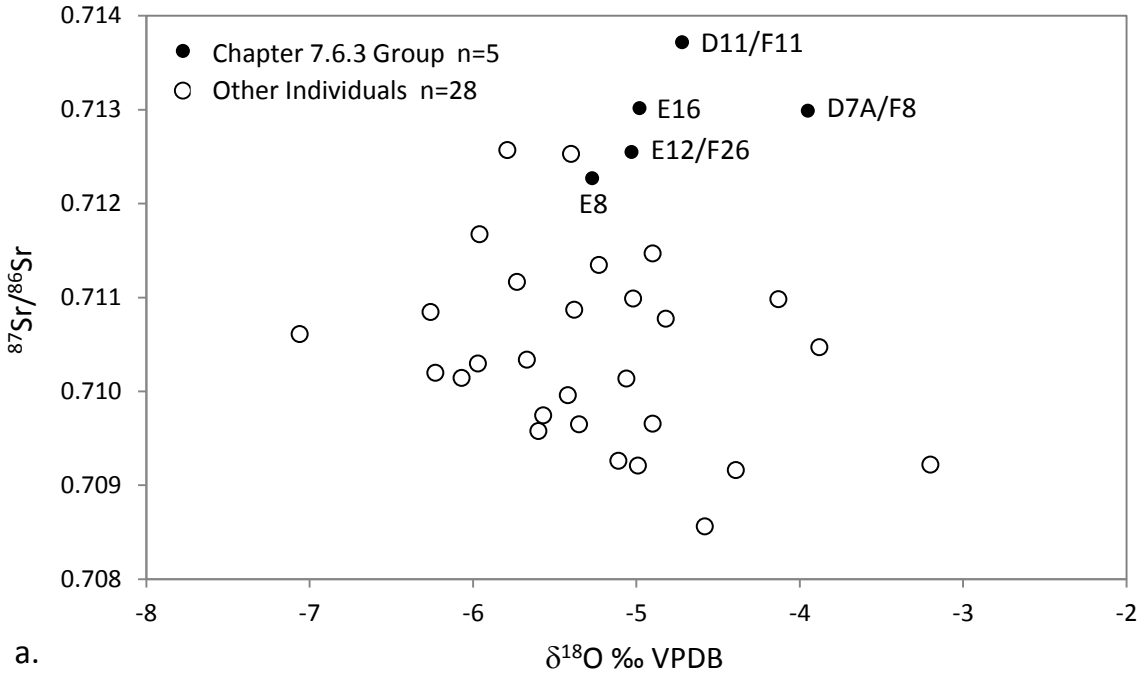


Figure 44. $\delta^{18}O_{DW}$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (n=33, Table 27) with individuals H3, F30, and A18 identified and $\delta^{18}O_{PPT}$ values for areas of Ste. Agathe and Truro, Canada and Dax and Breast, France (Table 28). Also shown are the $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ 2σ ranges.



