DOGS AS ANALOGS IN STABLE ISOTOPE-BASED HUMAN PALEODIETARY RECONSTRUCTIONS: ASSESSING THE CANINE SURROGACY APPROACH

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Dogs as analogs in stable isotope-based human paleodietary reconstructions: Assessing the Canine Surrogacy Approach

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Abstract

In contexts where human remains are scarce, poorly preserved, or otherwise unavailable for stable isotope-based paleodietary reconstruction, domestic dog bone collagen as well as other tissues may provide a suitable analogical material for addressing questions relating to human dietary practices. The premise of this "Canine Surrogacy Approach" (CSA) is that dogs likely consumed scraps from human meals and feces and thus could have shared an isotopically similar diet with contemporaneous humans.

This thesis has three objectives. The first is to provide an overview of the CSA's development and use. A literature review and a cross-contextual comparison of human-dog dietary similarities shows that dogs can most often provide a rough dietary analogy for their human keepers in a wide variety of contexts. The ensuing discussion details where and why the CSA is most likely to be applied as well as where future methodological innovation is likely to occur.

Second, theoretical considerations indicate how CSA applications are essentially analogical inferences which can be divided into two groups, each providing specific types of information and requiring different levels of substantiation. A framework for three categories of factors is outlined to aid in establishing positive, negative, and neutral elements of comparison of dog and human diets. These considerations show that CSA applications can benefit from explicitly detailing the type and nature of the analogical reasoning employed and from providing a systematic assessment of the degree to which stable isotope values of dogs and humans under comparison are thought to be like, unlike, or of unknown likeness.

Third, a case study is presented to test the CSA. Stable carbon and nitrogen isotope analysis of dog and (previously analyzed) human bone collagen is used to reconstruct human diet among two related Late Archaic maritime oriented hunter-gatherer groups – the Moorehead and the Maritime Archaic Indian. Based on a demonstrated human-dog similarity in these contexts, the CSA is then applied to help understand human diet in a similar archaeological context in which no human remains have been recovered - the Moorehead occupation of the Turner Farm site.

Dedication

This work is dedicated to Derek and Della Malivoire. I would not be where I am today if not for their care, patience, encouragement, and wisdom.

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Chapter One

Introduction

1.1 Introduction

Reconstructing dietary regimes is one way that archaeologists understand ancient human lifeways. Stable-isotope analyses have been established as an effective method for reconstructing ancient diet (Katzenberg 2008). Stable isotope-based paleodietary reconstructions are conducted based on the premise that 'you are what you eat,' and that different kinds of foods have distinguishable isotopic compositions. With this foundational knowledge, archaeological bone chemists study stable carbon and nitrogen isotope compositions preserved in ancient human tissues to understand past dietary trends. This form of paleodietary reconstruction is important, as it is one of few ways that archaeologists can obtain direct information on past human dietary and nutritional practices. Though highly valuable, stable isotope work is destructive. For this reason, in some parts of the world, isotopic analysis has led to concerns among various academic, non-academic and indigenous communities regarding the ethical treatment of ancestrally and scientifically important human remains (Hublin et al. 2008; Katzenberg 2001; Walker 2008:25-26).

In light of legislation such as the Native American Graves Protection and Repatriation Act (NAGPRA), archaeological bone chemists contending with issues of the inaccessibility of human remains for stable isotope-based research have sought materials that may provide an alternative to human remains. The 'Canine Surrogacy Approach' (CSA; Cannon et al. 1999; Guiry 2012) has been one result of these efforts. The CSA analyzes ancient dog (*Canis*

familiaris) remains as a human proxy material in order to understand human dietary practices (e.g. Cannon et al. 1999). This approach is based on the fact that dogs have often subsisted on the scraps of human meals and feces and thus may have isotopic dietary signatures similar to contemporaneous humans.

The CSA is a model in which dogs are used as a dietary analogy for their contemporaneous human keepers. However, unlike more traditional uses of analogy in archaeological interpretation, which are often ethnographical (see Ascher 1961; Orme 1974; Wylie 2002:136-153), the CSA provides a relatively unique case in which the analogy is essentially biological. The CSA analogy relies on biochemical and other assumed metabolic similarities yet is simultaneously influenced by cultural, environmental and biobehavioral factors.

Over the past 30 years the CSA has developed and evolved at varying rates, at different times and places, and for a variety of reasons. Despite a recent flurry of more sophisticated development, researchers are still stressing an unrealized potential for dogs to act as proxies for humans (e.g. Spence and White 2009:240). At the same time, there remains some confusion in the literature with regards to what the CSA is, as well as criticism of its validity as an effective tool for studying human diets (e.g. Bocherens et al. 2000; Eriksson 2004; Eriksson and Zagorska 2003:160-162). These issues may reflect the fact that the complex analogical nature of CSA inferences has rarely been addressed in the literature (for some examples see Allitt 2008; Cannon et al. 1999; Eriksson and Zagorska 2003; Noe-Nygaard 1988; Tankersley and Koster 2009; White 2004) and/or that very little work has been done towards surveying and cohesively summarizing potential issues which might arise during CSA interpretations.

This thesis explores and characterizes the CSA's development and validity as a technique in three parts. The first part (Chapter 4) provides an outline of the CSA's origin and evolution with particular emphasis on identifying the impetuses for, and trends in, its development. In addition to clarifying the inception of the CSA as well as where and why it is applied today, this review and assessment allows for the identification of future directions for methodological innovation.

The second part (Chapter 5) explores the analogical nature of CSA applications and attempts to show why such considerations are necessary for producing more convincing interpretations of ancient human diet. Although dog and human bone collagen stable isotope values generally track one another to varying extents independent of spatial, temporal, or cultural context, this chapter demonstrates the need for CSA authors to explicitly consider the different ways in which dogs can be used to provide information on human dietary practices and the factors which can influence human-dog dietary proxy relationships. Examining different CSA applications in terms of their unique analogical context indicates how varying applications provide different kinds of information that, in turn, may require different sets of qualifying considerations. These considerations are critical when formulating compelling CSA interpretations.

The third part (Chapter 6) provides a case study testing the CSA's validity for reconstructing human diet between two related Late Archaic archaeological cultures – the Moorehead and the Maritime Archaic Indian. These groups were marine-oriented hunter-gatherers inhabiting the northeastern coasts of North America between Maine and Labrador. Stable carbon and nitrogen isotope analysis of bone collagen is used to demonstrate human-dog dietary similarities in these cultural, environmental and temporal contexts. Based on this

demonstration, the CSA is then applied to help understand human diet in a similar archaeological context in which no human remains have been recovered – the Moorehead occupation of the Turner Farm site. This chapter also provides the first demonstration of techniques and theoretical considerations developed during Chapter Five, and offers an example of how the CSA can be substantiated. Chapters Two and Three give theoretical and methodological background information on stable isotope-based paleodietary reconstructions. These chapters are intended to provide the reader with sufficient understanding of archaeological bone chemistry to effectively interpret the results and discussion sections of Chapter Six.

Chapter Two

Stable Isotopes: A Theoretical Background

2.1 Introduction

Paleodietary reconstructions using stable isotope analysis of skeletal tissues have become a well established and common application during archaeological studies of past human lifeways (Ambrose 1993; Katzenberg 2008; Sealy 2001). This chapter lays out the basic theoretical underpinnings of stable isotope analysis of archaeological bone collagen to provide background information relevant to later chapters.

The feasibility and utility of stable isotope-based paleodietary reconstruction was demonstrated in the late 1970s and early 1980s (e.g. Ambrose 1993:61-63; Schoeninger et al. 1983; Van der Merwe 1982; Van der Merwe and Vogel 1978). Since this time stable isotope work has been used to reconstruct ancient human diets and food-related behavioural patterns in many cultural, geographical and environmental contexts spanning human existence. For example, studies have tracked the origin and spread of crops such as maize and millet in the Americas and Asia, respectively (e.g. Barton et al. 2009; Tykot 2006); identified the remains of individuals who have immigrated into a given population (e.g. Müldner et al. 2011); indicated variation in dietary practices of different status and gender groups within the same population (e.g. White 2006); and reconstructed infant weaning practices (Fuller et al. 2006; Schurr 1998).

Stable isotope analysis of human bone tissue is one of few direct ways of analyzing human diet; however, interpreting stable isotope information often depends on prior knowledge of the archaeological context. Lacking contextual information, stable isotope values cannot indicate specific dietary contributions but may be able to show general dietary trends.

Interpretations of stable isotope information should be constrained within the frame of a set of probable dietary options. This information is often derived from direct historical or ethnographical analogies as well as paleoethnobotanical and zooarchaeological data.

2.2 The Nature, Notation and Measurement of Isotopes

Unless otherwise cited, the following discussion is composed of foundational scientific knowledge detailed in most elementary chemistry textbooks (e.g. Timberlake 1999). For further information on any concept see Hoefs (2009).

Atoms are elemental units composed of a specific number of protons, neutrons and electrons that together create the qualities and characteristics of a given chemical element. Protons, which have appreciable mass, carry a positive charge countered by the negative charge of associated electrons that have virtually no appreciable mass. Unlike protons and electrons, neutrons carry no charge and have a mass similar to that of protons. Within an atom the proportional relationship between protons and electrons is often equal. While atoms will usually also have an equal number of protons and neutrons, together making up a majority of the atom's mass, variation in number of neutrons can occur. These variations constitute different isotopes, or isotopic species, of an element. For example 99% of carbon atoms have six protons matched by six neutrons making up an atomic mass of 12. This particular carbon isotope is chemically denoted by the symbol "^{12}C", where "C" stands for carbon and the superscript "12" indicates the atomic mass contributed by six protons and six neutrons. A relatively small number of carbon atoms will have one or two additional neutrons giving them atomic masses of 13 and 14 and these carbon isotopes are shown as ^{13}C and ^{14}C, respectively.

Isotope species may be radioactive (e.g. ^{14}C) or stable (e.g. ^{12}C and ^{13}C). The additional mass of extra neutron(s) may or may not allow an isotope species to become radioactive causing the atom to decay spontaneously (Hoefs 2009:1). Isotope species that are not radioactive, on the other hand, are by definition stable and are known as stable isotopes. This thesis deals specifically with four varieties of these stable isotopes – ^{12}C and ^{13}C as well as ^{14}N and ^{15}N.

With the same number of protons and electrons, isotope species belonging to the same element share similar electrical and, for the most part, chemical properties. With differing masses, however, isotope species of the same element have slightly differing physical properties including variations in tendency to engage in chemical reactions or state transitions (Hoefs 2009:4-11). These differing tendencies can cause isotopic fractionation - a process in which isotopes involved in a reaction are to some degree preferentially routed to certain products or left in reactants (Hoefs 2009:5). If occurring in a systematic manner, fractionation may cause distinctive isotopic patterning between different constituents of an environment or biological entity called isotopic signatures or labels.

The isotopic composition of a material is measured using an isotope ratio mass spectrometer (IRMS) (Ambrose 1993:67-71; Hoefs 2009:23-26). Briefly, when analyzing relative proportions of stable carbon and nitrogen isotopes, a sample is combusted in the presence of oxygen, converting the carbon and nitrogen atoms contained within to carbon dioxide (CO_2) and nitrogen gas (N_2), respectively. These gases are carried by an inert gas-carrier such as helium through a curved passage, called a flight tube, past a magnet within the IRMS. The magnetic force separates the trajectories of different isotope species as they pass through the flight tube based on mass-charge ratio. At the end of the flight tube, different isotopes meet detecting surfaces, known as faraday cups, at separate points allowing for the detection of

relative quantities of each isotopic species. Compositional difference between isotopes is reported as a delta (δ) value relative to a conventional isotopic standard and is expressed in parts per thousand (‰) as a ratio between heavier and lighter isotopic species (i.e. $^{15}N/^{14}N$ and $^{13}C/^{12}C$) as follows: [$\delta = ((X_{standard}/X_{sample}) - 1) \times 1000$]. International standards for stable carbon ($\delta^{13}C$) and nitrogen isotope ($\delta^{15}N$) ratio measurements are the Vienna PeeDee Belemnite geological formation (VPDB) (Hut 1987) and the Ambient Inhalable Reservoir (AIR), which is atmospheric N^2 (Mariotti 1983). Comparing the elemental concentrations of sample materials to those of elemental standards with known concentrations of carbon and nitrogen allows for determination of elemental concentrations (see Section 3.4).

2.3 Stable Carbon Isotopes

Carbon is the most abundant and fundamental elemental building block of life. The VPDB isotope standard used for determining stable carbon isotope composition derives from a marine limestone deposit and has a $\delta^{13}C$ value of 0‰. Carbon in most terrestrial biological substances has less ^{13}C relative to ^{12}C when compared to the VPDB and thus $\delta^{13}C$ measurements of biological materials will usually produce negative values.

2.3.1 Stable Carbon Isotopes in Terrestrial Ecosystems

Stable carbon isotope values from bone collagen can offer information on sources of dietary intake. The most biologically significant stable carbon isotope fractionation phenomena occur during plant photosynthesis – the juncture at which inorganic atmospheric carbon is incorporated into organic materials. Plants incorporate, or 'fix', carbon using one of three photosynthetic pathways; however, the majority of plant species rely on one of two pathways:

the Calvin Cycle or the Hatch-Slack Cycle (Stern et al. 2003:182-185). The initial step in the Calvin Cycle produces a carbon molecule with three carbon atoms whereas the first step of the Hatch-Slack Cycle produces a carbon chain incorporating four atoms; and, based on this distinction, plants belonging to either of these categories are known as C_3 or C_4 plants, respectively. These differences in carbon fixation methods, as well as other morphological differences have evolved to provide C_3 and C_4 plants with adaptive advantages for different environments. A majority of plant species and domesticates use the C_3 pathway. The C_4 photosynthetic pathway is slightly less energy efficient, but in conjunction with other adaptations, enables C_4 plants to conserve water in arid environments (Stern et al. 2003:184). Plants with C_4 photosynthetic pathways belong mainly to tropical grasses, and include domesticates such as maize, millet, sorghum, and sugarcane. During carbon fixation, C_3 plants discriminate against isotopically heavier ^{13}C relative to ^{12}C more than C_4 plants (Bender 1968; O'Leary 1981, 1988; Tieszen 1991). For this reason, C_3 and C_4 plants produce large but non-overlapping ranges of $\delta^{13}C$ values that average -27.1±2.0‰ (1σ) and -13.1±1.2‰ (1σ), respectively (O'Leary 1988).

The third photosynthetic pathway is Crassulacean Acid Metabolism (CAM) (Stern et al. 2003:182-185). Succulents and a few other plant groups use the CAM pathway which can employ both C_3 and C_4 photosynthetic processes and is best adapted for arid environments. For this reason, CAM plant species produce variable $\delta^{13}C$ signatures reflecting the metabolic strategy that had predominated during tissue growth, most often falling between -10‰ and -20‰ (O'Leary 1988). CAM plants, however, were probably not a significant dietary component for the ancient peoples discussed in this thesis and for this reason will not be considered further.

Stable carbon isotope signatures of plants are passed on to the tissues of their herbivorous and omnivorous consumers (DeNiro and Epstein 1978) with relatively little fractionation (although for bone collagen, see Section 2.5). Likewise, when plant consumers become prey, their $\delta^{13}C$ values are passed up the food chain to the carnivorous or omnivorous consumer. Therefore, based on the distinction between $\delta^{13}C$ values of plants with differing photosynthetic pathways, and the faithful transmission of these signatures up the food chain, relative proportions of C_3 and C_4 plants contributing to human diet can be determined (Van der Merwe and Vogel 1978).

2.3.2 Stable Carbon Isotopes in Aquatic Ecosystems

Aquatic plants mainly use the C_3 pathway and source some of their carbon from CO_2 deriving from dissolved bicarbonates (HCO_3). Dissolved carbon in ocean water is much less depleted in ^{13}C ($\delta^{13}C$ ~0‰) than atmospheric carbon ($\delta^{13}C$ ~-7‰) (Craig 1957; 1970). For this reason marine and, to some extent, freshwater plants begin their photosynthetic fractionation processes with a larger proportion of ^{13}C relative to ^{12}C and generally produce $\delta^{13}C$ values similar to those of terrestrial C_4 plants.

Dissolved carbon in freshwater ecosystems can have variable $\delta^{13}C$ values due to the differences in the composition of local geologies that provide dissolved bicarbonates. For instance, dissolved carbon $\delta^{13}C$ values in a single Canadian drainage system were found to range over 20‰ (Hitchson and Krouse 1972). Additional factors contributing to variation in freshwater ecosystem $\delta^{13}C$ values include water temperature, water column depth, habitat variation and species composition (Hecky and Hesselin 1995; Katzenberg and Webber 1999). For these

reasons, caution should be taken when interpreting $\delta^{13}C$ values in contexts were freshwater resources may have contributed to diet.

The isotopic distinction between different carbon sources used by aquatic and terrestrial plants can allow for the differentiation of diets based on marine and C_3 dominated terrestrial ecosystems (Chisholm et al. 1982; Tauber 1981). Consumption of C_4 and ^{13}C enriched aquatic plants can produce similar $\delta^{13}C$ signatures. Therefore, when considering $\delta^{13}C$ values from humans that had occupied environments containing appreciable amounts of C_4 plants, or had practiced a C_4-focused agricultural system, interpretations of aquatic *versus* terrestrial dietary carbon sources should be made with caution (Klepinger 1984) and/or with the consideration of additional isotope systems (e.g. Privat et al. 2007).

2.3.3 Variability in Stable Carbon Isotopes

This thesis considers stable isotope data from different environmental contexts. Therefore, a variety of other factors contributing to variation in $\delta^{13}C$ values are borne in mind. These sources of $\delta^{13}C$ variability, operating on physiological and environmental scales, underline the importance of contextualizing isotope data when interpreting diet.

Some research has indicated that a small and poorly understood increase in $\delta^{13}C$ may occur between trophic levels during digestion of plant and especially animal tissues and subsequent incorporation into the consumer's tissues (Schoeninger 1985; Van Klinken et al. 2000:46-47). Estimates vary between studies as well as the species analyzed but a trophic level increase of between 0 and 2‰ (Bocherens and Drucker 2003; Boceherens and Mariotti 2002:1328-1329) is most commonly observed.

The $\delta^{13}C$ composition of atmospheric carbon fixed into organic materials by plants has varied spatially and temporally. For instance, research has documented lower $\delta^{13}C$ values in plants from densely forested areas (Vogel 1978) relative to open-air environments owing mainly to the relatively slow movement and repeated recycling of ^{13}C depleted air through forested environments (Medina et al. 1986; Van der Merwe and Medina 1991). Atmospheric $\delta^{13}C$ composition has also been raised by over 1‰ since the industrial revolution due to anthropogenic carbon contributions from fossil fuel burning (Friedli et al. 1986; Van der Merwe 1989:109-112).

Local environmental conditions may affect plant physiology and thus $\delta^{13}C$ composition of consumers' diets (Ambrose 1993:86-94; Tieszen 1991). For instance, factors such as declining irradiance (Ehleringer et al. 1986), nutrient stresses, and low temperatures (Tieszen 1991) have been found to increase plant $\delta^{13}C$ values. Meanwhile, factors such as aridity and water stress (Farquhar and Richards 1984), increasing altitude (Körner et al. 1988), high salinity, and osmostic stresses (e.g. Guy et al. 1980) have been found to decrease plant $\delta^{13}C$ values. The $\delta^{13}C$ compositions of C_3 and CAM plants are more strongly affected by such environmental influences than those of C_4 plants (Tieszen 1991).

2.4 Nitrogen Isotopes

Nitrogen is a substantial and isotopically homogeneous component of earth's atmosphere. For this reason, a $\delta^{15}N$ value of 0‰ for AIR (Ambient Inhalable Reservoir), which is atmospheric N^2, has been used as the international standard for stable nitrogen isotope analyses (Mariotti 1983).

2.4.1 Stable Nitrogen Isotopes and the Trophic Level Effect

Archaeologically, the most significant aspect of $\delta^{15}N$ information is a stepwise enrichment of ^{15}N relative to ^{14}N with each ascending trophic level of a food web (DeNiro and Epstein 1981; Minagawa and Wada 1984). While the cause of this enrichment is not fully understood, it is thought to partially result from biokenetic isotope fractionation as well as fractionation within transamination and deamination pools during metabolic processes and urea excretion (Ambrose 1991; Macko et al. 1986; for discussion see Ambrose 1993:93-101; Van Klinken et al. 2000:47-48). Although there have been conflicting results as to what the enrichment value between trophic levels is, most researchers agree that, as a general rule, $\delta^{15}N$ values increase by between 3 and 5‰ between autotrophs and herbivores, and herbivores and carnivores (Hedges and Reynard 2007).

In addition to providing information on trophic level, $\delta^{15}N$ values can give an indication of marine dietary input (Schoeninger et al. 1983). As marine and freshwater ecosystems can often have food chains with several levels of carnivory, high trophic level marine mammals, birds, and fish often have very high $\delta^{15}N$ values which do not usually occur in terrestrial ecosystems (Schoeninger and DeNiro 1984). Based on this distinction it has been possible to differentiate human diets based on marine *versus* terrestrial foods.

The $\delta^{15}N$ trophic level effect also applies to breastfeeding relationships between infants and mothers (Fogel et al. 1989). Infants are born with $\delta^{15}N$ values matching their mothers'. Once breastfeeding begins an infant will effectively be one trophic level ($\delta^{15}N$~+3‰) above the individual from which they nursed. As the infant is weaned onto the foods consumed by its mother, the $\delta^{15}N$ values of the infant's newly synthesized collagen will begin to converge with those of adults (assuming an isotopically homogenous diet between different age groups). After

the weaning process is complete, infant $\delta^{15}N$ values will remain elevated in bone collagen formed during breastfeeding until this material has been replaced by new bone collagen formed during childhood growth. Research conducted by Fuller and colleagues (2006) on infant finger nails confirms that this trophic level relationship between mother and child $\delta^{15}N$ values also extends to the $\delta^{13}C$ signature which becomes enriched by ~+1‰ (see Bocherens and Drucker 2003). Based on this relationship, researchers are able to reconstruct weaning practices among a particular group by analyzing bone and dentine collagen of infants and adults (e.g. Schurr 1998; Holt 2009).

2.4.2 Variability in Stable Nitrogen Isotopes

Several physiological and environmental factors contribute to variability in archaeological $\delta^{15}N$ signatures. Consideration of these sources of variability can help contextualize isotope data during paleodietary reconstructions.

The degree of ^{15}N enrichment occurring between trophic levels can be influenced by physiological factors in a variety of ways. For instance, protein stress (Hobson and Clark 1992; Hobson et al. 1993) and bone pathologies (Katzenberg and Lovell 1999) have been found to increase ^{15}N enrichment. Meanwhile, the effects of a high protein diet are poorly understood, having been found to both increase (e.g. Pearson et al. 2003; Sponheimer at al. 2003) and decrease (e.g. Robbins et al. 2005) ^{15}N enrichments between diet and body tissues. Additional variability in ^{15}N enrichment between diet and animal tissue has been noted on inter-tissue (Hobson and Clark 1992; Hobson et al. 1993), -individual, and -species (Minagawa and Wada 1984; Hedges and Reynard 2007) levels as well as between animals with different drinking habits (Ambrose and DeNiro 1987) and digestive physiologies (Sponheimer et al. 2003);

however, processes underlying this variability remain poorly understood (Hedges and Reynard 2007; Vanderklift and Ponsard 2003).

As nitrogen often enters the food chain through plants, the degree of ^{15}N enrichment found in an ecosystem will be relative to the $\delta^{15}N$ values of local autotrophs. In terrestrial environments, many plants satisfy their nitrogen needs by taking up nitrogenous compounds such as nitrites from adjacent soil. Biologically available nitrogen in soil can have widely variable $\delta^{15}N$ values over very small and large distances. Factors such as aridity or water stress (Heaton and Vogel 1986), salinity (Heaton 1987), soil ammonia volotization (Mizutani et al 1985), high altitude (Mariotti et al. 1980), and the nature and quantity of local bacterial activity (for review see Van Klinken et al. 2000:43-6) have been found to increase $\delta^{15}N$ values of soils and surrounding ecosystems. Natural variability in $\delta^{15}N$ values in certain contexts is further complicated by anthropogenic influences on soil nitrogen composition. For instance, the continued application of manure or modern synthetic fertilizers to fields can increase (Fraser et al. 2011; Koerner et al. 1999) or decrease (DeNiro and Epstien 1981; Freyer and Aly 1974), respectively, $\delta^{15}N$ values of affected soils and the plants growing on them.

Another source of isotopic variability in terrestrial and marine (particularly coral reefs) and estuarine ecosystems comes from plants such as legumes and blue-green algae (phylum of cyanobacteria) that have a symbiotic relationship with nitrogen-fixing bacteria. This symbiosis allows some plants to draw their nitrogen from atmospheric sources with little fractionation of stable nitrogen isotope ratios. For this reason, these plants usually have $\delta^{15}N$ values of around 0‰ (e.g. Capone and Carpenter 1982; Verginia and Delwiche 1982).

Considering these potential sources of variability in soil and plant $\delta^{15}N$ values, and that plants represent the junction at which much nitrogen enters vertebrate food webs, it is important

to carefully consider the ecological and agricultural context which frames a given paleodietary reconstruction.

2.5 Tissues Analyzed

While, stable carbon and nitrogen isotope ratios can be measured in most biological tissues, the dietary signatures they represent can vary between different types of tissues belonging to the same individual due to differences in formation time, composition, and rate of turnover (e.g. Hobson and Clark 1992). Durable osseous tissues (i.e. bone and tooth materials) commonly survive in the archaeological record and for this reason are often used by stable isotope analysts for paleodietary reconstructions.

Fresh bone tissue is composed of roughly 25% organic matter and 75% inorganic mineral by weight (for review see Martin et al. 1998:29-77). Ninety percent of the organic matter is composed of Type 1 collagen, a protein made up of three polypeptide chains in triple helix formation. The remaining 10% of organic matter is made-up of non-collagenous proteins and lipids. Bone collagen fibrils crosslink forming a lattice structure which acts as a reinforcement mesh substrate upon which binds the mineral phase of bone, predominantly hydroxyapatite crystals.

Bone collagen is the analyte in this thesis and has been a primary material studied during stable isotope-based paleodietary reconstructions in archaeology for multiple reasons. During early stable isotope methodological development, collagen was an attractive and convenient material because procedures for extracting this protein from archaeological bone were already available from previous radiocarbon dating work (Katzenberg 2008:415). Also, partially owing to encasement within the mineral phase of bone (Collins 1995), collagen can survive intact for

long periods of time, thousands of years or perhaps even longer, under ideal post-depositional conditions (e.g. Bocherens et al. 1996; Avci et al. 2005). Other factors making bone collagen an appropriate material for analysis include its conservative structure (Ambrose 1993:72), its insolubility and ease of extraction (Hedges and Law 1989), its abundance in bone, and its recording of a relatively long period of dietary intake (Collins et al. 2002). Research has also found that factors such as age and sex do not affect how bone collagen records stable isotope dietary information (e.g. DeNiro and Schoeninger 1983; Lovell et al. 1986)(although infants are expected to be one trophic level higher than adults in $\delta^{15}N$ – see Section 2.4.1; e.g. Schurr 1998). Most importantly, however, collagen molecules contain carbon and nitrogen in sufficient quantities for efficient isotopic characterization.

2.5.1 Bone Collagen: Time Period of Dietary Representation

Over 30 years of research (Geyh 2001; Hedges et al. 2007; Manolagas 2000; Stenhouse and Baxter 1979; Ubelaker et al. 2006; Wild et al. 2000) has demonstrated that bone tissue formation and homeostasis occur more slowly than in other bodily tissues and that bone collagen may contain dietary signatures reflecting up to, or more than, 20 years of dietary intake (e.g. Wild et al. 2000). The pace at which old bone material is replaced with new bone is called the turnover rate. Bone turnover rates are known to vary according to several factors including bone density, thickness, age, sex, and pathological influences as well as by skeletal element and localized geometrical bone growth pattern (Hedges et al. 2007). Dense and thick regions of cortical bone turnover more slowly than spongy thin cancellous bone (Snyder et al. 1975:75). For this reason, bone from skeletal elements such as ribs will turnover in a fraction of the time (perhaps less than a decade) taken by compact bone from a femur and will contain proportionally

more bone collagen laid down at later stages of life. For this reason, analyzing skeletal elements with different turnover rates from the same individual can help assess dietary changes over time (e.g. Cox and Sealy 1997; Sealy et al. 1995). Bone tissue formation and remodeling are accelerated during childhood growth (up to 10-15% turnover/year between ages of 10 to 15) but slow down as an individual reaches adulthood (Hedges et al. 2007). Research by Hedges and colleagues (2007) has tentatively suggested that bone turnover rates are more rapid in adolescent males than in females of the same age. Their study also demonstrated the opposite for adults, with female bone collagen turnover rates changing from 4% turnover/year to 3% turnover/year between the ages of 25 and 80, and males turnover rates slowing from 3% turnover/year to 1.5% turnover/year during the same age period. Hedges and colleagues (2007) further indicate that complete turnover of bone collagen between the stages of adolescence and adulthood may not be attained within denser and thicker bone tissues such as femoral diaphyses. Bone collagen turnover may also be influenced in a variety of ways by bone pathology in affected regions of bone. For instance, bone material formed in the process of healing a fracture will contain bone collagen reflecting diet during and after the healing process. As the effects of bone pathologies on stable isotope composition of bone collagen are poorly understood, it is a common practice to avoid sampling bone which is suspected of having been influenced by pathological processes when sampling bone materials for the purpose of stable isotope-based paleodietary reconstruction (e.g. Katzenberg and Lovell 1999)

2.5.2 Dietary Components Reflected by $\delta^{13}C$ and $\delta^{15}N$ Values of Bone Collagen

Dietary isotope signatures from bone collagen do not accurately represent an average of all components of whole diet – carbohydrates, lipids, and proteins – but rather tend to be biased

towards the protein contributions to diet (e.g. Ambrose and Norr 1993). Carbohydrates and lipids do not contain nitrogen and, for this reason, most researchers assume that bone collagen $\delta^{15}N$ values must reflect only dietary protein (e.g. Ambrose et al. 1997; Van Klinken et al 2000:51). Carbon, on the other hand, is present in all three dietary components. As a protein, collagen is composed of essential amino acids (EAAs), which cannot be synthesized by the human body and must be derived from dietary sources, and non-essential amino acids (NEAAs), which the human body is capable of synthesizing *de novo*. Carbon atoms included in the EAA component of diet will necessarily reflect only dietary protein sources. Like EAAs, NEAAs may also be routed directly from diet but can additionally be constructed from amino acid precursor molecules deriving from carbohydrates, lipids or other proteins. For this reason, NEAAs contributing to collagen synthesis may have stable carbon isotope values reflecting both protein and non-protein dietary components (for review see Jim et al. 2006). The proportion of NEAAs constructed from dietary protein as opposed to non protein sources may be dependent on several poorly understood metabolic processes occurring in deamination and transamination pools as well as factors such as physiology or dietary stresses (e.g. Ambrose et al. 1997). Independently producing NEAAs *de novo* would be less energy efficient than reusing existing NEAAs deriving from dietary protein intake and, based on this reasoning, it is commonly assumed that some NEAAs used in collagen synthesis will also have been routed directly from dietary sources (Ambrose et al. 1997). Several controlled feeding experiments have supported this theory by showing that bone collagen stable carbon isotope values more strongly reflect dietary protein sources than other bone components such as bone mineral or cholesterol (e.g. Ambrose and Norr 1993; Jim et al. 2004, 2006; Tieszen and Fagre 1993). The implications of these experiments for interpreting bone collagen stable isotope information for the purpose of paleodietary

reconstruction are: 1) that all $\delta^{15}N$ values reflect dietary protein sources; and 2) that, where stable carbon isotope compositions differ between protein and non-protein dietary components, bone collagen $\delta^{13}C$ values will not reflect whole diet, but rather will show a bias towards the protein component.

2.5.3 Offset in $\delta^{13}C$ between Diet and Bone Collagen

Controlled experiments have shown that different tissues from the same individual can have stable isotope values which are consistently offset from those of whole diet (e.g. Hobson and Clark 1992). The offset in stable isotope composition of bone collagen must be known in order to reconstruct diet using this material. Although substantial variation relating to diet quality and differences between $\delta^{13}C$ values of protein and non-protein dietary components has been observed in some studies (e.g. Ambrose and Norr 1993; Tieszen and Fagre 1993), most researchers assume an average ^{13}C enrichment of 5‰ between whole diet and human bone collagen (e.g. Hedges 2003; Jim et al. 2006). Aside from the trophic level effect outlined in Section 2.4.1, $\delta^{15}N$ values are not offset between diet and the bone collagen of a consumer (DeNiro and Epstein 1981; Ambrose 1993:97).

2.6 Diagenesis

Bone collagen diagenesis, as considered here, is the physical or chemical alteration of biogenic stable isotope values of bone collagen occurring between the time an individual died and the time of excavation. Stable isotope-based paleodietary reconstructions can be skewed if diagenetic processes have altered the stable isotope compositions of a specimen such that they are dissimilar to the biogenic stable isotope ratios (Hedges 2002). For this reason, identification

of specimens that have undergone diagenetic processes is imperative for accurate and credible paleodietary reconstructions. Techniques for detecting diagenesis are detailed in Section 3.3. This section will very briefly outline current understandings of diagenetic processes of collagen loss and alteration and their effects on stable isotope ratios.

Several factors influence collagen loss, alteration and preservation. For instance, collagen degradation is mitigated by encasement in bone mineral (Kronick and Cooke 1996) and close packing of collagen fibrils (Miles and Ghelashvili 1999). For this reason processes acting against the preservation of these relationships can accelerate collagen diagenesis. Although underlying processes remain poorly understood, collagen loss is thought to be more strongly influenced by events occurring relatively early after death and interment (Fernádez-Jalvo et al. 2002) and is encouraged by increasing thermal age (Nielsen-Marsh et al. 2000), microbial activity (Child 1995), excessive pH and organic acids (Collins et al. 2002; Rudakova and Zaikov 1987) as well as antemortem factors such as collagen glycation reactions and increased bone porosity (Collins et al. 2002).

Most diagenetic alterations involve hydrolysis of weaker peptide bonds in collagen molecules (Bada 1985). With continued hydrolysis, a collagen molecule is shortened and smaller fragments may gelatinize, becoming soluble and allowing them to be leached from the bone under certain conditions (see Collins 1995 for modeling). Survival and recovery of gelatin in bone is rare and usually limited to specimens recovered from very dry depositional environments (e.g. Iacumin et al. 1996). Due to this tendency for loss of smaller fragments of collagen, bone specimens affected by diagenesis can morphologically appear to be well preserved but may actually contain very little original collagen. An additional problem is that hydrolysis, whether it is induced by microbial or abiotic activity, has been shown to fractionate stable isotope ratios

(Bada et al. 1989; Silfer et al. 1992). Some research, for instance, has indicated that digenesis occurring via microbial activity decreases $\delta^{13}C$ values and increases $\delta^{15}N$ values (Grupe et al. 2000).

The changing composition of other organic materials in bone during diagenesis can also shift stable isotope values. Collagen loss can be accompanied by an incorporation of non-collagenous proteins that are often resistant to degradation (Masters 1987; Weiner and Bar-Yosef 1990). Additionally, remaining smaller collagen fragments with stable isotope ratios that may differ from intact collagen can crosslink, thereby attaining some stability and enhancing collagen preservation (Collins et al. 1995). These processes can, but will not always, change the amino acid compositions of residual organic matter in bone and thus the stable isotope composition (Dobberstein et al. 2009). Aside from collagen degradation products and non-collagenous proteins, other exogenous contaminants such as humic acids (Van Klinken and Hedges 1995), free amino acids, and polysaccharides (Hedges and Law 1989) as well as the fragmentary remains of bacteria, fungi and other consumers may also become bonded to or otherwise accompany bone collagen. If exogenous additions have stable isotope ratios that differ from those of the biogenic collagen, resulting isotope values may be skewed to reflect contaminants that were not removed during the collagen extraction process (see Section 3.3).

Chapter Three

Methods

3.1 Introduction

This chapter lays out the procedures for analyzing stable carbon and nitrogen isotope ratios of bone collagen and includes background information on sample selection, bone collagen extraction, collagen quality assessment and isotopic characterization. Chapter content is presented in two sections. The first section reviews methods for collagen extraction providing context for the technique used in this study. For inter-study comparative research, it is important to select methods with caution as variations in collagen extraction techniques can produce systematically differing stable isotope values (e.g. Bell et al. 2001; Brock et al. 2010; Jørkov et al. 2007). In the second part of this chapter, a more detailed description of the techniques used in this thesis is given.

3.2 Review of Collagen Extraction Methods

Collagen extraction procedures are based on techniques developed to provide contamination-free bone material for radiocarbon dating (e.g. Longin 1971). Three basic methods have been developed for extraction of bone collagen in stable isotope-based paleodietary reconstructions. Each method ultimately seeks to demineralize bone in order to access the collagenous proteins preserved within. Depending on a researcher's choice in methodology, each technique may be subject to a number of procedural modifications.

3.2.1 Demineralization Procedures

The first commonly employed method, developed by Longin (1971) and later modified by DeNiro and Epstein (1981) and Schoeninger and DeNiro (1984), involves the demineralization of ground bone in weak, 1M hydrochloric acid (HCl) followed by gelatinization in mildly acidic warm water. The resulting gelatin is then evaporated to dryness. Researchers have experimented with variations in HCl concentration (Chisholm et al. 1983; Pestle 2010; Schoeninger et al. 1989), length of HCl exposure (e.g. Ambrose 1990; Grupe and Peipenbrink 1987; Pestle 2010), and duration of gelatinization period (Semal and Orban 1995) but most have found optimal collagen yields by using weaker (0.5M or less) HCl and adhering to previously outlined exposure periods (DeNiro and Epstein 1981; Schoeninger and DeNiro 1984). Modifications including gelatin filtration, sample agitation, larger initial bone particle size, and temperature alteration have also been suggested (Brown et al 1988; Collins and Galley 1998; Semal and Orban 1995).

The second method, also commonly used, was developed by Sealy (1986:51) and will be referred to as the 'chunk' method. Like the modified Longin (1971) method, bone is demineralized in dilute HCl, but rather than a ground powder, collagen is extracted from small un-milled chunks of bone. This demineralization technique leaves a collagen lattice, or psuedomorph, model of the original bone. Research has suggested that the chunk method produces higher quality collagen yields as collagen fibrils are not highly segmented after powdering by milling or grinding (Collins and Galley 1998; Jørkov et al. 2007). It is pertinent to note that some research has shown that the 'chunk' and modified Longin methods may produce $\delta^{13}C$ values that differ by as much as 1‰ (Bell et al. 2001). For this reason caution should be exercised when comparing stable isotope data between methods.

A third, less common, method has been initiated by Tuross and colleagues (1988; Olsson et al. 1974), and employs ethylene-diamine-tetra-acetic acid (EDTA), a calcium chealator, rather than HCl to demineralize bone chunks or powder. Research has shown that, although much slower than HCl-based techniques (Collins and Galley 1998), this gentler method can produce higher collagen yields and remove certain contaminants from bone material (Tuross et al. 1988, 1994; Bocherens 1996). This method, however, requires extensive rinsing of demineralized collagen residue (15 times according to Tuross et al. 2008) as EDTA contains potentially contaminating carbon and nitrogen (Ambrose 1993:73).

3.2.2 Removal of Humic Acid Contaminants

Analysis of bone from humic-rich post-depositional environments may necessitate removal of humic acids and other base-soluble contaminants from a specimen. Some researchers using HCL-based extraction techniques prefer to remove these contaminants with an extra step between the demineralization and gelatinization phases involving a soaking in a weak sodium hydroxide (NaOH) solution (e.g. Ambrose 1990; Gurfinkle 1987; Haynes 1967). It has also been shown that the EDTA-based collagen extraction method removes humic contaminants (Tuross 1988; Collins and Galley 1998); although, in extreme cases of contamination NaOH treatment has also been used to further remove residual humic acids (e.g. Tuross 1994).

Treatment with NaOH has some disadvantages. For instance, research has shown that NaOH treatment can damage amino acids (such as serine and threonine, for review see Chisholm 1989:25-28) thereby reducing collagen yield (Chisholm et al. 1983; Liden et al.1995; Katzenberg 1989). Collagen losses of several percent can be detrimental to the collagen yields of poorly preserved bone specimens (Liden et al. 1995). The preferential loss of certain amino acids may

also alter $\delta^{13}C$ signatures of bone collagen (Chisholm et al. 1983; Jørkov et al. 2007). In cases where humic acid contamination is not severe and bone samples are well preserved, differences in $\delta^{13}C$ values between methods that use NaOH and those which do not are quite small, perhaps less than 0.35‰ for $\delta^{13}C$ (Jørkov et al. 2007), and may be within the margin of analytical error (Chisholm et al. 1983). Furthermore Jørkov and colleagues (2007) have demonstrated that there is no statistically significant difference in results for $\delta^{15}N$ values between methods. For these reasons, many researchers choose not to treat their samples with NaOH (eg. Richards and Hedges 1999).