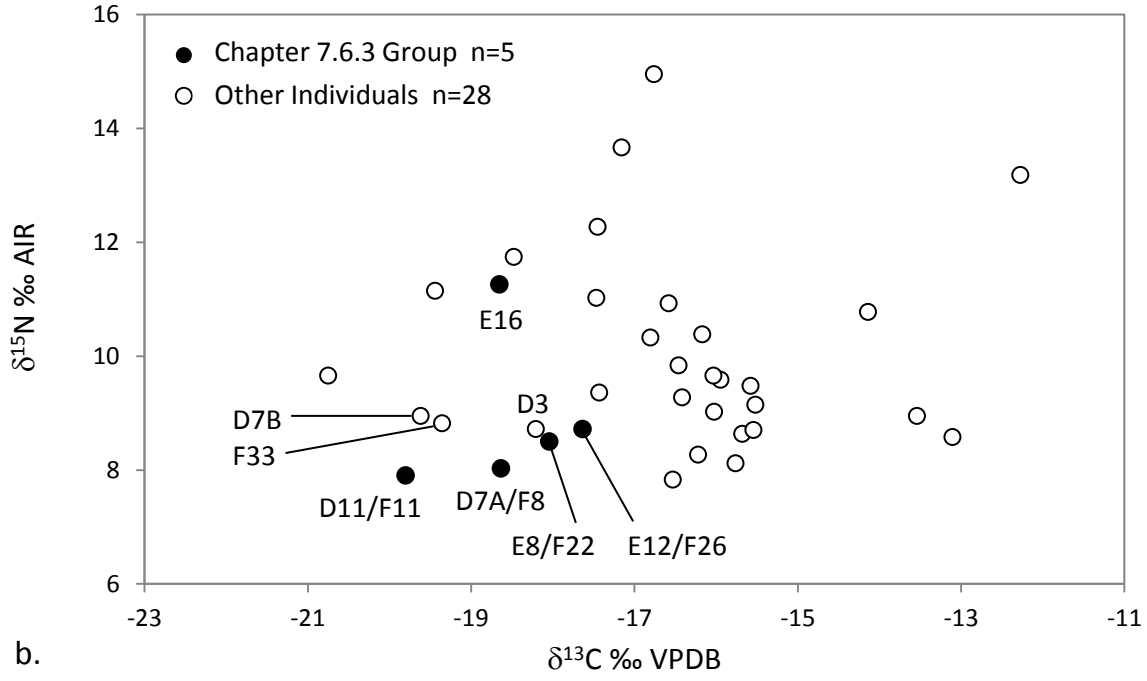
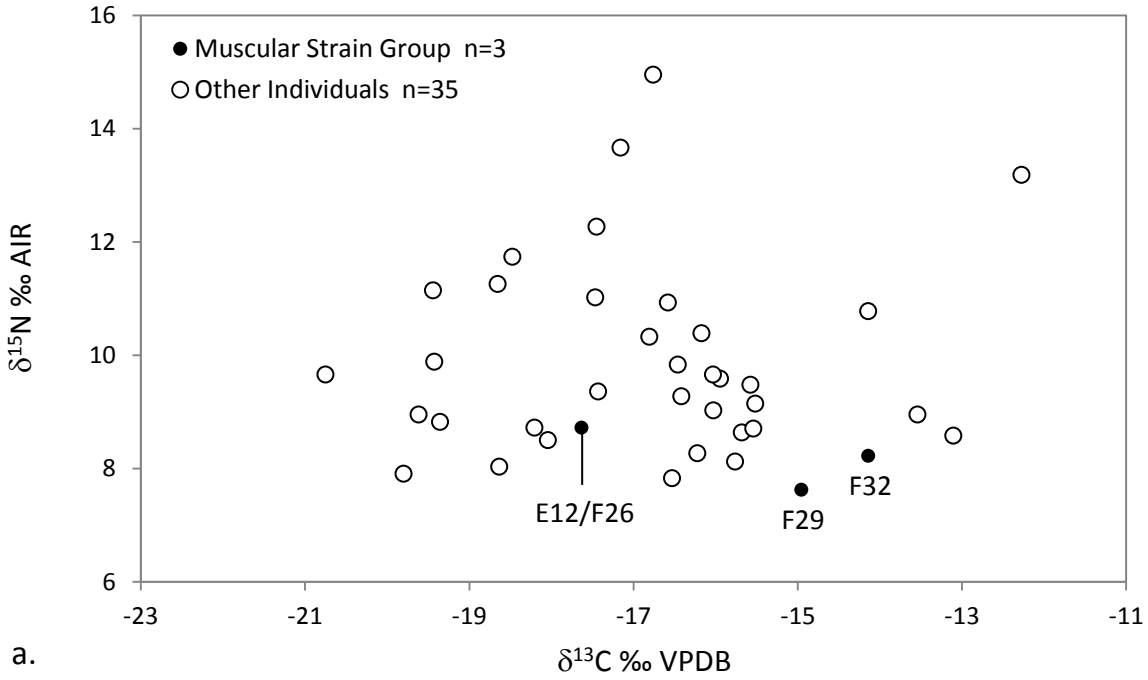


Figure 45. (a) $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values and (b) $\delta^{13}C$ and $\delta^{15}N$ values for the Ste. Marie individuals (Table 22) with individuals from Chapter 7.6.3 identified.