Alternatives to the NaOH-based removal of humic acids exist. Maintaining a pH of 3 during the genaltinization phase is a common and effective method for removing base soluble contaminants (Chisholm et al. 1983). Another alternative involves EZEE® filtering (Elkay Laboratory Product) followed by ultra-filtering (Centricon 30, Amicon Canada) of collagen samples after the gelatinization phase (Beaumont et al. 2010; Brown et al. 1988; Bronk Ramsey et al. 2004). Ultra-filtration separates collagen from contaminants by molecular weight, accepting only materials larger than 30kDa thereby excluding humic acids that should have a smaller size range (Brown et al. 1988). As this process removes collagen fibrils of low molecular weight some collagen is lost, reducing collagen yields in samples with highly degraded and fragmented collagen (Jørkov et al. 2007).

3.2.3 Removal of Lipids from Bone

The lipid fraction of bone is known to produce $\delta^{13}C$ values of up to or more than 7‰ below those of bone collagen (Ambrose 1990; Celeste et al. 2010; Post et al. 2007; Smith and Epstein 1971; Vogel 1978). Preservation of lipids in bone varies with conditions of post-

depositional context as well as age, but may survive for thousands of years (c.f. Liden et al. 1995). For this reason it is necessary to consider the possible residual presence of lipids when working with archaeological bone material and, when appropriate, take measures to remove them.

There are two common methods for removing lipids from archaeological bone. Ambrose (1990) suggested that the NaOH pretreatment method used for removing base-soluble contaminants is also an effective technique for removal of most lipids in modern and archaeological bone. A study by Liden and colleagues (1995), however, has demonstrated that the NaOH pretreatment does not remove any lipid content. The second method, as recommended by Liden and colleagues (1995; Chisholm et al. 1983; Lee Thorp et al. 1989) is a chloroform-methanol pretreatment (see Kates 1986) prior to the demineralization phase. While this method is an effective means of eliminating most lipid materials in bone, chloroform-methanol contains organic compounds that, like EDTA, can introduce carbon contamination into a sample. For this reason, samples must be thoroughly rinsed after chloroform-methanol treatment (Liden et al. 1995). An alternative and effective means for removing lipids, which tend to have a molecular weight lower than 30kDa, is ultrafiltration (Jørkov et al. 2007; Brown et al. 1988). Ultrafiltration, however, is expensive and may reduce collagen yields (see Section 3.2.2).

3.3 Collagen Quality Assessment

In this study, collagen quality has been assessed using three well established indicators: collagen yield, atomic carbon to nitrogen ratios (C:N), and carbon and nitrogen elemental concentrations (Ambrose 1990, 1993; Van Klinken 1999). Other less routinely used and costly collagen quality indicators, not elaborated on here, include histological preservation (e.g. Pfeiffer

and Varney 2000), amino acid profiles, enzymatic analyses (e.g. DeNiro and Weiner 1988), gel electrophoresis (e.g. Dobberstein et al. 2009; Grupe et al. 2000; Tuross et al. 1980), and infrared spectroscopy (e.g. DeNiro and Weiner 1988; Wiener and Bar-Yosef 1990).

3.3.1 Collagen Yields

Collagen yields serve as a general proxy for bone preservation (DeNiro and Weiner 1988) and are expressed as a percentage of the amount of collagen (dry weight) extracted from a sample relative to pre-demineralization sample weight. Collagen preservation is assessed by comparing collagen yields of archaeological bone to that of fresh bone (~5.7 to 28.3% in non-human bone according to Ambrose 1990). Bone specimens producing particularly low collagen yields are more likely to contain degraded or contaminated collagen (Ambrose 1990; DeNiro and Weiner 1988; Van Klinken 1999). For this reason, samples producing particularly low yields should be approached with caution. One way of improving collagen quality is the use of 'gentler' collagen isolation procedures. These might include use of the chunk method (Collins and Galley 1998; Jørkov et al. 2007), demineralization at lower temperatures (Collins and Galley 1998), and avoidance of NaOH pretreatments (Chisholm et al. 1983). Another way of improving collagen quality is use of ultra-filtration. While this application will further reduce collagen yields, resulting collagen will be decontaminated of lower molecular weight fibrils and other materials that are most likely to contribute contamination (Beaumont et al. 2010; Brown et al. 1988).

Estimates of the minimum collagen yield suitable for isotopic analysis vary. Some have found that biogenic isotope values tend to become skewed when collagen yields fall below 5% (Ambrose and DeNiro 1989; Schoenigner et al. 1989) while other research suggests that values of 1-2% are still viable (Ambrose 1990; DeNiro and Weiner 1988; Dobberstein et al. 2009; Van

Klinken 1999). Identification of a 'cutoff' value is further complicated by research suggesting collagen yields lower than 1% can produce biogenic stable isotope signatures (e.g. Dobberstein et al. 2009).

Collagen yield values that are higher than fresh bone also require caution. Such yields may result from the presence of residual carbonates, which can persist after incomplete demineralization of bone mineral (Ambrose 1990) or inclusion of clay minerals and salts (Kyle 1986).

While collagen yield values are a good general indicator of collagen quality they can be misleading in cases where small amounts of non-collagenous residues remain in a sample after collagen extraction, thus making the collagen yield percentages artificially high. For this reason, collagen yields should be viewed as one of several tools for generalizing collagen quality used in conjunction with other indicators (Ambrose 1990; Van Klinken 1999).

3.3.2 Atomic C:N Ratios and Carbon and Nitrogen Concentrations

Like collagen yield values, atomic C:N ratios are used as an indicator of collagen quality based on comparison of archeological bone values with those expected from fresh bone (DeNiro 1985). Fresh bone produces atomic C:N ratios between 3.2 and 3.3 (Ambrose 1993:74-76) and DeNiro (1985) has found that viable stable isotope measurements can be obtained from collagen with a slightly larger range falling between 2.9 and 3.6. Collagen producing atomic C:N ratios outside of this range is more likely to have stable isotope values unreflective of biogenic dietary signatures. Such collagen may have been diagenetically altered by preferential loss of certain amino acids or by contamination with materials from the post-depositional environment (DeNiro 1985). To reduce the possibility of obtaining defective stable isotope results some researchers

have suggested that the range of acceptable atomic C:N ratio values be narrowed to between 3.1 and 3.5 (e.g. Van Klinken 1999). This suggestion, however, does not appear to have been widely adopted.

Several researches have investigated possible factors influencing variation in atomic C:N ratios. For instance, Masters (1987) found that higher atomic C:N ratios may result from the loss and replacement of substantial amounts of collagen with non-collagen proteins. High values may also be the result of contamination from materials with elevated amounts of carbon and lower amounts of nitrogen such as humic acids or lipids. Low atomic C:N ratio, on the other hand, may be due to contamination with nitrogen rich, carbon poor materials such as ammonia (Masters 1987) or polyamines (Schoeniger et al. 1989). Additionally, some studies have indicated that other poorly understood factors can alter isotopic signatures without changing atomic C:N ratios (e.g. Ambrose 1990). For this reason, like collagen yields, atomic C:N ratios should not be relied upon wholly for collagen quality assessments, but rather should contribute to a multi indicator assessment.

Deriving from the same data used to create C:N ratios, collagen carbon and nitrogen concentrations (measured in percent) are another useful indicator of collagen quality (Ambrose 1990; Brock et al. 2010). In comparison with collagen from fresh bone, which produces carbon and nitrogen concentrations of 15.3% to 47.0% and 5.5% to 17.3 %, respectively, elemental concentrations in archaeological bone are considered in order to assess the likelihood of diagenetic alteration (Ambrose 1990). Ambrose (1990) has shown that collagen samples with carbon and nitrogen concentrations of at least 13% and 4.8%, respectively, can be considered appropriate for stable isotope analysis, although lower concentrations may be acceptable (Ambrose and Norr 1992). Values falling below these cutoffs are often correlated with low

collagen yields or aberrant atomic C:N ratios and likely indicate collagen degradation and contamination (Ambrose 1990). On the other hand, disagreements between carbon and nitrogen concentrations and other indicators have been documented (e.g. Schoeninger et al. 1989) and, for this reason, this collagen quality criterion should also be used as one of several indicators.

3.3.3 Use of Multiple Collagen Quality Indicators

The variability in factors influencing the validity of collagen quality indicators necessitates use of multiple methods for assessing collagen integrity. It is important to bear in mind that each indicator only singles out worst-case scenarios and that caution should be exercised when even one collagen quality indicator suggests a sample may be poorly preserved (Van Klinken 1999; Ambrose 1990).

In addition to the well-established methods discussed above, this study will also consider qualitative factors in assessing collagen quality. An important consideration involves careful observation of bone samples during the demineralization process (Sealy 1986:51). When preservation is good, demineralization of collagen using the chunk method results in a rubbery collagenous model or pseudomorph of the original sample. Pseudomorphs that become crumbly or disintegrate during demineralization may have poor collagen quality and mark these samples as candidates for close scrutiny.

3.4 Methodology Used in this Study

This section will outline the sample collection, collagen extraction, quality assessment and analyses procedures used in this study. They are detailed in their respective sequential order during analysis.

Sample selection targeted cortical tissue from long bone diaphyses, as denser regions of bone tend to resist deterioration and foster superior preservation (Ambrose 1990). A contextual approach was adopted while collecting samples as preservation and curatorial issues sometimes necessitated the sampling of trabecular bone from ribs and longbone epiphyses. Bone of good gross morphological preservation was targeted. An effort was made to avoid regions exhibiting evidence of burning or pathology, as such bone can produce isotope signatures unreflective of long-term diet (e.g. DeNiro et al. 1985; Katzenberg and Lovell 1999; White and Armelagos 1997).

Physical sampling and preparation of bone material took place in the Bioarchaeology Laboratory at Memorial University's Department of Archaeology and was achieved using a handheld Dremal® microdrill with a carbide cut-wheel. Periosteal and endosteial surfaces, which may harbor residual contamination from direct contact with the depositional environment, were removed by abrasion using a diamond coated dental bur on the same apparatus. Samples were then cut into tiny cubes (~2mm^3) to increase surface area and expedite the demineralization process.

The widely used collagen extraction procedure (Jørkov et al. 2007) employed here follows Sealy's (1986) 'chunk' method as modified by Richards and Hedges (1999) with a slight alteration in that samples were EZEE® filtered (Elkay Laboratory Product) (e.g. Honch et al. 2006). This method has been selected to provide high collagen yield returns while reducing opportunities for method-induced contamination and preferential amino acid loss that can alter isotope values. Cleaned bone chunks were demineralized in 10mL test tubes by immersion in 0.5M HCl at 4°C and refreshed roughly every 48 hours to remove products of demineralization reactions. After demineralization, samples were rinsed to neutrality in deionized water. Samples

were then gelatinized on a heating block (VWR® model) for 48 hours at 70°C in deionized water adjusted to a pH of 3 with 0.5M HCl. The resulting solution was centrifuged (Eppendorf Centrifuge 5804®) and filtered with 5-8μm mesh EZEE® filters (Elkay Laboratory Product). Gelatinized samples were then frozen for at least 24 hours at -20°C and lyophilized for 48 hours in a freeze dryer (VirTis Lyotroll®). The resultant fluffy white or light brown mass of collagen was weighed using a Mettler Toledo microbalance to obtain collagen yield values. Collagen extracts failing to meet this criterion (see below, this section) were not subjected to further analyses.

Stable isotopes analyses and elemental carbon and nitrogen concentration measurements were conducted in the CREAIT Network's Stable Isotope Laboratory located in the Department of Earth Sciences at Memorial University. Approximately 1mg of collagen extract was weighed into tin capsules which were then folded shut to minimize sample contact with atmospheric gases. Tin capsules were then combusted at 1800°C in a Carlo Erba NA 1500 Series II Elemental Analyser® and separated with a gas chromatograph. Resulting CO_2 and N_2 gases were then carried in a continuous flow of helium gas to a ThermoElecton DeltaVPlus Gas Source Isotope Ratio Mass Spectrometer®. Elemental concentrations were measured by comparison with ultra pure CO_2 and N_2 reference gases as well as standards. Stable isotope ratios were determined relative to multiple appropriate internationally recognized isotope standards. Table 3.1 provides details on all standards used. All stable isotope values are reported to the same (second) decimal place as the standards used during analyses. Based on sulfanilamide standards (n=18), the instrumental error (1σ) for $\delta^{13}C$ and $\delta^{15}N$ measurements was ±0.18‰ and ±0.10‰, respectively.

Collagen quality assessment was accomplished using the collagen yield, atomic C:N ratio, and carbon and nitrogen concentration criteria. Acceptable stable isotope data required a

collagen yield greater than 2%, an atomic C:N ratio between 2.9 and 3.6, and carbon and nitrogen concentrations of greater than 18% and 6%, respectively. Samples failing one of these criteria were rejected and a secondary collagen extraction from the same bone specimen was attempted. Additionally, values of individual criterion were plotted against one another to analyze relationships and trends in data. Outlying samples were considered with caution.

Chapter Four

Nature and Timeline of CSA Development

4.1 Introduction

In 1978, the same year that Van der Merwe and Vogel (1978) published the first stable isotope-based paleodietary reconstruction using human remains, researchers discovered that analyzing domestic dog tissues might also provide information on human dietary practices in ancient times (Burleigh and Brothwell 1978). Over the last 33 years the CSA has developed and evolved at varying rates, at different times and places, for a variety of reasons. Yet despite a recent flurry of more sophisticated development, researchers are still stressing an unrealized potential for dogs to act as proxies for humans (e.g. Spence and White 2009:240). The purpose of this chapter is to provide an outline of the CSA's origin and evolution with particular emphasis on identifying the impetuses for, and trends in, its development. This chapter follows directly from work (Guiry in revision) that has recently been submitted for publication in *Archaeological and Anthropological Science*. Original concepts and ideas presented in that paper have been developed with the intention of contributing to this thesis.

4.2 Early Indications of Human-Dog Food Sharing Relationships

Early development of the CSA occurred at different rates for stable carbon and nitrogen isotope analyses and was often a byproduct of research aimed at interpreting other aspects of human and animal diet. For the most part, this form of 'passive' development continued

throughout the 1980s and 1990s. The following discussion provides a comprehensive overview of this early development.

4.2.1 The $\delta^{13}C$ Evidence

During a routine radiocarbon dating exercise on ancient Peruvian dog hair, Burleigh and Brothwell (1978) found elevated $\delta^{13}C$ values and interpreted them as evidence that maize had been a significant component of dog diet. Burleigh and Brothwell (1978) extended these analyses to dog bone collagen from post-agricultural- era precontact Ecuador and Mexico and estimated that these dogs consumed a diet composed of over 60% maize. Later demonstration that similar human $\delta^{13}C$ values can result from consumption of marine derived foods (Tauber 1981), as well as the possibility that such values could also reflect dogs' consumption of human feces, resulted in some criticism of this interpretation (Klepinger 1984:86; Noe Nygaard 1988). However, the implication that humans had been provisioning their dogs remained unquestioned.

Later radiocarbon dating projects (e.g. Nelson 1989) involving precontact dog remains from eastern North America during the 1980s yielded $\delta^{13}C$ values that Little and Schoeninger (1995:362-363) interpreted as reflecting human provisioning of marine derived foods. Additionally, a series of radiocarbon dates taken from unidentified animal bones from precontact Mayan contexts in Central America yielded elevated $\delta^{13}C$ values (Hedges et al. 1991:132) that prompted Tykot and colleagues (1996:356) to suggest that these remains belonged to maize-fed dogs. Furthermore, during the early 1990s $\delta^{13}C$ work on dog hair and bone collagen from coastal precontact British Columbia, Canada, and Arizona, USA, provided evidence that dog diets had been strongly influenced by human exploitation of marine foods and maize, respectively (Berry 1992:141; Ezzo and Stiner 2000; Schulting 1994).

In 1988 Noe-Nygaard published pioneering work that would lay the foundation for using stable isotope information derived from dogs as a proxy for their human keepers. In light of the paucity of human remains recovered from Mesolithic and Early Neolithic Danish sites, Noe-Nygaard sought to: A) establish a similarity between the bone collagen $\delta^{13}C$ values of dog (n=15) and human (n=4) remains at 16 coastal and inland sites; and, B) assess whether or not they would show the same dietary shifts between Mesolithic and Neolithic observed in another northern group (Tauber 1981). Like the humans, all dogs, save three, produced stable isotope ratios showing the expected trend of decreasing $\delta^{13}C$ values (a greater reliance on terrestrial resources) as they moved temporally from the Mesolithic into the Neolithic. Noe-Nygaard concluded "Dog bone collagen from prehistoric sites may be used as a supplement to prehistoric human bone collagen $^{13}C/^{12}C$ estimates of diet in prehistoric man" (1988:94). Noe-Nygaard (1995: 248, 261-262) later applied this technique to additional Scandinavian dog remains in lieu of appropriate human materials and found similar $\delta^{13}C$ results.

Further utilizing this new technique, Noe-Nygaard uncovered information not only on human dietary practices but also on seasonal mobility. In 1990, Clutton-Brock and Noe-Nygaard published work in which the diets of three dogs from various inland and coastal sites in England (Star Carr and Seamer Carr) and Denmark (Kongemose) were characterized via $\delta^{13}C$ analysis. Stable carbon isotope signatures from two dogs collected from inland sites produced elevated $\delta^{13}C$ values consistent with a marine diet. The authors interpreted this data as suggesting that these dogs and their human keepers seasonally migrated to coastal areas to exploit marine resources. Although the northern environmental settings in which these sites are located likely precludes potential dietary inputs from C_4 plants, the interpretation of these dogs' $\delta^{13}C$ values was questioned based on a localized anomalous 'hard water' effect discovered at the Seamer

Carr site (Day 1996). Later application of $\delta^{15}N$ analyses to dog remains from this site settled the dispute in favor of Clutton-Brock and Noe-Nygaard's argument (Dark 2003; Schulting and Richards 2002; 2009). This and the other abovementioned questionings of interpretations of dog diets based only on $\delta^{13}C$ values highlights the importance of applying multiple lines of analyses, such as $\delta^{15}N$ or stable sulfur isotope ($\delta^{34}S$) measurements, when establishing the suitability of dogs as a proxies for their humans keepers.

4.2.2 The $\delta^{15}N$ Evidence

In 1986 (Katzenberg 1988:311) and 1988 (Katzenberg and Kelly 1991:212), analyses of human and dog remains from Ontario, Canada, and New Mexico, USA, respectively, provided early indications that, in addition to $\delta^{13}C$ values, dog $\delta^{15}N$ values may also reflect human food provisioning. These findings were echoed in research by Murray and Schoeninger (1988:163-164) on Iron Age remains from Slovenia, by Katzenberg (1989) on Huron remains from historic Ontario, Canada and by White and Schwarcz (1989) on precontact Mayan remains from Belize.

Studies published during the early and mid 1990s continued to apply $\delta^{15}N$ analyses in tandem with $\delta^{13}C$ analyses to dog and human remains, albeit mainly in post-maize agricultural contexts in South America and southern North America (Gerry 1993:157-159, 162, 164, 1997; Gerry and Kruger 1997:201; Tuross et al. 1994; Tykot et al. 1996:358; White et al. 1993). Most authors comment on the $\delta^{13}C$ evidence suggesting that dogs consumed substantial quantities of human-provisioned maize; however, no in-depth discussion of dog $\delta^{15}N$ values in relation to those of humans is provided. One study conducted on precontact marine-hunting Asiatic groups produced data demonstrating similarities between dog and human diet in both $\delta^{13}C$ and $\delta^{15}N$

values but focused instead on a discussion of the greater degree of variation observed in dog $\delta^{15}N$ values when compared to those of humans (Chu 1994:38-39, 52).

Following in the path of Noe-Nygaard (1988), Cannon and colleagues (1999) published the first attempt to use $\delta^{13}C$ and $\delta^{15}N$ values of dog bone collagen as a proxy for those of unavailable humans at a precontact marine-oriented hunter-gatherer site in British Columbia, Canada. The authors note that, whereas human remains recovered from the site are dated to a relatively restricted time period, dog remains are available from all time periods. To enhance the temporal resolution of the paleodietary record for humans at the site they analyzed dog remains that stratigraphically and temporally flanked and overlapped with those of humans to: A) establish a similarity between human and dog $\delta^{13}C$ and $\delta^{15}N$ values; and, B) if sufficiently congruent, rely upon dog stable isotope signatures to approximate human dietary trends before and after the time periods for which human data could be obtained. Although discussion focused mainly on dog $\delta^{13}C$ values, the authors conclude that "Dogs appear to be valid surrogates for human consumers in isotopic studies of north-west coast diet" (Cannon et al. 1999:405) (see Section 5.3.3 for further discussion of this work). In addition to Burleigh and Brothwell (1978) and Noe-Nygaard (1988), Cannon and colleagues' (1999) study has become a foundational citation in publications utilizing dog remains as a proxy for those of their human keepers.

4.3 Later Work: The 1990s to Present

Building upon the CSA framework established in the 1980s and 1990s, archaeological scientists have explored many possibilities relating to the potential uses of dog remains as proxies for their human keepers. While, these developments started off slowly, in recent years a marked increase in frequency of CSA-related publications has occurred and it is now routine for

some researchers to include dog remains whenever possible in stable isotope-based paleodietary reconstructions (e.g. Choy et al. 2010; Choy and Richards 2010; Fischer et al. 2007a, b). Furthermore, impetuses for CSA use have diversified and researchers have begun to explore the applicability of a variety of techniques in addition to $\delta^{13}C$ and $\delta^{15}N$ analyses of dog bone collagen in an effort to identify new ways in which dogs may be used as surrogates for associated humans. This section will outline these explorations and developments.

4.3.1 Increase in the Analyses of Dog Remains

CSA applications are now relatively common in the literature. (e.g. Allitt et al. 2008; Barton et al. 2009; Black 2003; Cannon et al. 1999; Chilton et al. 2001; Choy and Richards 2009, 2010; Choy et al. 2010; Grier 2006:132-133; Hogue 2003, 2006; Noe-Nygaard 1995:245; Rick et al. 2011; Schulting and Richards 2002, 2009; Tankersley and Koster 2009; White et al. 2001). Furthermore, a substantial number of studies including human and dog bone collagen stable isotope data indicate general similarities (within 2-3‰ of associated human data clusters in both $\delta^{13}C$ and $\delta^{15}N$) in various cultural and temporal contexts in many areas of the world (Table 4.1).

CSA research has not been evenly spaced in terms of time of publication/dissemination or geographical region of focus. Studies prior to 2000 (see Section 4.2) including stable isotope information on dog remains are relatively few in comparison to those occurring since. Figure 4.1 plots the number of theses, dissertations and publications from all journals and conference proceedings known to the author (see Table 4.1) that include similar stable isotope data from dog and human remains from similar contexts by year. This plot clearly demonstrates significant and

sustained growth in the analyses of dog remains after 2000, and suggests that the archaeological bone chemistry community has begun to explore CSA applications more seriously.

The majority of growth in publications including data on humans and dogs has occurred within a limited geographical region that notably excludes Africa and Australia. Figure 4.2 presents a bar graph contrasting the relative quantities of publications that are cited in Table 4.1 by broad geographical region. The majority of growth in publication of dog data alongside human data has occurred in Europe and the Americas with a substantial number of publications also coming from Asia. These regions coincide with the areas in which bioarchaeological research communities have been most active according to a recent analysis of articles published in the *Journal of Archaeological Science* (JAS) (Butzer 2009), and are the locations in which stable isotope-based paleodietary reconstructions appear to be more common. This suggests that one reason that CSA applications have not been conducted in Africa and Australia is because there is relatively less stable isotope wok occurring in these regions. Although JAS is an international publication, it has traditionally been dominated by European and American Anglophone authors (Butzer 2009). As JAS has become the premier journal for archeological science publications, this pattern has begun to change as the wider archaeological science community increasingly submits papers for publication (Butzer 2009). Therefore, while a comparison of Table. 4.1 with JAS publication statistics is somewhat biased, this geographical correlation may still explain why CSA applications have not been conducted in Africa and Australia.

4.3.2 Beyond Bone Collagen: Experimenting with Other Tissues and Techniques

Other dog tissues, in addition to bone collagen and hair, have been analyzed alongside those of humans. These analyses often utilize techniques focusing on additional isotope systems and have addressed other questions beyond those related to reconstructing diets. Explanation of appropriate background information on each of these techniques is beyond the scope of this thesis; however, a brief mention of some of these studies is given below in order to illustrate the variety of ways in which researches have begun to consider the suitability of dogs as proxies for humans.

Several studies have analyzed stable carbon and oxygen isotopes in dog bone and tooth apatite either incidentally during routine faunal analyses (e.g. Bösl et al. 2006; Gerry 1997; Gerry and Krugger 1997; Pechenkina et al. 2005; Prowse et al. 2004) or to intentionally assess the use of these materials as a dietary proxy for humans (e.g. Allitt et al. 2008; Chilton et al. 2001). While often similar, these studies have found some variability in the degree of congruence between human and dog stable isotope signatures. Larger scale studies would help further assess similarities between humans and dogs during stable carbon and oxygen isotope analyses of apatite.

Dog bone collagen and apatite have been characterized using several other stable isotopes. Studies have analyzed stable sulfur isotope ratios in dog bone collagen (e.g. Nehlich and Richards 2009) and found that, of all fauna, dogs produce $\delta^{34}S$ signatures most similar to humans (Privat et al. 2007). A very limited amount of stable hydrogen (δD) and calcium ($\delta^{44/42}Ca$) isotope measurements have also been published for dog and human bone, but relations between the two were not discussed by the authors (Reynard and Hedges 2008; Reynard et al. 2010).

Compound-specific $\delta^{13}C$ analyses of dog and human bone collagen amino acids have indicated similarities supporting the use of dog materials as a surrogate for their human keepers (Choy and Richards 2010; Choy et al. 2010; Corr et al. 2009). Such compound-specific analyses can provide greatly improved resolution of nutritional components contributing to diet and for this reason may offer refined comparisons of human and dog dietary similarities. Future work comparing humans and dogs from several cultural, geographical and temporal contexts might allow for enhanced characterizations of the suitability of dog remains as proxies for humans in CSA applications.

Strontium isotope ratio analyses of dog tooth apatite, which can help identify migration and possibly marine dietary affinities (Bentley 2006), have been recommended by some researchers to complement bone collagen $\delta^{13}C$ and $\delta^{15}N$ work (Chilton et al. 2001). Several studies have characterized strontium isotope ratios from dog tooth apatite while reconstructing patterns of human mobility but have not commented in-depth on data deriving from dogs (e.g. Giblin 2009; Thornton 2011). Smits and colleagues (2010), however, briefly note similarities between humans and dogs. Shaw and collogues (2009) have used strontium isotope information from pigs to track human movements and colonization events through Oceania and it may be possible that dogs, as another commensal animal, could serve as a proxy for their human keepers in the same way.

Dog remains have also served as surrogates for human remains in a physical capacity (i.e. non-chemical) for studying diet and health related patterns. Bathurst (2000) found similarities in skeletal stress indicators between humans and dogs and suggests that dogs be considered an independent indicator of health status for associated human populations. Bathurst and Barta (2004) further show that it may be possible to extend this surrogacy to the biomolecular level for

the identification of diseases among human populations. Other recent research has demonstrated that in some contexts dental microwear analyses of dog teeth can show results similar to those of associated humans (Hogue 2006:126; Hogue and Melsheimer 2008) and for this reason studies of dog tooth dental microwear could aid in human paleodietary reconstructions.

In sum, a great deal of preliminary experimentation has been conducted on dog remains. The majority of isotopic work assessing human and dog dietary similarities has focused on $\delta^{13}C$ and $\delta^{15}N$ signatures in bone collagen and some researchers have stressed a need to expand this relatively narrow focus (e.g. White 2004). Taken as a whole, the body of research reviewed above suggests that further developing and applying multiple lines of bone chemistry analyses to human and dog remains could enhance our understanding of the feasibility of CSA applications.

4.4. Justification for Studying Dogs Rather than Humans

Researchers have found it preferable or necessary to analyze dog remains rather than their human counterparts for several reasons. Early studies often cited a variety of issues relating to poor preservation and a paucity of human remains recovered from certain archeological contexts as the impetus for relying on dog remains (Black 2003; Cannon et al. 1999; Clutton Brock and Noe Nygaard 1990; Craig 2007; Hogue 2006:123; Katzenberg 2006:272; Noe-Nygaard 1988, 1995:245; White et al. 2001).

More recently researchers have experienced issues with availability of human remains due to legal and political factors and have cited cultural sensitivities of the descendants of archeological populations as the primary reason for relying on dog remains (Allitt 2011:73; Allitt et al. 2008; Chilton et al. 2001; Hogue 2003; Rick et al. 2011). In the USA this claim is often associated with the passing of NAGPRA and related legislation (c.f. Jenkins 2011), which

curtailed the availability of many previously excavated human remains (Katzenberg 2001; Walker 2008:24). Cultural sensitivity with regards to the destructive analysis of human remains is also cited in contexts outside of the US, such as Canada (Grier 2006:132), where repatriation laws are still in the process of development (Katzenberg 2001). To the author's knowledge, however, no studies of dog remains outside of the Americas have cited cultural sensitivity as a reason for avoiding the analysis of their human counterparts. As Europe and increasingly the Middle East and Asia are the focus of much stable isotope work (e.g. Butzer 2009), this difference in reasoning for CSA application suggests impetuses for CSA use are influenced by cultural, political and geographic factors. In other words, unlike Europe, a reason that CSA applications often appear to be related to cultural sensitivities in the Americas is that the strength and nature of cultural, political, and ethical factors impeding access to human remains are more robust there.

As CSA applications become more common, some researchers have begun including dogs in studies alongside humans (either explicitly or implicitly) to increase the quantity of data provided on human dietary practices (Allen and Craig 2009; Choy and Richards 2009, 2010; Choy et al. 2010; Corr et al. 2009; Craig et al. 2006; 2009; Craig 2009:19-20; Fisher et al. 2007a,b; Herrscher and Le Bras-Goude 2010; Schulting and Richards 2000:56-57). Although such studies usually include only a few dogs, they have potential to provide comparative contextual evidence for dog and human dietary similarities (Guiry 2012).

Another potential impetus for relying on dog tissue to avoid destructive analyses of human remains might be to preserve limited human materials for posterity. Although not yet cited in any CSA publication, this reason may apply in contexts where human remains exist but

are exceedingly rare or unique and might be more efficiently analyzed with as yet unavailable technologies (Hublin et al. 2008).

A final commonly cited reason for conducting stable isotope research on dog remains, for CSA applications or otherwise, is that information on dog diet is interesting and valuable in and of itself (e.g. Eriksson 2003:22; Guiry 2012). For instance, CSA and other stable isotope and biomolecular work on dog remains has illuminated aspects of dog husbandry and breeding (Schulting 1994), seasonal migration (Clutton-Brock and Noe-Nygaard 1990), dog worship and spirituality (White et al. 2001), dog domestication (Germonpré et al. 2009) and dog trade (Eriksson and Zagorska 2003:167).

Chapter Five

Dogs as Analogs: A Cross-Contextual Analysis

5.1 Introduction

This chapter follows directly from, and expands upon, work that has recently been published in the *Journal of Archaeological Method and Theory* (Guiry 2012). The literature review-based assessment of the CSA's cross-contextual feasibility (Section 5.2), as well as theoretical and methodological concepts for effective CSA applications (Section 5.3) presented in that article, have been formulated with the intention of contributing to the present research.

5.2 Cross-Contextual Analysis: A Literature Review

Despite the large quantity of stable isotope research including dogs and associated humans, no study has systematically assessed similarities between human and dog diets on a global scale. Such a comparison may allow for: 1) a generalization of the degree to which dog stable isotope values reflect those of their human keepers; and, 2) the identification of trends in temporal, cultural and environmental contexts which either foster or discourage convergence of dog and human diets. Additionally, cohesively considering commentary made on human and dog dietary relationships during CSA applications may further pinpoint trends in commonly observed offsets between human and dog stable isotope values as well as provide an opportunity to itemize and assess the hypotheses currently offered to account for them. This chapter provides a cross-contextual analysis of studies that include appreciable amounts of associated human and dog data to address this issue. Comments on how future work might improve the comparability of human and dog data are offered.

5.2.1 Comparing Human and Dog Diets

As outlined in Chapter Four, a large amount of paleodietary reconstruction work has illustrated that dog stable isotope values often fall within 2-3‰ of associated human data clusters. In order to compare similarities and differences between various contexts, data from several studies (Table 5.1) have been collected and compiled in Figure 5.1. The pool of available studies known to the author is detailed in Table 4.1. The primary basis for selection of a particular study is inclusion of stable isotope values from at least five dogs and five humans. These quantities have been selected somewhat arbitrarily; however, they suit the purposes of this cross-contextual analysis for two reasons: comparing greater quantities of dogs and humans should reduce potential for data drift; and, had the cutoff number been lowered to four the quantity of studies included would overwhelm graphic representation thus obscuring some dietary relationships. Dogs and humans compared must also derive from the same site and general time period; however, due to omission of these relationships in most studies, it was necessary to make some assumptions. Another selection criterion was that data must be derived from bone collagen and include both $\delta^{13}C$ and $\delta^{15}N$ values. Furthermore, due to the variation in $\delta^{15}N$ values of younger individuals resulting from the weaning effect (Section 2.4.1) only data from adults was included. This criterion could only be applied to humans as few studies offer indication of dog ages.

An attempt was made to include studies from diverse geographical, temporal and cultural backgrounds; for the most part, available studies allowed for inclusion of data from a wide variety of cultural contexts and time periods. Difficulty was encountered when attempting to identify studies containing data from regions outside of Europe and the Americas. Few studies

have presented human and dog data from Australia or Africa (see Section 4.3.1) making it necessary to omit these regions in this comparison. To include data representing other regions from which fewer paleodietary reconstructions have been conducted, such as Oceania and Asia, certain selection criteria have been waved on a case-by-case basis (see Table 5.1 for details). Although these criteria cannot provide a strictly random sampling of comparative data from Table 4.1 there has been no active selection for studies with particularly similar dog and human data. For this reason, comparisons can be considered relatively unbiased.

To further compare dog and human dietary convergences, Table 5.1 and Figure 5.2 show the average difference (and statistical significance) between mean dog and human $\delta^{13}C$ and $\delta^{15}N$ values for each study. These values have been calculated by subtracting mean human stable isotope values from mean dog values. The averaged difference between means of dog and human stable isotope values across all 15 studies (1σ) is 0.19 ±0.77‰ for $\delta^{13}C$ and -1.16 ±1.28‰ for $\delta^{15}N$. Stable nitrogen isotope values show a larger and more negative range (0.89‰ to -3.79‰) than $\delta^{13}C$ values (1.99‰ to -.0.89‰). Relatively few statistically significant differences were found between human and dog $\delta^{13}C$ (n=1; Rick et al. 2011) and $\delta^{15}N$ (n=5; Borić et al. 2004; Eriksson 2004; Eriksson et al. 2008; Gerry 1993; Jay and Richards 2006) values (One Way ANOVA and *Post Hoc* Bonferroni test, 2σ; see Figure 5.2)

5.2.2 Trends in Cross-Contextual Data Analysis

Quantification of human and dog dietary similarities from these comparative data is complicated by variation in the dimensions of dog and human associations as well as methods for collagen extraction and analysis between studies. Nonetheless, Figure 5.1 and 5.2 clearly suggest that dog stable isotope values often, to varying extents, track those of their human

keepers in many contexts across temporal, cultural and geographical boundaries. This provides strong supporting evidence for suggestions that dogs generally have diets reflecting food-sharing relationships with humans.

A lack of contextual information on the archaeological association between dogs and humans has made it difficult to identify trends in human and dog dietary similarities between the groups. For a start, there do not appear to be any trends between groups with differing modes of subsistence or in differing environmental contexts. For instance the mean $\delta^{15}N$ values of dogs from European agricultural contexts may be very close (within 0.25‰) to those of their human keepers (e.g. Craig et al. 2009; Lightfoot et al. 2009) or more than 2‰ distant (e.g Jay and Richards 2006). The same is evident from dog data deriving from hunter-gatherer contexts (Cannon et al. 1999; Eriksson et al. 2008; Eriksson 2004; although see Section 6.6.1). Other influences of factors discussed in Section 5.3.6 such as the relative geographical isolation of small island contexts (n=4) as opposed to mainland occupations (n=11) do not appear to produce any trends in human and dog dietary similarities either.

Furthermore, due to the relatively small sample populations of dogs relative to humans in most studies, it is difficult to assess the extent to which human dietary variability is reflected in dogs' stable isotope values. While standard deviations of some groups of associated dogs and humans show a generally similar spread proportionally between $\delta^{13}C$ and $\delta^{15}N$ values (e.g. Jay and Richards 2007), others do not. For instance, among European agricultural contexts standard deviations for dogs' $\delta^{15}N$ signatures may be much larger (e.g. Jay and Richards 2006) or smaller (e.g. Lightfoot et al. 2009) than those of humans. However, this may also partially reflect differences in the number of humans and dogs being compared.

Overall this comparison provides some valuable insights into variability of human and dog dietary relations. While supportive of human-dog diet-sharing relationships, results stress the contextual nature of human and dog stable isotope value convergences and suggest that caution should be taken when using dog stable isotope signatures as proxies for human diets. Inadequate description of human and dog relationships in most studies, as well as variability in data parameters, have prevented the identification of trends between human and dog dietary similarities in different types of contexts. These issues might be remedied if future studies incorporate the analysis of larger quantities of dog materials alongside humans in addition to efforts to outline, as fully as possible, the archaeological associations between dogs and humans.

5.2.3 A Review of Commentary on Human and Dog Diet Similarities

Some researchers have offered qualitative observations to characterize general relationship trends between human and dog bone collagen stable isotope values. Most commonly noted are observations that dog remains may consistently produce lower $\delta^{15}N$ values (Allitt et al. 2008; Cannon et al. 1999; Houge 2003; Katzenberg 2006:266; Katzenberg et al. 2010:185; Kusaka et al. 2008), of perhaps a trophic level reduction, relative to humans. Hypotheses regarding the underlying cause of this relationship include trophic level shifts due to human consumption of dog meat (Richards et al. 2009), the canid practice of caceaotrophy (Allitt et al. 2008; Cannon et al. 1999) and possible intrinsic differences between human and dog metabolism and tissue-isotope incorporation (Cannon et al. 1999; Clutton-Brock and Noe-Nygaard 1990; Jay and Richards 2006). These factors are discussed in Section 5.3.6. Data compiled in Figure 5.2 shows an average difference of -1.16 ±1.28‰ (1σ, all data) between mean dog and human $\delta^{15}N$ values which agrees with the suggestion that dogs often produce $\delta^{15}N$ values which are lower

relative to associated humans. Despite similar trends between many other studies (see also Bösl et al. 2006; Coltrain 2009; Fornander et al. 2008; Hollund et al. 2010; Jay and Richards 2006; Jørkov et al. 2010; Katzenberg 1989; Katzenberg and Kelly 1991:212; Losey et al. 2011; Müldner and Richards 2005, 2007; Schulting and Richards 2000:57), Figure 5.1 also indicates that under some circumstances dogs have very close, or even higher, $\delta^{15}N$ values relative to their human keepers (see also Le Bras-Goude and Claustre 2009; Lightfoot et al. 2009; Lösch et al. 2006; Murray and Schoeninger 1988:160; Tankersley and Koster 2009).

Trends in offsets between human and dog $\delta^{13}C$ values have also been commented on (e.g. Lightfoot et al. 2009; Rick et al. 2011) but have remained less theorized. From Figure 5.1 and 5.2, aside from being generally similar and producing an average difference of 0.19 ±0.77‰ (1σ, all data), there appears to be little consistency in the relative relationship of $\delta^{13}C$ values between dogs and humans.

5.2.4 Implications for CSA Application

This cross-contextual analysis illustrates how dog stable isotope information often tracks that of humans but also indicates that currently available data offers no hard-and-fast rules for predicting the degree of congruency and/or general offset between human and dog stable isotope values. Yet, if dog stable isotope information is to be taken as a proxy for humans, it is necessary to assume a range of acceptable divergence between human and dog values. There has been disagreement in the literature with regards to what constitutes stable isotope value similarities that are 'close enough' for dogs to provide credible information on human dietary activities. This is evident in situations where various authors cite a particular data set, for instance from Katzenberg (1989), as either supporting (see Cannon et al. 1999; Hogue 2006) or refuting (see

Eriksson 2004; Eriksson and Zagorska 2003:162) arguments for human-dog comparability when drawing CSA inferences. While this issue is necessarily subjective, clarification might be offered by considering the type of dietary information being sought. For instance: are dog stable isotope values intended to provide a relatively accurate or rough proxy for human diet, or, are they simply an indication of the presence or absence of certain foods? This issue may be further resolved by explicit and systematic clarification of probable influences on the faithfulness of dogs' stable isotope values reflecting those of their human keepers. Section 5.3 deals with these issues.