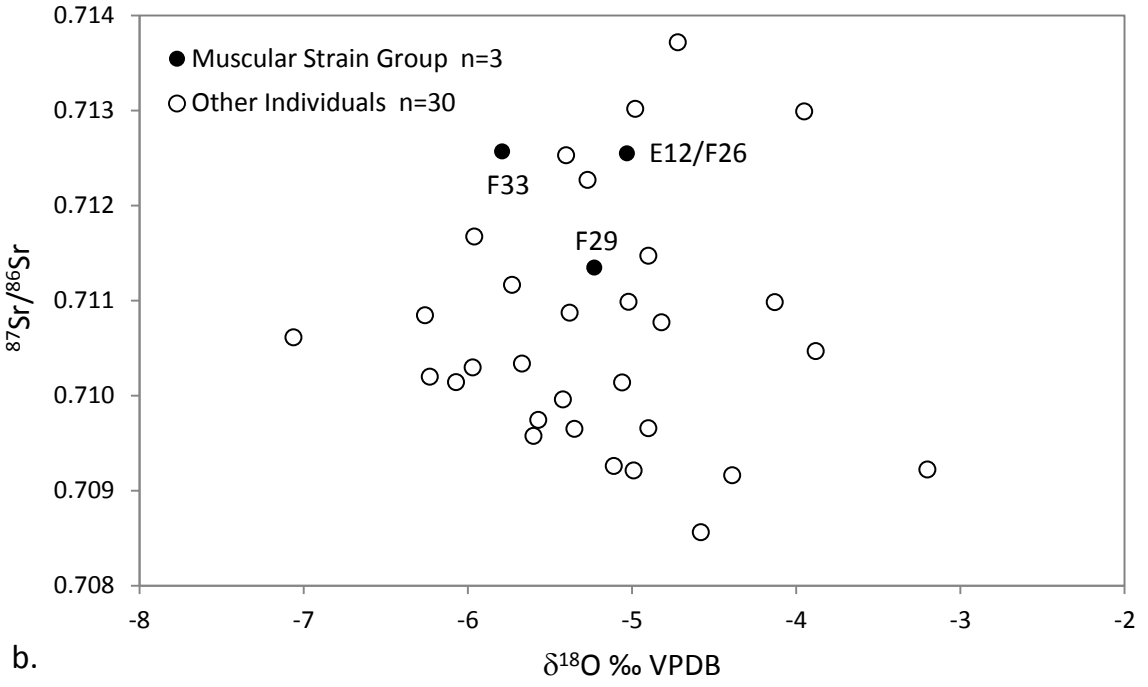
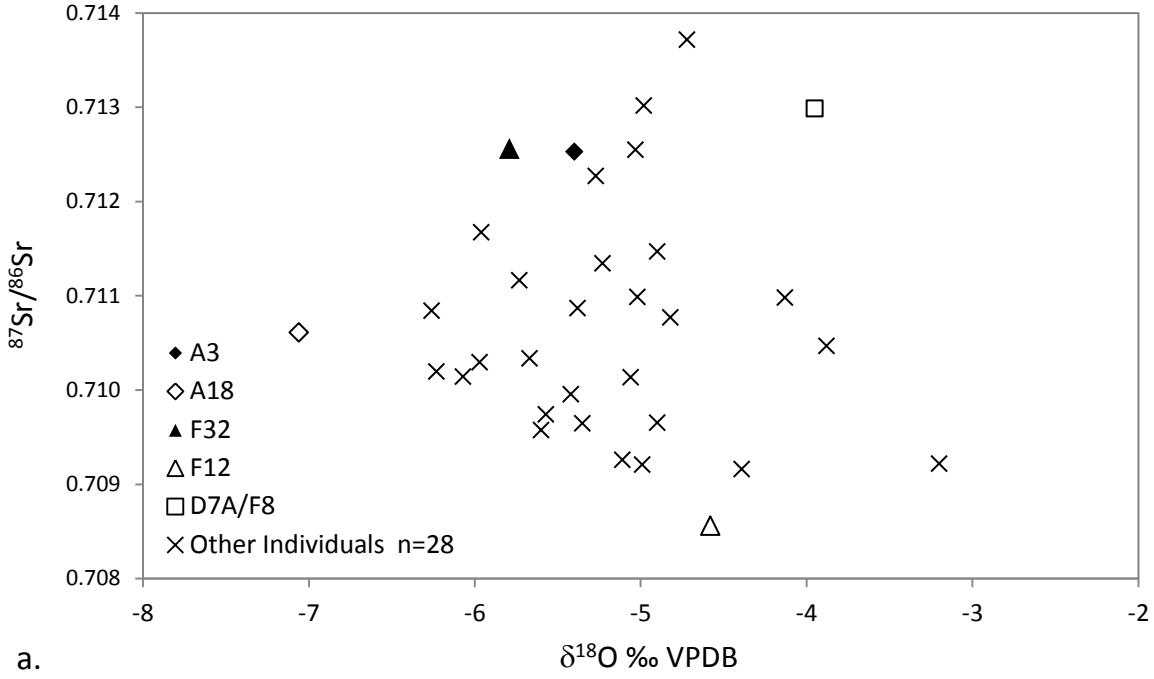
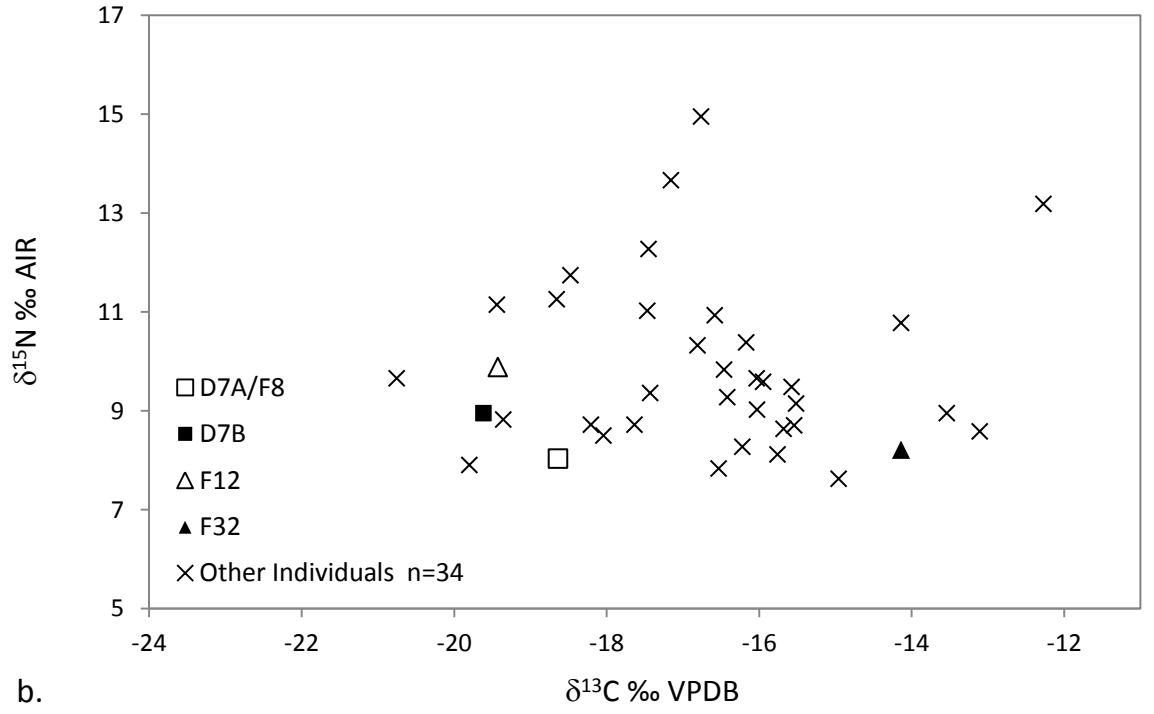


Figure 46. (a) $\delta^{13}C$ and $\delta^{15}N$ values and (b) $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values for the Ste. Marie individuals (Table 22) with individuals with indications of muscular strain identified (n=3, Table 17) (see Chapter 7.6.4).



a.



b.

Figure 47. (a) $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ values and (b) $\delta^{13}C$ and $\delta^{15}N$ values for the Ste. Marie individuals (Table 22) with sub-adults (solid markers) and women (open markers) identified (see Chapters 7.6.5 and 7.6.6).

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