5.3 The Role of Analogy in CSA Interpretations

There have been no systematic or cohesive theoretical considerations of the ways in which dogs might be used to reflect human diet or the potential for differing dietary influences (although for brief discussions see Allitt 2008; Cannon et al. 1999; Eriksson and Zagorska 2003; Noe-Nygaard 1988; Tankersley and Koster 2009; White 2004). By considering the implications of the analogical nature of CSA applications, this section distinguishes between two basic ways in which dog bone collagen stable isotope values have been used to help characterize those of their human keepers. Following this is a categorical framework for considering possible variations in influences on dog diet relative to human diet as well as how such considerations might strengthen and add transparency to CSA interpretations.

5.3.1 How Dogs Become Human Analogs

One way of clarifying issues in the interpretation of stable isotope values from dog remains for the purpose of human dietary reconstruction is to consider the different types of

information CSA applications can provide and how this might influence the forms of criticism to which resulting inferences can be subjected. As an analogy, the parameters and credibility of information provided by a CSA inference are determined by the components of its analogical reasoning. These components can be considered in order to separate distinctive types of CSA application – those based on direct analogies, and those which are based on indirect analogies.

5.3.2 Analogy in Archaeology

Before considering analogical components of CSA applications, it may be helpful to define an analogy and review associated terminology. Following Wylie, an analogy is made by selectively transposing information from a source to a subject "on the basis of comparison that, fully developed, specifies how the terms compared are similar, different, or of unknown likeness.... These dimensions of comparison establish positive, negative and neutral components of analogy" (2002:147). Strong analogical inferences take the relevance of each piece of information into account, thus considering some factors as more, or less, important than others. In the context of CSA applications the terms "subject" and "source" refer to associated humans and dogs, respectively. The specified terms for comparison are the degree (or expected degree) of congruency shown by their respective bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. The degree of similarity is determined through the positive, negative and neutral analogical components considered by researchers claiming that in a given context dogs should, to a certain extent, provide an indication of human dietary activities.

5.3.3 Direct CSA Analogies

In many applications the CSA is used as a tool for characterizing human diet and dietary changes over time by bridging gaps in the paleodietary record. A well-known example of this type of CSA application is its use by Cannon and colleagues (1999) to enhance the temporal resolution of the paleodietary record of a human group in what is now northwest coastal British Columbia. This was accomplished by establishing congruencies between the stable isotope values of contemporaneous dogs and humans present in the archaeological record and then analyzing dog specimens that stratigraphically and temporally flanked those from available humans based on the assumption that dogs in these time periods would also have shared similar stable isotope values. Dog stable isotope values were able to 'confirm' trends in changing human diet indicated by zooarchaeological analyses of associated faunal materials. In this type of CSA application, information regarding the source (dogs in the past) is transposed directly on to the archaeologically unavailable subject (their human keepers in the past). This argument is a direct analogical inference requiring consideration of the dimensions of comparison that establish positive, negative or neutral components of the analogy. An argument for positive aspects supporting the transposition is made in noting that other lines of inquiry corroborate the observed dietary trend and also that differences between dog and human $\delta^{15}N$ values might be explained by trophic level shifts related to the canine practice of cacaeotrophy (see Section 5.3.6.1.3). Negative and neutral aspects of the comparison are also suggested when the authors consider the dearth of information on early human-dog social and working relationships in the region as well as a lack of comparative studies detailing possible metabolic differences between human and dog tissue-isotope incorporation. In making these considerations and concessions the authors have clarified the ways in which the dogs in this particular CSA analogy are thought to be like and

unlike their human keepers and thus fortified their argument against a variety of criticism relating to their underlying analogical reasoning. Additional possible factors (see Section 5.3.6) can be considered in order to further strengthen or weaken this inference.

5.3.4 Indirect CSA Analogies

In other cases, dog stable isotope values are used to identify the relative availability of important foodstuffs within certain archaeological contexts. Several researchers have been able to show the presence and abundance of maize and provide an indication of its relative availability for human consumption in various temporal and cultural contexts as its cultivation and use spread across the precontact Americas (e.g. Allitt et al., 2008; Burleigh and Brothwell, 1978; Chilton et al., 2001; White et al., 2001). The success of this form of CSA application is dependent on the isotopic composition and ecology of the environment within which humans and their dogs lived relative to that of major local cultigens or other food sources. More specifically, it has been possible for researchers to identify that dogs had consumed substantial quantities of maize (a C_4 plant producing higher $\delta^{13}C$ values) only because the local natural environment in which the dogs lived was monopolized by C_3 plants (which produce lower $\delta^{13}C$ values). In these cases the transposition of information is not directly from dog to human, but rather the focus is on evidence of dog diets incorporating foods that demonstrate human dietary activities. These indirect analogies are not necessarily subject to the same kinds of considerations as direct analogies since the subject of the comparison is not complete human diet but rather one aspect of human dietary practices. By shifting the subject of comparison from highly complex aspects of whole human diet to a single component of human dietary activities, which can be determined relative to known isotopic endpoints (O'Leary 1988; Schwarcz and Schoeninger 1991), these

applications may require fewer considerations of comparative dimensions which establish positive, negative or neutral components of the analogy. For this reason, they may be less susceptible to critiques of strengths and weaknesses of source-subject comparisons.

5.3.5 Supporting the Analogical Inference

A consideration of the direct or indirect nature of the analogical inferences made by CSA applications may allow for a more systematic assessment of their credibility by providing a structured framework for critically assessing their claims. Explicitly identifying the types of information provided by each kind of application not only clarifies the ways in which dogs are being used as surrogates for human diet but can also facilitate (most importantly in cases of direct analogy) more informed considerations of the degree of congruency between human and dog stable isotope values necessary to provide meaningful indications of human dietary practices. The following section provides a framework for approaching the positive, negative and neutral comparative dimensions to be considered when contextually assessing the degree of similarity between human and dog stable isotope values in CSA analogies.

5.3.6 Approaching Comparative Dimensions of CSA Analogies: A Categorical Framework

CSA applications make two foundational *a priori* assumptions that specify the ways in which dogs should share similar dietary stable isotope signatures with humans: A) that dogs had access to human foods through scavenging, handouts, and cacaeotrophy (e.g. Cannon et al. 1999); and B) that dogs and humans metabolize and incorporate their food intake in a similar manner such that rates of isotopic fractionation and incorporation into respective tissues are comparable for both (e.g. Jay and Richards 2006; Noe-Nygaard 1988, 1995:262). While there

have been some recent ethnoarchaeological indications that humans and dogs isotopically incorporate foods into hair proteins very similarly (Tankersley and Koster 2009; Van der Merwe et al. 2000:32), further studies are needed to confirm whether the same is true for bone collagen. Granting these assumptions, there are three categories of factors originally itemized by Guiry (2009:38-49) which are further developed here that might influence the degree to which dog diet isotopically reflects human diet:

1. Inherent *biological* or *behavioral* differences existing between humans and dogs that could alter the expression of dietary isotopic signatures in their respective tissues.
2. *Cultural factors* affecting human-dog relationships, thereby contributing to dogs eating or being fed foods with isotopic signatures disproportionate to those of the bulk food constituent of their human keepers' diet.
3. *Environmental* stimuli affecting how humans fed and/or cared for their dogs.

The relevance, as well as the supportive *versus* contradictory nature of these factors will affect the confidence with which dietary stable isotope information from dog remains can be transposed to archaeologically unavailable associated humans. In Wylie's (2002:147) terms these factors can be neutral (i.e. they are unlikely to influence dog diet relative to human diet), negative (i.e. they are likely to skew dog diet such that it is less isotopically consistent with human diet), or positive (i.e. they are likely to contribute to a convergence of dog and human diet). Following are examples of factors within each category and a discussion of how they might influence the relative strength of analogical inferences with regards to source-subject similarity or difference and their contextual relevance. Consideration of these comparative dimensions can help specify how source and subject are of like, unlike or unknown likeness thereby fortifying

CSA inferences based on direct analogies, rendering them more transparent and less susceptible to criticism.

5.3.6.1 Challenges Pertaining to Dog Behavior and Biology

Regardless of whether or not dogs maintained a diet isotopically similar to their human keepers, biologically and behaviorally they are different from humans and it is possible that related factors may cause stable isotope values from similar foods to be expressed slightly differently by each. The following issues represent potential sources of error in CSA arguments with respect to the foundational assumption that dogs may be biologically analogous to humans.

5.3.6.1.1 Lifespan and Bone Remodeling

Bone growth and maintenance occur at different rates in humans and dogs, contributing to differing lengths of dietary representation in their respective bone collagen stable isotope values (Allen and Craig 2009; Ambrose 1986; Noe-Nygaard 1988; Schulting and Richards 2002; White et al. 2001). Healthy human bone remodels slowly over a long period of time and hence produces isotopic signatures representing a dietary average of up to or more than 20 years (Geyh 2001; Hedges et al. 2007; Wild et al. 2000; see Section 2.5.1). This relatively long span of dietary representation in human bone is advantageous as it is less likely that periods of anomalous dietary intake will be reflected in human bone collagen stable isotope values. Dogs, on the other hand, have much shorter life spans and their bones initially grow and are remodeled much more rapidly (six months to three years; Fischer et al. 2007a:2127; Noe-Nygaard 1988:92). This shortens the time span of dietary averaging and means that the isotopic signatures of dog bone collagen are more prone to reflecting perturbations during brief periods of dietary

abnormality. In other words, dog stable isotope values could reflect a greater degree of dietary variability relative to humans in a given context. While this factor has been used by some researchers to identify variability in the availability in certain foods which may have previously gone unrecognized based on human stable isotope values (Allen and Craig 2009; Cannon et al. 1999), it may contribute to undermining human and dog dietary similarities. For these reasons, to strengthen CSA inferences, dog specimens should be selected for applications with care to avoid (or at least treat with caution) particularly young individuals whose bone collagen stable isotope values reflect the shortest periods of dietary averaging. Avoiding younger dog specimens is further advisable as these individuals can produce elevated $\delta^{15}N$ values reflecting consumption of milk during the nursing period (e.g. Eriksson et al. 2008).

5.3.6.1.2 Domestic, Wild, or Hybrid?

The mistaken sampling of non-domestic canids, such as wolves, coyotes, foxes or jackals, during CSA applications would result in invalid source-to-subject transpositions. Dogs and their wild progenitors have always shared a large sympatric range and hybridization events did occur in precontact and prehistoric times (e.g. Crockford 2000:305). The offspring of such unions would have obtained qualities of both wild and domesticated forms yet may still have been accepted and treated as domestic by human groups. Distinguishing whether canid remains were those of wild rather than hybrid dogs can sometimes be difficult or impossible via standard zooarchaeological analyses. To prevent the possibility of analyzing non-domestic samples, and thus rendering this factor irrelevant, it would be optimal to avoid the use of morphologically ambiguous canid remains when formulating CSA inferences.

DNA work may provide an alternative solution. A recent ancient DNA (aDNA) study (e.g. Horsburgh 2009; Tito et al. 2011) has demonstrated that in some cases it is possible to differentiate the domestic *versus* wild status of some morphologically ambiguous canid remains recovered from archaeological contexts. While the majority of canid DNA studies have focused on modern populations (e.g. Savolainen 2006), aDNA work on archaeological dog samples continues to identify ancient dog haplotypes (e.g. Deguilloux et al. 2009) that will be necessary to differentiate wild forms from domestic dogs. With further work, this technique may become more widely available to CSA analysts.

5.3.6.1.3 Caecotrophy among Dogs

Caceotrophy, the consumption of feces, is a behavior common among dogs (Hofmeister et al. 1998) and is not normally practiced by humans. It has been demonstrated that urine is depleted in ^{15}N relative to diet (Minagawa and Wada 1984); and, although it has not been empirically studied, some have suggested that it may be possible that a similar relationship exists between dog or human feces and diet (e.g. Cannon et al. 1999). It could then be plausible that given the regular consumption of human feces as a dietary supplement, some dogs would consistently produce $\delta^{15}N$ values that are somewhat lower than those of their keepers. This behavioral difference has been invoked by several researchers to account for differences (on the order of one trophic level) between the $\delta^{15}N$ values of otherwise isotopically similar humans and dogs (e.g. Allitt et al. 2008; Cannon et al. 1999). However, recent research into the fractionation of stable nitrogen isotopes in the digestive systems of various herbivorous and one carnivorous mammal species suggests that feces are, to varying degrees, slightly enriched or equal in ^{15}N relative to diet regardless of reliance on hind or foregut fermentation (Ben-David et al. 1998;

Hwang et al. 2007; Sponheimer et al. 2003). This research (Ben-David et al. 1998) also shows that stable nitrogen isotope fractionation occurs at different levels and directions as food passes through the digestive tract on inter- and intra-species scales. Unfortunately none of the species thus far examined have been mid-sized omnivorous mammals using hindgut fermentation similar to the digestive systems of humans and dogs. Until further controlled studies are conducted on these or similar species this difference in human and dog behavior presents an unaddressable variable in CSA applications and for purposes of transparency should be noted as such in interpretations.

5.3.6.2 Challenges Pertaining to Cultural Context

Human perception and treatment of dogs is a culturally mediated, and therefore highly variable, phenomenon (cf. Serpell 1995). The following cultural factors represent some interpretive aspects of transposing dietary information from dogs to humans as well as the relevance each might have to the strength of a given direct analogical CSA application.

5.3.6.2.1 Spiritual Significance of Dogs

The spiritual significance of dogs in a given cultural context may affect their feeding habits as well as the range of food items available to them. The isotopic composition of different groups of dogs' diets and the strictness to which these were adhered could affect the degree to which human and dog diets converged. For instance, White and colleagues (White 2004; White et al. 2001, 2006:145) found that dogs buried in ritual cache contexts in a number of Mayan sites produced stable isotope values disparate from both humans and other dogs. These cache dogs had apparently maintained a diet that was almost exclusively maize based. These studies

demonstrate the possibility that, for spiritual reasons, certain dogs may have been fed an intentionally restricted diet which can be unlike that of their human keepers' and cautions the unselective and/or wholesale transposition of dog dietary stable isotope information to the human subject without giving consideration to the archaeological conditions under which the dog remains in question were collected.

5.3.6.2.2 Dogs for Dinner

Dogs have been eaten among many ancient peoples not only as ceremonial or emergency food supplies (e.g. Kerber 1997a; Serpell 1995:248-250) but as common fare (e.g. Wing 1978). If, in a given context, diet was similar between humans and dogs except for the former's consumption of the latter, then, due to the trophic level effect (see Section 2.4.1), human $\delta^{15}N$ values will be slightly higher than dogs. This possibility has been employed in some studies to help account for human $\delta^{15}N$ values which are elevated over dogs (Borić et al. 2004; Richards et al. 2009). Such dietary inconsistency may become further complicated if dog meat was considered a prestige or otherwise unusual food item and thus eaten most by a subgroup of the human population. Thus cultural norms regarding the regular consumption of dog meat may result in some human $\delta^{15}N$ values becoming elevated relative to dogs. Potential for this factor to influence similarity between human and dog stable isotope values may be difficult to address for more ancient contexts in which direct historic ethnographical analogies cannot be considered or where zooarchaeological evidence of dog consumption is absent. For this reason the relevance of dog consumption as a factor in determining the strength of a CSA argument may be challenging to assess in some cases.

5.3.6.2.3 Separate Treatment of Differing Dog Breeds

Some ancient groups bred dogs for special tasks or roles not fulfilled by common domestic dogs, including hunting unusual or dangerous animals such as bears (e.g. the Tahltan bear dog: Crisp 1956; Wilcox and Wallkowicz 1995:266), as special companions, or as food items (e.g. Mexican hairless dogs; Cluton-Brock and Hammond 1994). If these alternate tasks or roles resulted in certain breeds receiving different treatment, it may be reasonable to suspect them of possibly having had a restricted or otherwise unusual diet. For instance, Schulting (1994) confirmed the speculated existence of a dog bred solely for its hair among the Coast Salish culture of what is now coastal British Columbia, Canada. These dogs had been kept in special pens to ensure purity of their bloodline and were sheared for their wool to make blankets. Schulting notes that according to ethnographical sources and $\delta^{13}C$ values measured in the fibers of a preserved dog hair blanket, these wool dogs may have been fed a special diet, based almost entirely on salmon (1994:62), a diet which could have differed from contemporaneous human and common dog diets. If multiple breeds are recognized in applicable ethnographic and archaeological literature or are osteologically (or genetically) distinguishable, it may be necessary to conduct preliminary isotopic comparisons to confirm that breed type did not have bearing on diet within a given context. In short, this factor might negatively affect CSA arguments that do not assess potential for differential treatment of dog breeds in a given context. In contexts where only one breed existed this factor may be irrelevant.

5.3.6.2.4 Technological Change

Dogs have been a form of technology for ancient peoples who relied upon them for services including hunting acumen, sentry and traction capacity (cf. Serpell 1995). It is possible

that processes or events resulting in technological change could have affected the ways in which humans interacted with dogs or relied upon their services. For example, the introduction of snowmobiles in some northern regions provided indigenous communities with a new technology whose traction capacity far exceeded their traditional sled dogs. In the Canadian Arctic this resulted in the widespread abandonment of dog sledding among Inuit groups (Smith 1972). With little use for large dog teams that require constant feeding, many sled dogs were dispatched shortly after (Smith 1972). In other more ancient contexts where dogs may still have provided alternative services, such a technological shift may only have resulted in a change in roles. This role transfer could easily affect human views and thus feeding of dogs. Potential for this factor to influence similarity between human and dog stable isotope values is also difficult to address with regards to ancient contexts in which no appeal can be made to direct historic ethnographic analogies. Again, for this reason the relevance this factor may hold in determining the strength of a CSA argument may vary.

5.3.6.2.5 Economic Transactions

Some ancient groups valued canid remains and have viewed them as a material that could be traded. When objects incorporating dog skeletal elements are passed between groups with distinctive dietary regimes their stable isotope values may not reflect diet in the secondary cultural context. Eriksson (2003; Eriksson and Zagorska 2003) provides an example of this problem when analyzing dog teeth from tooth-pendent necklaces among inland European hunter-gatherers. Eriksson (2003; Eriksson and Zagorska 2003:167) found that while some teeth produced isotope values generally consistent with contemporaneous human data, others produced a distinctive marine dietary signal. This was interpreted by the authors as possible

imported materials from a coastal region. This example illustrates the potential for trade of dog remains to result in misidentification of correct source (dog) materials that are applicable to the targeted subject (associated human keepers) in CSA applications. This factor might be addressed by employing other mobility-oriented isotope systems such as strontium isotope analyses (for review see Bentley 2006). Initially, however, it would be advisable to treat dog remains suspected of having been incorporated into archaeologically curated objects with special caution. In this way the relevance of this potentially negative factor may be reduced.

5.3.6.3 Challenges Pertaining to Environmental Context

The physical environment that an ancient group occupied could have influenced the degree to which human-dog symbiosis was experienced – potentially constraining or enabling various activities and relationships. The following factors represent challenging aspects of environmental circumstances and stimuli for CSA interpretations.

5.3.6.3.1 Dependence on Dog Services

Within some ancient contexts, the role of dogs in daily life may have been of pivotal significance, such as the use of sled dogs for transportation and traction among some northern groups. A strong inter-dependence can result in intensified human control over dog activities and thus feeding might have been carefully monitored to ensure the health of working dogs. For example, among the early 20th century Netsilik Inuit of what is now Nunavut, Canada, food availability was generally low and at times little excess food was available for dog feed (Balikci 1970:56). In order to maintain well-fed working dogs with the vitality needed to pull a sled in the winter and carry heavy packs in the summer, family groups usually limited themselves to

keeping only one or two dogs (Balikci 1970:56). Where dogs' capacity to work, and by extension their health, were of great importance, it might be expected that dog diet was more likely to reflect direct human provisioning of food. Thus, while it may be irrelevant in many archaeological contexts where humans were not significantly reliant on dogs' services, this factor could positively reinforce CSA applications in certain environments, particularly in northern areas. There have been relatively few studies characterizing stable isotope values of associated human and dog remains from Arctic regions (Chu1994:39; Coltrain 2009; Katzenberg et al. 2010:185; Losey et al. 2011) and future cross-contextual analyses would provide an opportunity to assess this possibility.

5.3.6.3.2 Isolation

A human group's proximity to geographical barriers can affect how they make dog related economic transactions. For instance trade of living socialized dogs may have been avoided due to their loyal quality of returning to the original owner shortly after the transaction. This was the case among early 20th century Plains Cree groups of what is now Manitoba, Canada, who would not trade their dogs with local neighbors but would trade with long distance Hudson's Bay Company travelers who were sure to transport a dog far enough away that its return was unlikely (Mandelbaum 1979:66). Under these conditions (and recognizing that this loyalty is likely a quality common to most fully domesticated dogs independent of time and space), it may be reasonable to suggest that most domestic dog remains present in an archaeological context are likely to represent animals endogenous to a particular group and their diet.

On the other hand, in some environments this might not have been the case, such as island or other contexts where isolation could keep dogs from escaping their new owners regardless of group socialization. As would be the case with human immigrants (e.g. Müldner et al. 2011), depending on the traded dog's post-transaction lifespan, its bone collagen stable isotope values could still reflect the dietary regime of previous keepers. Thus, in cases where a dog died shortly after it was traded, its stable isotope values would likely reflect an exogenous dietary regime thereby complicating CSA inferences. Furthermore, in contrast with artifact trade-based complications, where dog remains may have been fashioned into recognizable cultural objects, the remains of traded living dogs may not be readily distinguished from those of endemic dogs. Thus, the relevance of this factor to the strength of CSA inferences may be considered mainly in contexts sufficiently isolated to preclude escape of traded dogs. Comparing the isotope values of different dogs and considering the possibility that outliers may have been traded into the group shortly before death could potentially address this problem and strengthen CSA arguments.

5.3.6.4 Summary

While the above factors are not an exhaustive survey of possible influences on the suitability of dog remains as surrogates for their human keepers' stable isotope values, they do provide examples of the kinds of considerations necessary for substantiating CSA inferences relying on direct analogical reasoning. Several of these factors have appeared in discussions of CSA results but rarely have researchers devoted a substantial amount of systematic consideration to the ways in which these dimensions of comparison can positively, negatively, or neutrally influence the strength of conclusions regarding the appropriateness of dog stable isotope values

as surrogates for those of humans during paleodietary reconstructions. Significantly, this lack of consideration has led to some researchers' wholesale cautioning against use of the CSA (Bocherens et al. 2000; Eriksson 2004; Eriksson and Zagorska 2003:160-162). While these warnings are productive contributions to debates over CSA validity, such criticism might be partially obviated, and CSA interpretations clarified, by systematic and explicit recognition of both the type of analogical inference being employed and the relevance and nature of the dimensions of comparison.

Chapter Six

Testing and Applying the CSA

6.1 Introduction

CSA applications have most often been conducted on an *ad hoc* basis and for this reason there have been few studies that, from the outset, intended to test the approaches' suitability for a particular context. This chapter presents a test of the CSA's suitability for reconstructing human diet among two related groups of Archaic maritime-oriented hunter-gatherers who inhabited North America's northeast coast –the Maritime Archaic Indian (MAI) at the Port au Choix site (EeBi-2; Tuck 1976) and the Moorhead at the Nevin site (40.1; Byers 1979). The CSA is then used to assess human diet at the Moorehead occupation of the nearby Turner Farm site (29.9; Bourque 1995, 2001) from which no human data can be obtained. In the first step, the suitability of dogs as human analogs is assessed by: 1) considering the factors outlined in Section 5.3.6; and, 2) comparing dog stable isotope information to that of previously analyzed humans to assess dietary similarity. Having established the suitability of dogs as human analogs, in the second step dog isotope information from another site of similar cultural, temporal, and environmental affiliation is considered to approximate archaeologically unavailable humans by way of direct analogy (see Section 5.3.3). For reviews of MAI and Moorehead occupations at the Port au Choix, Turner Farm, Nevin and other sites see Bourque (1995, 2001), Byers (1979) Tuck (1976) and Fitzhugh (1978). This chapter follows directly from work (Guiry and Grimes in preparation) that will be submitted for publication in the *Journal of Anthropological Archaeology*. Original concepts and data presented in that manuscript were developed for this thesis.

6.2 Site Selection and Comparability

Several factors were considered during site selection. To help control for temporal, environmental and cultural variables it is important that comparisons between different sites be made between groups with similar subsistence and settlement strategies and which lived in generally similar physical environments and time periods. While the MAI and Moorehead had somewhat different dietary regimes (see below, this section), they both followed primarily marine oriented subsistence strategies with varying degrees of terrestrial protein and other dietary inputs (Spiess 1992). MAI and Moorehead material culture, ceremonialism, and settlement patterns are similar and, for this reason, these groups were once thought to belong to a cohesive cultural unit occupying coastal areas between Newfoundland and Labrador, Canada, and Maine, USA (Tuck 1976:109-112). However, based on differences between the primary focuses of MAI and Moorhead subsistence strategies and material culture, they are now considered to be different but related or potentially culturally convergent (Bourque 2001:55-61).

The environmental contexts of the MAI site of Port au Choix, and Moorhead Nevin and Turner Farm sites differ on macro and micro scales. The Port au Choix site on the western side of Newfoundland's Northern Peninsula (Figure 6.1) and the Nevin (Figure 6.2) and Turner Farm (Figure 6.3) sites in Maine's Penobscot Bay are separated by roughly six degrees of latitude contributing to differing climates and, possibly, resource availability (e.g. Cordin et al. 2000). For instance, Spiess (1992:178) suggests that whereas seals were abundantly available to MAI occupants at the Port au Choix site, they were relatively less available to Moorehead populations in the Penobscot Bay region. Despite such environmental differences, MAI and Moorhead occupied coastal regions of the North Atlantic, which offered a generally similar suite of maritime subsistence options.

Temporally, these sites were occupied during the Late Archaic period. The Moorehead occupations at the Turner Farm and Nevin sites have been radiocarbon dated to the Late Archaic between 4500 and 3800 B.P. (uncalibrated) (Bourque 1995:43; Byers 1979:5; Spiess and Lewis 2001:3). The MAI site of Port au Choix has been dated to between approximately 4270 to 3950 B.P. (uncalibrated) (Jelsma 2000:191). For this reason, variability relating to changes in human-dog relations over time is not expected to influence the comparability of human-dog dietary convergence between sites.

The availability of data from previously analyzed humans as well as well-preserved and contextualized dog remains has also been a key factor in site selection. An adequate number of human remains have previously been analyzed at the MAI burial site of Port au Choix (Locus 2) (Jelsma 2000:91, 288; n=30) as well as from the Moorehead component of the Nevin Site (Bourque and Krugger 1994:200; n=10). In contrast, the Moorehead component of the Turner Farm site has no associated preserved human remains. Dog burials occur in small but adequate numbers at each site with four individuals at the Port au Choix site (Tuck 1976:77), six individuals at the Turner Farm site (Bourque 1995:42), and at least four individuals at the Nevin site (Bonnie Sousa, personal communication).

6.3 Human Diet at the Port au Choix, Nevin and Turner Farm Sites

Several lines of evidence have been used to characterize human diets at selected sites. Paleoenvironmental considerations have allowed for hypotheses about the type of resources that would have been available in the region during the Late Archaic. Good organic preservation at each site has allowed for in-depth faunal analyses. In some cases, stable isotope analyses of human remains have provided direct evidence for diet. To contextualize the discussion of human

and dog diets (Section 6.5), this section provides a brief overview of human diet through consideration of resource availability, zooarchaeological studies and stable isotope evidence from MAI and Moorehead human remains.

6.3.1 MAI Diet and Subsistence

Resource Availability

According to Spiess (1993:74) "sea mammal hunting defines the [MAI] tradition..." Caribou hunting was also of some importance; however, the degree to which MAI relied on caribou has been a subject of debate. Spiess (1992, 1993) offers a compelling argument that MAI would not have seasonally migrated inland for a caribou hunt, but rather, had multi-seasonal access from habitation bases on the coast. Several possible scenarios have been offered, most suggesting that the MAI on insular Newfoundland could have practiced forms of sea mammal and caribou hunting during the fall, winter and spring, with a variety of possible contributions from birds, furbearers, caribou and berries in addition to cod and/or salmon fishing during the summer (Jelsma 2000:24-28; Spiess 1993:90).

Zooarchaeological Evidence

MAI faunal remains derive from burial contexts such as the Port au Choix site (Locus 2) and habitation sites such as the Fowler site (EjBe-14) (McGhee and Tuck 1975:45-49), each of which have their own interpretive biases (reviewed by Spiess 1993:90-91). Port au Choix burials have yielded the largest collection of faunal remains (as funerary offerings) including various species of whales, seals, fish, shellfish, and birds as well as walrus, caribou, beavers and other furbearers. Taken as a whole, faunal evidence reflects "a competent maritime adaptation,

possibly including the hunting of whales and definitely including the hunting of walrus" (Spiess 1993:92) as well as a strong focus on seal hunting. In addition to this maritime focus there is "a strong forest and freshwater trapping/fishing competence and some level of reliance on caribou" (Spiess 1993:93).

Isotopic Evidence

As part of Johan Jelsma's PhD dissertation (Jelsma 2000) stable carbon and nitrogen isotope analyses was conducted on bone collagen from 30 individuals of varying ages, sex, and social status at Port au Choix (Locus 2). These data are reproduced in Table 6.1. Associated faunal remains were not analyzed during his paleodietary reconstruction. Mean stable isotope values (n=30; 1σ) for humans from all areas of the Locus 2 burial site for $\delta^{13}C$ and $\delta^{15}N$ are -13.91 ±0.74‰ and 19.76±1.78‰, respectively. Jelsma (2000:140) notes that the stable isotope data supports the marine dietary focus suggested by faunal remains associated with MAI burials. He further suggests that this population was "highly dependent on marine resources and must have spent a great deal of their lives at the coast" (2000:141). These marine resources are suggested to include seals, whales, walruses, and salmon. Dietary variability is apparent in the data with a few individuals producing lower $\delta^{13}C$ and $\delta^{15}N$ values reflecting a greater reliance on terrestrial resources such as caribou and beaver.

6.3.2 Moorehead Diet and Subsistence

Resource Availability

Moorehead populations south of contemporaneous MAI groups were probably equally proficient marine hunters but their proximity to rich riverine and interior resources would have

provided other attractive subsistence opportunities involving freshwater fish, deer, small mammals and reptiles (Spiess 1992:171, 177). Additionally, unlike the Strait of Belle Isle at the Port au Choix site, the Gulf of Maine would have supported few seals thus providing Moorehead occupants with relatively limited access to large marine mammals (Spiess 1992:178). At the same time, seasonally warmer surface waters between 4000 and 5000 B.P. would have attracted swordfish further into the gulf making them more easily accessible and providing an alternative large marine carnivore dietary option (Spiess and Lewis 2001:134; Spiess et al. 1983:102).

Faunal Evidence

Faunal and artifactual data at the Nevin and Turner Farm sites indicate a strong dietary focus on marine resources (Bourque and Krugger 1994:203). Unlike the Port au Choix site, faunal remains collected from the Turner Farm site derive from a midden context and, for this reason, biases associated with faunal remains from burial contexts are not expected to affect zooarchaeological reconstructions of the Moorehead occupation at that site.

A thorough analysis of faunal remains from the Turner Farm site by Spiess and Lewis (2001:154) shows that deer, cod and swordfish were dominant food species with a lesser reliance on clams, seals, flounder, sculpin, birds and furbearers. In sum, faunal analyses suggest that the Moorhead population at the Turner Farm site primarily relied on deer during the winter and early spring, supplemented with shellfish in late winter. Subsistence during late spring might have involved travel to intercept runs of anadromous fish such as alewife, shad, sturgeon, and salmon on the mainland coast (Spiess and Lewis 2001:153). Cod and swordfish were probably a main focus during the summer and possibly fall months. Fall may also have brought a focus on catadromous species such as eels.

Several publications have resulted from excavations at the Nevin Site but zooarchaeological reports could not be obtained (Bouque 1971:57; Byers 1979; Shaw 1988). However, Bourque and Krugger (1994:203) note subsistence similarities between the Nevin and Turner Farms sites by stating that faunal and artifactual data from each indicate a strong marine component in dietary protein.

Isotopic Evidence

Stable carbon and nitrogen isotope analyses of bone collagen extracted from 10 individuals of various ages and sex from the Nevin site are reported graphically by Bourque and Krugger (1994:203). Isotopic data are not given numerically but this information was provided in a supplementary Excel file by Dr. Bruce Bourque (Bourque, personal communication) and is presented in Table 6.2 with his permission. Mean $\delta^{13}C$ and $\delta^{15}N$ values (n=10, 1σ) for humans from all areas of the burial site are -13.50 ±0.98‰ and 17.83±1.42‰, respectively, indicating a strong marine dietary component. Although Bourque and Krugger (1994:203-204) do not further interpret general dietary composition from these isotope values, they do observe some dietary variation by noting that two individuals maintained slightly more terrestrial diets. Though no Moorhead human stable isotope data are available from the Turner Farm Site, Dr. Bourque generously offered a large quantity of additional data from faunal remains collected from that site. These data include stable isotope ratios from white-tailed deer, mink, sea mink, swordfish, cod, flounder and sculpin. As these data are unpublished they are selectively presented here (with Dr. Bourque's permission) only as averages and are not numerically itemized on an individual basis (Table 6.3). No stable isotope data from the Nevin site faunal material were available.

6.4 Contextualizing Human and Dog Relations in the Northeast Late Archaic

Human and dog relations may be characterized using archaeological evidence and in some cases by ethnographical analogy. This section explores the utility of each of these lines of inquiry and details what is known about human-dog relations at each site during the Late Archaic.

6.4.1 Ethnographic Evidence

A wealth of ethnohistorical information exists on contact period Native American human-dog relations in northeastern North America. These observations have usually been made by European travelers and pertain to populations with subsistence strategies and cultural norms that may be dissimilar to those of the MAI and Moorehead groups occupying the same regions thousands of years earlier. For this reason, use of such information as an ethnographical analogy for Archaic contexts would be fraught with interpretive problems (see Ascher 1961; Orme 1974; Wylie 2002:136-153). However, ethnohistorical information can help demonstrate the potential diversity of ways humans and dogs might have interacted in maritime coastal contexts of the MAI and Moorhead.

Authoritative reviews of human-dog relations in the northeast (Kerber et al. 1989; Kerber 1997a,b:84-101; Strong 1985) indicate that dogs fulfilled a variety of roles as pets, afterlife companions, sources of clothing, religious sacrifices, spiritual guardians, emergency and ceremonial food resources, and hunting partners (Kerber 1997a:82). Based on Jesuit accounts, Kerber notes that "the vast majority of references to Native American dogs pertain to the interrelated role of religious sacrifice, afterlife companion, and ceremonial food supply" (1997a:89). Among other things, dogs were sacrificed to honor a guest or to ward off disease.

Once sacrificed, dogs may be eaten and their remains discarded in a midden, or honored with elaborate burials. At times dogs were poorly treated and at others, shown deep compassion, being invited into their owner's sleeping quarters, nursed with human breast milk, or painfully mourned after death. Dog feeding practices also varied widely. In several accounts certain animal food items were withheld from dogs either to avoid familiarizing them with eating economically important resources or to observe respect for the spirits of certain human prey species. On the other hand, some accounts indicate that dogs were "held as dear as the children... and share the...plates, and food of their masters" (Lalemant 1639:13,15; in Kerber 1997a:90). While these accounts have been made from a Eurocentric perspective, and on populations that are likely culturally distant from the MAI and Moorehead, they confirm other demonstrations (c.f. Serpell 1995) of the great diversity of potential ways in which humans might have viewed and interacted with their dogs. For this reason, ethnographic analogies will be of relatively limited, anecdotal, use for interpreting CSA suitability in such ancient contexts as the Moorehead and MAI.

6.4.2 Archaeological Evidence

Archaeological evidence for human-dog relations varies between sites and, for this reason, will be discussed on a site-by-site basis. An additional discussion of other MAI and Moorehead sites containing dog remains is also given.

Turner Farm Site

Six individual dog burials have been excavated at the Turner Farm site and are considered one of the most prominent features associated with the Moorehead occupation (Bourque 1995:42; Spiess and Lewis 2001:6, 147, 149). Dogs range in age and size from newborn to medium-sized adult (Bourque 1995:86). Age and sex profiles are not offered for most individuals. Information on the presence of multiple dog breeds has not been indicated, suggesting that all dogs may be of the same breed or, perhaps, that morphological analyses were unable to determine breed affinity. The Moorehead faunal assemblage also includes 22 dog bone specimens from midden contexts (Spiess and Lewis 2001:77). This number is probably conservative as upward mixing of materials between the second (Moorehead) and third (Sasquahana) occupation layers is suspected to have reduced the number of faunal specimens firmly associated with the earlier phase by approximately 14% (Spiess and Lewis 2001:8-9). Spiess and Lewis (2001:6) also suspect that at least some of the loose midden dog specimens originally derive from dog burials disturbed by the activities of later site occupants.

Spiess and Lewis (2001:150) state that the Moorehead population occupying the Turner Farm site made much of their dogs, and Bourque (1995:86) further notes that special mortuary treatment strongly suggests the importance of dogs to Moorehead populations at the site. Additionally, faunal materials that were probably included as offerings in dog burials are unusual and informative. For example, the faunal suite associated with one burial contained "two Cervid distal tarsal bones (*naviculo-cuboid*), one each from a deer and a moose, as well as a sea mink skull" (Spiess and Lewis 2001:149). Moose remains are rare among Moorehead associated fauna and Spiess and Lewis (2001:149) believe this funerary offering must have had some significance, although they comment no further. Bourque (1995:317), however, raises the possibility that each

of these bones may represent an economically valuable prey species for the associated dog. At least three dog burials included red ocher (Bourque 1995:86), a key ceremonial feature of Moorehead and MAI human burials (Bourque 1995:223). This may suggest that the Moorehead viewed some dogs as having qualities necessitating certain human burial rites. Furthermore, the observation that no dog specimens exhibit cut marks (Spiess and Lewis 2001:77) suggests that human keepers did not eat their dogs and could be interpreted (perhaps ethnocentrically) as further evidence supporting a high degree of respect accorded dogs among Moorehead populations.

The archaeological record provides a glimpse into the possible roles performed by dogs in Moorehead society. Spiess and Lewis interpret the great attention given to dog burials as "especially mean[ing] that trained dogs must have contributed to finding or driving deer" (2001:147) as well as in the hunting of moose and trapping of sea mink. Other roles that dogs may have played in Moorehead society are not clear. It is also possible that dogs were used for traction, possibly carrying packs during hunting forays on trips to the mainland or island interior; however, no evidence has been found directly supporting this hypothesis. It seems unlikely that these dogs played a sacrificial role. No perimortem trauma of any kind has been documented (Spiess and Lewis 2001), although to the current author's knowledge detailed analyses of dog remains have not been conducted. In the absence of human burials the possibility of dogs acting as afterlife companions for humans cannot be assessed. However, dog burials and funerary offerings clearly suggest that humans perceived dogs as beings with a spiritual afterlife. It also seems probable that dogs played a sentry role at the site. This is suggested by the relative positions of what have been interpreted as a dog tie-up area and the main human habitation area. Dogs appear to have been tied up behind the human shoreward habitation (Spiess and Lewis

2001:6, 150) and this could have provided protection from landward dangers. While the lack of cut marks on dog specimens from burial contexts could suggest that dogs were not used as a source of food or clothing, associated middens contained a substantial amount of *Canis* specimens that could represent domesticated dogs. Select *Canis* specimens have been analyzed here to help assess this possibility on the basis of diet. Identification of a substantial number of domesticated dogs from midden contexts would provide evidence for possible human consumption of dogs at the Turner Farm site.

It is probable that dogs routinely helped dispose of human food waste. Remains of at least two species, caribou and seal, record evidence of dog chewing; however, faunal analysts note that no systematic documentation of gnawing was attempted (Spiess and Lewis:55, 150). Based on the discreteness of fishbone dumping episodes in areas away from the dog tie-up area, Spiess and Lewis (2001:150) suggest that the feeding of fish and certain other faunal elements to dogs was intentionally avoided. The rationale behind this is that "fish bones (especially the size of cod bone) and bird bone, as well, are notorious for choking dogs..." and, for this reason, "... most owners of working dogs would avoid feeding them defleshed fish "racks" or bird carcasses" (Spiess and Lewis 2001:150). Rather, based on gnawing and other evidence they suggest that dogs were preferentially fed meat associated with seal bones and deer mandibles. It has further been suggested by way of ethnographic analogy, that seal meat may have been considered dogs' food that was unfit or unpalatable for humans (Bourque 1995:91, 349; Spiess and Lewis 2001:150).

Port au Choix Site

Excavations at the Port au Choix Cemetery site collected the remains of four dogs, two found together in primary context that were interred as funerary offerings for the associated three-person burial and two found in burial fills (Tuck 1976:77, 132). The former are extremely well-preserved and were part of a large and prestigious collection of mortuary materials in burial 50 (Locus 2). Both dogs found in burial fills are fragmentary and incomplete and may have originally been interred as offerings for other persons buried there (1976:77).

Tuck has investigated the possibility of multiple breed representation. Though there is variation in size and predicted body weight, dogs were probably of the same breed, between the size of terriers and retrievers (Tuck 1976:78), and related to the Large or Common Indian Dog (see Allen 1920:459; Ritchie 1945:7-8).

Thorough osteological analyses were conducted on dogs from burial 50 and, to a lesser extent, dogs from burial-fills to assess ages, sex and peri-mortem trauma. All dogs were adults. Both burial dogs were males and relatively larger than burial-fill dogs. Sex determination based on morphology of burial-fill dogs was presumably not possible due to fragmentation. Size differences are interpreted as sexual dimorphism suggesting that both burial-fill dogs were female (Tuck 1976:77). Blunt force trauma, likely a club blow, to the left zygoma and parietal of the older and larger burial dog suggests that it was sacrificed or otherwise dispacthed at the time of burial. The other burial dog does not exhibit clear evidence for cause of death but does show marks consistent with sharp force trauma around the proximal end of the right ulna, which could be related to a sacrificial event (Tuck 1976:77). According to Pferd (1987:52), Tuck has also suggested that this dog may have been strangled. Tuck (1976) does not discuss possible circumstances of death for the burial-fill dogs.

These remains provide evidence for the roles that dogs may have filled in MAI society as well as human-dog relations. Burial dogs exhibit well-developed muscle attachments suggesting that they had been put to work (Tuck 1976:78). Tuck is careful to note, however, that this does not necessarily mean that dogs were used as traction animals. Rather he suggests that dogs most likely served humans with their hunting acumen as well as occasionally acting as pack animals (Tuck 1976:78). Additionally, dogs would have served as human companions during life (Pferd 1987:52-53; Tuck 1976:78) and into the afterlife. The sacrificial nature of at least one dog's death, and the association of blunt force trauma, may be symbolic and speak to the way in which dogs accompanied humans into the afterlife. Among MAI mortuary contexts, other associated funerary objects were routinely intentionally broken prior to burial and Tuck (1976:96) suggests that this act may have symbolically released the spirit of an implement so that it, and not the implement itself, can serve the deceased in the afterlife. Such a ceremony may explain why at least one dog was clubbed – caving-in part of its skull (Plate 6.1). Finally, the way in which burial dogs were positioned relative to accompanying humans may suggest that dogs played a sentry role in the afterlife. Rather than being buried in direct contact with the humans, as one (perhaps ethnocentrically) would expect from a relationship purely based on companionship, dogs were separated from humans by ~30cm of burial-fill (see Plate 6.2; Pferd 1987:52). Though speculative, this clear separate placement of dogs between the deceased and the world of the living may have symbolized the protective sentry role that these dogs were intended to play in their afterlives. If this were the case, then it would also be reasonable to suggest that dogs occupied this role during life as well.

Unfortunately, faunal evidence for human-dog food sharing relationships is not present. Unlike dog burials at the Turner Farm site, MAI associated dogs at Port au Choix apparently

received no funerary offerings. While this could reflect a difference in human perception of dogs between these sites, it seems more likely a result of the differing circumstances of burial. It may be reasonable to assume that human-dog relationships were thought to be as symbiotic in the afterlife as they were during life. Thus, when buried alongside humans a dog should not need any provisions in the form of funerary offerings as they may when buried alone. Whatever the reason, no faunal remains are associated with MAI dogs at the Port au Choix site and dog diet based on this line of analysis remains unknown.

Nevin Site

Unfortunately, no publication detailing the excavation of dog remains from the Nevin site could be obtained. According to Bourque and Krugger (1994:200) and Spiess (personal communication), reports on the site's fauna do exist as unpublished manuscripts (Crader et al. 1995; Hamilton et al. 1993) on file at the Maine State Museum. These reports were not available. Through communications with Bonnie Soussa at the R.S. Peabody Museum of Archaeology, Andover, the following information has been obtained about the archaeological provenience of dogs sampled for this work.

There were at least four dog burials excavated at the site. Burials exhibit various levels of formality and have been found in refuse pits and formal red ochre burials. This suggests the Moorehead occupants at the Nevin site also perceived at least some dogs as beings with a spiritual afterlife worthy of honoring with certain aspects of burial ceremonies accorded to humans. Associated middens also contained one domesticated dog specimen as well as over 500 fragmentary specimens identified to the genus level of *Canis*. Select specimens were sampled to assess the possibility that midden-derived *Canis* specimens belong to domesticated dogs.

Identification of *Canis* specimens as domesticated dogs would provide tentative evidence for human consumption of dogs at the Nevin site. Lastly, as dogs are not listed amongst associated funerary offerings (c.f. Byers 1979) it might be assumed that dogs do not derive from human burials. Based on the temporal, geographical, and environmental similarities between Moorehead occupations, archaeological evidence for human-dog relations at the Turner Farm site should be applicable to the Nevin site.

Other Sites

Other sites along the northeast coast of North America provide evidence that dogs were kept during the Archaic period and are briefly noted here to illustrate the geographical extent of human-dog relations among MAI and Moorehead societies. In 1975 Fitzhugh (1978) discovered the remains of a dog in an MAI burial at the Rattler's Bight site (GcBi-7) in Labrador. The dog was part of a larger elaborate multi-human burial. These remains consist only of a few poorly preserved jaw fragments that were not available for analyses during the time of the author's research (William Fitzhugh, personal communication).

Dog remains from an Archaic occupation at the Ruth Moore site (site no. 31.17; Cox and Lawless 1994) on the Great Gott Island may also exist (Arthur Spiess, personal communication), however, the author was informed that sampling permission was unlikely to be granted as another researcher (Sharron Allitt) had already sampled them (Juliana Clark, personal communication). There is some confusion as to whether or not any Archaic period dog data has been made available in Allitt's research (Allitt 2011; Allit et al. 2008). Allitt (2011:92) indicates that a dog dating to 4570 B.P. was analyzed for her dissertation but also reports the date for this same dog sample as 2570 B.P. (Allitt 2011:85).

Reference to the presence of calcined dog remains is made for several other sites. According to Allitt (2011:56), an Archaic burial containing comingled cremated human and dog remains was discovered on Long Island, New York, by W.A. Ritche in 1959. Unfortunately, the reference citation was not listed. A probable information source has been identified (Ritche 1959) but could not be obtained. Spiess (1992; 174, 184-184) reports on the discovery of calcined specimens probably representing domesticated dogs from two other sites – the John Lund site (37.11; n=4) and the Briggham site (90.2C; n=1), both of which are in Maine dating to the Middle Archaic. Spiess (personal communication) also suggests that dog bone has been recovered at the Middle Archaic Gilman Falls site (74.106) but the unpublished manuscript could not be obtained (Sanger et al. 1994). These remains are also probably calcined (Sanger 1996:22). Calcined bone does not usually preserve collagen with biogenic stable carbon and nitrogen isotope signatures (DeNiro et al. 1985) and, for this reason, these remains are unsuitable for inclusion in this study. Presence of calcined bone at these sites could provide further evidence for ceremonial preparation of dogs before burial or possible human consumption of dogs among Archaic populations in the region.

6.4.3 Considering Human-Dog Comparability at MAI and Moorehead Sites

With the above zooarchaeological and ethnographic evidence (Section 6.4.1 and 6.4.2) it is now possible to consider the categorical framework of interpretive factors proposed in Section 5.3.6 that can help determine probable influences on human-dog dietary similarity at each site. The remainder of this section considers these interpretive factors in preparation for the presentation of results and discussions in Sections 6.5 and 6.6.

6.4.3.1 Biobehavioral Factors

Lifespan. Particular caution must be taken when interpreting the stable isotope values of two younger dogs (MARC 1019 and 1020) deriving from burials as well as two *Canis* specimens (MARC 1021 and 1028) from the associated midden at the Turner Farm site. Additionally, as domestic dogs are usually weaned between the age of 5 and 6 weeks (Rheingold 1963:177), an infantile specimen (MARC 1019) is expected to show elevated $\delta^{15}N$ values reflecting consumption of its mother's milk. Other domesticated dog and *Canis* specimens from the Nevin and Port au Choix sites have been identified as adults.

Domestic, Wild or Hybrid? All burial-derived specimens come from zooarchaeologically confirmed domestic dogs. *Canis* specimens deriving from middens at the Turner Farm and Nevin sites may have come from domesticated dogs or wolves (coyotes did not inhabit the region at that time; Gompper 2002). Their lower resolution taxonomic identifications probably reflect their fragmented and incomplete nature more than morphological ambiguity. These specimens will not be considered dogs unless compelling dietary evidence is found. Future ancient DNA work may further assist in taxonomic identification of these specimens.

6.4.3.2 Cultural Factors

Spiritual Signifcance of Dogs. Ethnographic evidence from the region suggests that later cultures sometimes viewed dogs with a deep sense of spirituality. Moorehead and MAI groups are probably too distant temporally to draw on such recent information. Archaeological data does, however, provide some evidence for human views of dog spirituality and perhaps worship. Dog burials clearly indicate that Moorehead and MAI believed that dogs had a spiritual afterlife. Inclusion of red ocher in dog burials at all three sites as well grave offerings left for dogs at the

Turner Farm site provide further evidence of the great respect and high standing accorded to dogs in some situations. It is possible that certain dogs have been given special treatment and unusual diets for spiritual reasons. If it can be determined that any of the *Canis* specimens collected from associated middens also derived from domesticated dogs it will be possible to assess this hypothesis. Stable isotope similarities between dogs from middens and burials would suggest that, despite special mortuary treatment given to certain dogs, dietary options did not differ.

Dogs for Dinner. No site has produced osteological evidence for human consumption of dogs. Cut mark documentation and analyses, however, have not been a focus of zooarchaeological work on dog and *Canis* specimens. At the Turner Farm and Nevin sites domesticated dog remains have been found in middens. These specimens could represent remnants of human meals rather than disturbed dog burials. These middens also contain relatively large quantities of *Canis* remains that could have derived from domesticated dogs. Based on this tentative evidence, it is possible that humans had consumed some dogs at least in emergency situations. This hypothesis would be supported if: 1) human $\delta^{15}N$ values are found to be elevated over dogs (though this would only occur if humans regularly consumed dog flesh); and, 2) some *Canis* specimens are determined to derive from domesticated dogs.

Separate Treatment of Different Dog Breeds. With the exception of two dogs from the Port au Choix site, dog remains analyzed have not undergone comprehensive zooarchaeological analyses that would be necessary to assess the likelihood of multiple breed presence. Considering the level of detail in which faunal remains from the Turner Farm site were analyzed, however, it would be surprising if the presence of dogs belonging to significantly different breeds went unrecognized. General descriptions of dog remains from the Turner Farm and Nevin sites

suggest that dogs were of medium, terrier size (Arthur Spiess, personal communication) (perhaps 10-20kg). This description is consistent with those of dogs from the Port au Choix site interpreted by Tuck to have been similar to the Large or Common Indian Dog. Although detailed comparisons would be required for confirmation, this cursory assessment suggests that dogs at all sites would have been of similar breeds. For this reason, separate treatment of different breeds will probably not influence human-dog dietary comparability.

Technological Change. It is difficult to assess the potential for technological change to influence dog roles in such ancient contexts. Interpretations of dog roles at the Port au Choix and Turner Farm sites have not proposed any shifts due to technological change and similarly suggest that dog roles involved hunting and occasional pack animal work. There have been no interpretations of the possible roles that dogs played at the Nevin site. However, based on cultural, temporal and environmental similarities between the Nevin and Turner Farm sites, dogs probably also worked as hunting and pack animals at the Nevin site. Based on this limited evidence, technological change is tentatively not expected to have influenced dog diets through time at intra- or inter-site scales.

Economic Transactions. No confirmed dog remains appear to have derived from archaeologically curated objects. It is possible that some midden-derived *Canis* specimens belonged to discarded artifacts but there is no evidence to support this notion. Therefore, this factor is not expected to influence dog and human dietary convergence.

6.4.3.3 Environmental Factors

Dependence on Dog Services. Based on the archaeological evidence, MAI and Moorehead dogs are thought to have provided companionship, sentry, hunting and minor pack

animal services, and may have played a spiritual role. There is no evidence that dogs provided crucial transportation or other subsistence services. The Port au Choix, Turner Farm, and Nevin sites are situated in close proximity to abundant local resources and there does not appear to be a compelling reason to suppose that human life-ways would have been significantly dependent on dog services.

Isolation. All three sites are located on islands that could provide a barrier disallowing the escape of 'homesick' dogs traded to islanders from mainland groups (although, the Nevin site may have become connected to the mainland during low tides [Byers 1979:3]). If dogs were traded into one of these sites from groups with an isotopically different dietary regime this factor might cause an incorrect source-to-subject transposition. For this reason, dietary outliers, especially younger individuals, will be considered with caution.

6.5 Sampling and Isotopic Results

This section provides a brief description of sampling activities aimed at acquiring appropriate faunal specimens followed by discussion of sample collagen quality, statistical analyses and a site-by-site outline of human, dog and other faunal $\delta^{13}C$ and $\delta^{15}N$ results.

6.5.1 Sampling

Three of the six dogs excavated at the Turner Farm site were available to be sampled at the Maine State Museum in Augusta, Maine. An additional nine samples were taken from various elements of possible dog remains taxonomically identified to the genus *Canis*. These latter remains derive from midden fragments and may not necessarily represent a discrete individual. To decrease the likelihood of sampling the same individual twice, specimen selection

targeted remains from separate 5'x5' excavation units along an east-to-west transect of the site. Depth below surface as well as north-south provenience varied widely. Additional faunal remains were not sampled because isotope data has already been made available by Dr. Bruce Bourque (unpublished; see Section 6.3.2; Table 6.3).

From the Port au Choix site, specimens from all four dogs were sampled at The Rooms Corporation (the provincial museum) and Memorial University, in St. John's, Newfoundland and Labrador. To help contextualize human and dog diets, additional faunal samples were taken as available from a collection held at Memorial University. These samples derive from separate features associated with a later Paleoeskimo cemetery (Locus 5). Due to potential temporal shifts in each species' diet, data from these specimens are intended to provide a general approximation of the stable isotope values for similar species available to the earlier MAI.

From the Nevin site, dog specimens from four burials were sampled at the R.S. Peabody Museum in Andover, Massachusetts. Additionally, the right calcanei were sampled from five other possible dogs identified as *Canid*. These specimens as well as nine samples from various other species derive from an associated Moorehead midden context.

6.5.2 Collagen Quality

Processing of three faunal samples (MARC 1022, 1050 and 249 in Tables 6.4, 6.5 and 6.6, respectively), one from each site, was halted after they produced inadequate collagen yields (below 2%). MARC 1054 (Table 6.5), a faunal specimen from the Nevis Site, also produced unacceptable collagen yields but processing of this sample was inadvertently completed (see Section 6.5.5). An additional sample from the Port au Choix site was affected by a technical IRMS issue and was also discontinued. All other samples provided atomic C:N values between

2.9 and 3.6, collagen yields above 2%, and carbon and nitrogen concentrations greater than 16% and 8% respectively. Additional comparisons of atomic C:N and collagen yield data against carbon and nitrogen concentration data did not identify any significant outliers. Qualitative observations during the collagen extraction process also did not identify samples requiring special concern.

It is important to note that at least some of the human and faunal data used for comparisons has been produced using methods different from those employed here (see Section 3.4). Collagen extractions performed on human remains from the Port au Choix site followed a methodology similar to Longin's (1971). Bourque and Krugger (1994:200) also used a modified Longin (1971) methodology developed by Krugger and Sullivan (1984:210-211) to extract bone collagen from human remains excavated at the Nevin site. Details on the collagen extraction method used in the processing of the unpublished Turner Farm site faunal data provided by Dr. Bruce Bourque were not available. It is therefore important to remain cognizant that this variation in methodology may contribute to relatively small systematic offsets between results produced in this thesis and comparative stable isotope data (see Section 3.1). Furthermore, some of this comparative data was produced before the acceptance of standardized methods for collagen quality assessment. For this reason, some data is unaccompanied by atomic C:N ratios, collagen yields, and carbon and nitrogen concentration values and could be influenced by diagenesis.

6.5.3 Statistical Analyses

Statistical analyses were performed using SPSS Statistics 17.0®. For all statistical analyses discussed below, a One Way ANOVA was first used to compare all possible groups and

identify statistically significant differences between data sets. A subsequent *Post hoc* Bonferroni analysis then performed comparisons between all group combinations to determine the statistical significance of differences between each possible group-dyad at a 95% (2σ) level of confidence. Unless otherwise noted, the statistical significance of a particular analysis is maintained for both $\delta^{13}C$ and $\delta^{15}N$ values. All averages and standard deviations were calculated using Microsoft Office Excel 2007® and are given at a 67% (1σ) level of confidence. Error bars in all graphical representations also represent a 1σ level of confidence.

6.5.4 Results from the Turner Farm Site

Dog, *Canis* and other faunal data from the Turner Farm site are presented in Table 6.3 and 6.4 as well as Figure 6.4. Three specimens from separate dog burials produced elevated mean $\delta^{13}C$ and $\delta^{15}N$ values of -12.68±0.34‰ and 17.88±1.09‰, respectively. MARC 1019 derives from a pup and thus the weaning effect can explain its slightly higher $\delta^{15}N$ value. These data clearly indicate that dog diets were strongly dependent on high trophic level marine-derived foods. Midden-derived *Canis* specimens (n=8), with a mean $\delta^{13}C$ value of -16.59±4.40‰ and $\delta^{15}N$ value of 10.91±6.02, were much more variable and range over 9‰ in $\delta^{13}C$ and nearly 14‰ in $\delta^{15}N$. However, these data can be clearly separated into two distinct clusters that are significantly different (One Way ANOVA, *Post Hoc* Bonferroni test, $P< 0.05$, see Figure 6.5). One group (n=4) is characterized by elevated $\delta^{13}C$ (-12.58±0.36‰) and $\delta^{15}N$ (16.25±1.12‰) values that are statistically indistinguishable from those of burial dogs (One Way ANOVA, *Post Hoc* Bonferroni test, $P> 0.05$). The other group (n=4) produced much more terrestrial $\delta^{13}C$ (-20.60±1.50‰) and $\delta^{15}N$ (5.57±2.67‰) values dissimilar to those of dog burial specimens (One Way ANOVA, *Post Hoc* Bonferroni test, $P< 0.05$). Two of these *Canis* specimens with

terrestrial diets, MARC 1025 and 1029, produced very similar isotope values and could have belonged to the same animal. This seems unlikely as the samples were collected roughly 110 feet apart. Regardless, averaging the stable isotope values of these two samples does not alter the significance of the statistical difference between *Canis* specimens with terrestrial diets (n=3) and dog burial (n=3) and *Canis* (n=4) groups with marine dietary signatures (One Way ANOVA, *Post Hoc* Bonferroni test, $P< 0.05$). It is therefore apparent that *Canis* specimens derive from two separate groups of animals with different diets, one focusing on marine foods and the other on terrestrial foods.

Based on the dietary similarity, as well as the fact that marine foods should generally not be as widely available to wild *Canis* species, it is probably safe to assume that marine-dieted *Canis* specimens also derive from domesticated dogs (also see Section 6.5.5). The possibility remains that these *Canis* specimens derive from wolves that had scavenged human middens rich in marine derived refuse; however, it seems improbable that wolves would have obtained the same kind of access to human food refuse as domestic dogs. This interpretation is supported by the location of a dog tie-up area at the site (Spiess and Lewis 2001:6, 150), which is positioned in a way that may have blocked access of wild animals to the site's middens. Considered together, dog and *Canis* specimens (n=7) with marine diets produced mean $\delta^{13}C$ and $\delta^{15}N$ values of -12.69±0.35‰ and 16.95±1.34‰, respectively.

The second group of *Canis* specimens, with more terrestrial diets, could have derived from wolves with little access to marine foods. MARC 1021 and 1023 have $\delta^{15}N$ values consistent with a predominantly terrestrial omnivorous/carnivorous diets that might be expected for wolves (e.g. Bocherens and Drucker 2003). On the other hand, MARC 1025 and 1029, whether originating from one animal or two, have $\delta^{15}N$ values lower than white-tailed deer from

the site suggesting a herbivorous diet that would be unusual for a wolf. An alternative option could be that these specimens come from wolves with a dietary focus on herbivores that, in turn, had a dietary regime based on nitrogen fixing plants with low $\delta^{15}N$ signatures such as legumes. Such diets, for instance, have been observed in white-tailed deer on nearby North Haven island (Bourque and Krugger 1994:197; see below also). It is also possible that *Canis* specimens with terrestrial diets come from domesticated dogs that, for one reason or another, consumed foods different from other dogs at the site. In the latter case, it may be that dogs were obtained from other groups with a terrestrial subsistence base or that certain dogs, for cultural or spiritual reasons, were denied marine foods. Future ancient DNA work could address questions of the domestic status of these *Canis* remains. However, for purposes of caution, *Canis* specimens with terrestrial diets are not considered to be dogs here.

Stable isotope data from other Turner Farm site fauna mainly derive from marine animals spanning the site's entire occupation. Sea mink (n=7) and mink (n=5) share close $\delta^{13}C$ (-9.66±1.09‰ and -11.65±0.51‰, respectively) and $\delta^{15}N$ (15.38±0.57‰ and 15.30±0.27‰, respectively) values suggesting that both are marine oriented carnivores. Cod (n=9), flounder (n=4) and sculpin (n=3) produce a mean $\delta^{13}C$ value of -11.86±2.13‰ and $\delta^{15}N$ value of 14.52±1.11‰ and provide a general baseline for the main marine fish species found at the site. Swordfish (n=12) produced a similar mean $\delta^{13}C$ value of -11.93±0.59‰ but are at least one trophic level lower with a mean $\delta^{15}N$ value of 9.16±1.40‰. The only terrestrial mammals included are black bears (n=9) and white-tailed deer (n=6). Together, these two species produce a mean $\delta^{13}C$ value of -22.80±1.21‰ suggesting that the local terrestrial ecosystem was dominated by C_3 plants. Black bears produced a mean $\delta^{15}N$ value of 5.25±1.63‰ indicating a relatively low baseline for local omnivores. White-tail deer have a higher mean $\delta^{15}N$ value of

6.03±2.01‰ suggesting that consumption of this species could provide a source of variability in the $\delta^{15}N$ values of human and dog diets.

6.5.5 Results from the Nevin Site

Stable isotope data from dogs, *Canis* and other faunal specimens from the Nevin site are presented in Table 6.5. This data is plotted alongside human data (Table 6.2) from this site in Figure 6.6. Four dog burial specimens produced a mean $\delta^{13}C$ value of -12.05±0.66‰ and $\delta^{15}N$ value of 15.97±1.38‰. Five *Canis* specimens deriving from the site's midden have stable isotope values that are similarly elevated (One Way ANOVA, *Post Hoc* Bonferroni test, $P > 0.05$) with a mean $\delta^{13}C$ value of -13.01±0.88‰ and $\delta^{15}N$ value of 15.84±1.37‰. Based on this dietary similarity, as well as the natural unavailability of substantial amounts of marine-derived foods to wild *Canis* species (i.e. wolves), it seems likely that these *Canis* samples also come from domesticated dogs. An argument might be made that these *Canis* specimens could represent wolves that had systematically scavenged human middens. This scenario, however, seems less probable as it would be difficult for a wolf pack to successfully, and routinely, raid a midden in close proximity to human habitation areas that were presumably guarded by domestic dogs. Considered together (n=9), dog and *Canis* specimens with marine diets produced mean $\delta^{13}C$ and $\delta^{15}N$ values of -12.58±0.90‰ and 15.69±1.03‰, respectively. Humans (n=10) have produced a mean $\delta^{13}C$ value of -13.50±0.98‰ and $\delta^{15}N$ value of 17.82±1.43‰ that are statistically indistinguishable (One Way ANOVA, *Post Hoc* Bonferroni test, $P > 0.05$) from the isotopic signatures of dogs and *Canis* specimens at the site (compared as individual groups and as a combined dog-*Canis* group).

Other fauna, representing potential prey species for site occupants and their dogs, were analyzed to aid in dietary reconstruction. A river otter and seal specimen produced similarly elevated $\delta^{13}C$ (-13.10‰ and -13.76‰, respectively) and $\delta^{15}N$ (15.14‰ and 15.51‰, respectively) values consistent with the expected aquatic carnivorous diets maintained by these species. A moose specimen produced a low $\delta^{15}N$ value (0.99‰) suggesting that this animal probably maintained a diet focusing or forbs, aquatic plants and deciduous tree twigs (Drucker et al. 2010a). Stable nitrogen isotope values of a beaver (4.51‰) and black bear (4.25‰) are consistent with herbivorous/omnivorous diets and provide a baseline for terrestrial fauna in the area. A $\delta^{15}N$ value of 9.40‰ for the deer specimen is curious. It was found that this specimen had produced an unacceptable collagen yield which may account for this aberrantly high value (see Section 6.5.2). A mean $\delta^{13}C$ value of -21.27±0.51‰ for moose, bear, and beaver specimens (n=3) suggests that the surrounding terrestrial environment was predominately composed of C_3 plants.

Two faunal specimens produced unexpected stable isotope values. The adult lynx and raccoon specimens have extremely high $\delta^{13}C$ (-9.66‰ and -10.81‰, respectively) and $\delta^{15}N$ (19.13‰ and 17.86‰, respectively) values consistent with a strong dietary focus on high trophic level marine derived foods. Raccoons are well known nocturnal scavengers and it is possible that this animal could have habitually raided human midden sites under the cover of darkness in order to obtain discarded marine derived foods. Studies of lynx inhabiting modern Canadian Maritime regions suggest that these animals usually maintain terrestrially focused dietary regimes (e.g. Matlack and Evans 1992; Saunders 1963a). Therefore, it may also be the case that this lynx specimen derives from an individual that had lived in close proximity to human occupations, taking advantage of available marine food refuse. Modern trappers have documented lynxes'

preference for bait composed of spoiled fish (e.g. Saunders 1963b) and a study of the stomach contents of a lynx shot at a Newfoundland garbage dump identified cooked fish as one of the animal's last meals (Saunders 1963a). Lynx are diurnal yet are also solitary and notoriously furtive and elusive. Thus, unlike a pack of wolves, a lynx may have been able to efficiently take advantage of marine food resources discarded in human middens without being noticed.

6.5.6 Results from the Port au Choix Site

Stable isotope data from humans, dogs and other fauna from the Port au Choix site are presented in Table 6.6 and Figure 6.7. Four dogs from Port au Choix produced a mean $\delta^{13}C$ value of -13.97±0.44‰ and $\delta^{15}N$ value of 17.97±0.72‰ indicating a dietary reliance on high trophic level marine animals that is statistically indistinguishable from that of previously analyzed humans (n=30; mean $\delta^{13}C$ = -13.91±0.73‰; mean $\delta^{15}N$ = 19.76±1.18‰; Table 6.1) from the same site (One Way ANOVA, *Post Hoc* Bonferroni test, P> 0.05).

Fauna collected from mortuary contexts of a later cemetery provide approximate background information on the region's isotope ecology. Taxonomic identification for birds (n=6) is of relatively low resolution and remains at the class level of Aves. Inter-species dietary variability is thus expected to have influenced the mean bird $\delta^{13}C$ value of -15.77±1.76‰ and $\delta^{15}N$ value of 16.45±2.45‰. These values indicate that consumed birds were, to varying extents, marine-derived carnivores. Seal specimens are classified to the level of family and may also represent multiple species. Seals (n=5) show less variability in stable isotope signatures with an average $\delta^{13}C$ value of -15.03±0.35‰ and $\delta^{15}N$ value of 16.11±1.42‰, which is consistent with the marine carnivorous diet expected for seals. One unidentified mammal specimen was also analyzed, producing stable isotope values ($\delta^{13}C$ of -15.61‰ and $\delta^{15}N$ of 17.042‰) that fall

within the range of seals, and therefore it is probable that this specimen also derived from a seal. A caribou specimen produced a $\delta^{15}N$ value of 1.98‰ and relatively high $\delta^{13}C$ of -18.76‰ which are consistent with a diet focusing on lichen (Drucker et al. 2001; 2010b). The muskrat specimen analyzed produced a $\delta^{15}N$ value of 3.57‰ and may be considered a tentative baseline for terrestrial/aquatic herbivore diets in the area. A $\delta^{13}C$ value of -22.64‰ for this muskrat sample suggests that the local terrestrial ecosystem was dominated by C_3 plants.

6.5.7 Summary of Results

Humans, dogs, and a majority of *Canis* samples deriving from middens produced stable isotope values suggesting strong dependences on marine-derived food. Based on dietary similarities and contextual considerations, many *Canis* samples with marine diets are suggested to have originated from domestic dogs.

Herbivorous fauna at all sites generally suggest that local terrestrial environments were dominated by C_3 plants. The $\delta^{15}N$ values of some terrestrial herbivores suggest that plants depleted in ^{15}N such as forbs, aquatic plants and lichen were available in these areas and may reduce trophic level distinctions between autotrophs and herbivores such as moose and caribou. Probable marine hunting birds as well as marine fish and mammals produce varying but always highly elevated stable isotope values. Terrestrial omnivores and carnivores have produced a wide range of isotope values probably owing to natural foraging strategies and opportunistic access to human middens.

6.6 Discussion: Interpreting Human and Dog Diet and Dietary Convergences

Figure 6.8 plots mean stable isotope values of all groups of humans and dogs as well as *Canis* specimens that probably originated from domesticated dogs. Figure 6.9 plots the difference between mean dog and human stable isotope values (e.g. [mean dog $\delta^{15}N$] – [mean human $\delta^{15}N$]). No statistically significant difference could be found between humans, dogs, and *Canis* specimens with marine diets at intra and inter-site levels (between all possible groups, One Way ANOVA, *Post Hoc* Bonferroni test, $P > 0.05$).

Mean human and dog burial stable isotope values at the Port au Choix site are closest, with dogs being 0.07‰ lower in $\delta^{13}C$ and 2.25‰ lower in $\delta^{15}N$ relative to their human counterparts. Human isotope values indicate a strong reliance on very high trophic level foods. In the context of associated faunal remains and reconstructed resource availability, these values probably reflect regular consumption of seals and birds and could also include dog meat. As dogs produced a nearly identical mean $\delta^{13}C$ value, their lower mean $\delta^{15}N$ value is less likely due to a greater consumption of terrestrial based foods, but, rather consumption of relatively lower trophic level marine foods. This suggests that relatively less seal and perhaps more fish was provided, or otherwise accessible, to dogs. Despite this difference, the majority of dog diets at Port au Choix were isotopically similar to their human keepers (One Way ANOVA, *Post Hoc* Bonferroni test, $P > 0.05$). For this reason, in the absence of human remains at this site dogs would provide an appropriate, albeit somewhat rough, proxy for their human keepers.

Mean human and dog burial stable isotope values are also similar at the Nevin site where dog burial specimens are 1.45‰ higher in $\delta^{13}C$ and 1.86‰ lower in $\delta^{15}N$ relative to humans. When probable dog specimens deriving from middens (i.e. *Canis* specimens with marine dietary signatures) are added to the mean of dog burial specimens the human-dog similarity is

maintained (One Way ANOVA, *Post Hoc* Bonferroni test, P> 0.05), with dogs producing $\delta^{13}C$ values 0.92‰ higher and $\delta^{15}N$ values 2.13‰ lower than humans. Mean Moorehead human stable isotope values provide strong evidence for a marine-oriented dietary regime supposed by Bourque and Krugger (1994:204) to reflect a focus on swordfish, other marine fish and deer. A consideration of human data from Port au Choix supports this notion. Moorehead humans have lower mean $\delta^{13}C$ and $\delta^{15}N$ values than MAI humans from Port au Choix suggesting that they may have consumed slightly more terrestrial-based foods as well as fish with lower $\delta^{15}N$ values. Swordfish from the Nevin site faunal collection were not analyzed; however, swordfish from the Turner Farm site show $\delta^{15}N$ values that are at least one trophic level below seals from both the Nevin and Port au Choix sites. In this context, with a slightly higher mean $\delta^{13}C$ value and lower $\delta^{15}N$ value, it appears that dogs maintained a diet incorporating more relatively low trophic level marine fauna, perhaps including anadomous fish and shellfish. Nonetheless, Moorehead humans and dogs at the Nevin site clearly share a dietary convergence similar to that observed between MAI dogs and humans at the Port au Choix site.

6.6.1 Implications for Moorehead Diet at the Turner Farm Site

Dietary convergences at the Nevin and Port au Choix sites provide compelling evidence that dogs and humans at the Turner Farm site would also have shared a similar diet. However, before transposing dietary information from the Turner Farm site dogs (and *Canis* specimens with marine diets assumed to be dogs) to archaeologically unavailable humans it is necessary to consider the biobehavioral, cultural and environmental comparative dimensions that may influence the suitability of dogs to serve as analogs in Moorhead and similar contexts. At the outset it is imperative to explicitly note assumptions limiting interpretations presented here. It is

assumed that dogs and humans metabolize and incorporate their food intake in a similar manner such that rates of isotopic fractionation and incorporation into respective tissues are comparable for both. It is also acknowledged that the canid practice of cacaeotrophy may be unpredictably, albeit systematically, shifting dog stable isotope values relative to humans.

Considering biobehavioral factors, differences between human and dog lifespan and bone remodeling do not appear to have strongly influenced human-dog dietary similarities as mean dog and human stable isotope values at the Port au Choix and Nevin sites, respectively, share generally similar standard deviations and spreads. This provides supporting evidence for the consistency of human diet over long periods of time in the Moorehead and MAI populations. Dogs and *Canis* specimens with marine diets at the Turner Farm site show slightly more $\delta^{15}N$ variability than their counterparts at the other sites and this may reflect the greater age range of selected animals. No difficulty was encountered when determining the domestic status of *Canis* specimens at the Nevin site with all five samples showing evidence of having had a human-influenced diet. A similar trend is shown by *Canis* specimens at the Turner Farm site with four of eight specimens showing strong marine dietary signatures indicating that they also most likely derived from domesticated dogs.

Cultural factors also do not appear to have influenced human and dog dietary similarities. Dogs from burial and midden contexts shared statistically indistinguishable stable isotope values (One Way ANOVA, *Post Hoc* Bonferroni test, $P > 0.05$) at both the Turner Farm and Nevin sites. Whatever the difference in treatment conferred to each group of dogs, diet was not influenced. Minor elevation of mean human $\delta^{15}N$ values over those of associated dogs at the Port au Choix and Nevin sites provides possible evidence for limited consumption of dog meat. A lack of concurrent elevation of human $\delta^{13}C$ values over those of dogs mitigates this hypothesis,

suggesting that if dogs were consumed, they probably did not form a major component of human diet and were perhaps more likely to have served as emergency foods. Nonetheless, this trend suggests that dogs at the Turner Farm site would also have $\delta^{15}N$ values slightly lower than humans (see below, this section). Dog diets at all sites do not provide evidence relating to the maintenance of different breeds or technological shifts in dogs' roles.

The only environmental factor that might have influenced human-dog dietary convergence depends on the circumstantial interpretation of the Turner Farm site *Canis* specimens with terrestrial diets as domesticated dogs rather than wolves. If this were the case, it is possible that the dogs were brought onto the island having been obtained from another population(s) with a strong terrestrial subsistence focus. For this reason, these *Canis* specimens will not be considered when transposing dog diets to archaeologically unavailable humans at the Turner Farm site.

The above consideration of potential influences on human and dog dietary similarity suggests that mean dog stable isotope values at the Turner Farm site should provide suitable proxies for their human keepers. Elevations of roughly 2‰ in mean human $\delta^{15}N$ values over those of dogs at both the Nevin and Port au Choix sites suggest that humans at the Turner Farm site might have been similarly enriched in ^{15}N relative to dogs. A similar trend is noticeable among all other northern marine-oriented hunter-gatherers for which a comparable amount of human and dog stable isotope data is available (Figure 6.10). At Namu in British Columbia, Canada (Cannon et al. 1999), as well as Gotland and Öland, Sweden (Eriksson 2004; Eriksson et al. 2008), mean human $\delta^{15}N$ values are roughly between 2.0 and 2.5‰ higher than associated dogs (see Table 5.1 for number of samples).

Furthermore, $\delta^{13}C$ value similarities between dogs and humans at other sites suggest that humans at the Turner Farm site would also have shared very similar $\delta^{13}C$ signatures with their dogs. Mean dog $\delta^{13}C$ values at the Nevin and Port au Choix sites as well as among other marine-oriented hunter gatherers fall within 1‰ of associated mean human values and have a slight tendency to be more positive (mean difference = 0.31‰; Table 5.1).

Based on these comparisons it is likely that humans at the Turner Farm site would have had a mean $\delta^{15}N$ value between 1.0 and 3.0‰ above the mean dog value and a mean $\delta^{13}C$ value 1.5‰ above or below the mean dog value. Dogs and *Canis* specimens with marine signatures (n=7) have mean $\delta^{15}N$ and $\delta^{13}C$ values of -12.69±0.35‰ and 16.95±1.34, respectively. Using dogs as a direct analogy, this suggests that a group of their human keepers would produce $\delta^{15}N$ values roughly between 18.0‰ and 20‰ and $\delta^{13}C$ values between -14.2‰ and -11.2‰. In the context of faunal stable isotope data from the Turner Farm site, transposing mean dog $\delta^{13}C$ and $\delta^{15}N$ values to humans suggests a dietary regime based on swordfish, other marine fish, deer and perhaps slightly more marine mammal carnivores such as seals or sea mink. This conclusion is consistent with dietary reconstructions based on zooarchaeological analyses of the Turner Farm site faunal remains (see Section 6.3.2).

One hypothesis put forward by Spiess and Lewis (2001:150), and supported by Bourque (1995:91, 349), would affect the relationship between human and dog $\delta^{15}N$ values. They suggest that seal meat may have been preferentially fed to dogs rather than being consumed by humans. Considering the relatively limited quantity of high trophic level marine mammal remains in the Turner Farm site faunal assemblage this would lead to a convergence of human and dog $\delta^{15}N$ values or perhaps even an elevation of the latter over the former. This trend is not supported by data from other marine-oriented hunter-gatherers. Significantly, this scenario is not consistent

with human and dog isotope data from the Nevin site, a nearby contemporaneous and culturally equivalent occupation. There, humans appear to be eating the highest trophic level marine fauna mixed with some terrestrial fauna. In contrast, dogs, while still consuming very substantial amounts of marine-derived foods, are feeding at a slightly lower trophic level with perhaps less input from terrestrial foods. A similar human-dog dietary relationship is conveyed by data from the Port au Choix site. At the Turner Farm site, it therefore seems less likely that dogs were preferentially fed seals, one of the highest trophic level species available in the region.

6.7 Summary and Conclusion

In sum, $\delta^{13}C$ and $\delta^{15}N$ information from dog bone collagen appears to provide a valid, albeit somewhat imprecise, dietary proxy for humans in MAI and Moorehead coastal contexts. Using this approach, as well as zooarchaeological and paleoenvironmental evidence, Moorhead diet at the Turner Farm site has been reconstructed. Direct transposition of dietary information was qualified by considering a suite of factors which could potentially influence food sharing relationships between humans and dogs and, in so doing, the ways in which dog diets are thought to have been like, unlike, or of unknown likeness to human diets have been clarified.

This CSA interpretation might be refined in several ways. The analyses of more dog remains would help to better characterize levels of dietary variability over time and would also increase the strength of the sample population. Second, additional information on the archaeological provenience, artifact associations, ages, sex, and perimortem trauma of each dog would help to better contextualize and interpret human-dog food sharing relationships. Genetic information on dog and *Canis* specimens with marine diets, would further allow for an assessment of the representation of multiple breeds at the site. Such information may, in turn,

help explain why some dogs were buried and other's discarded in middens and allow for further questions to be asked about human and dog relationships in the Late Archaic northeast.

Chapter Seven

Conclusion

7.1 Conclusion

This thesis has made several important contributions to stable isotope-based human paleodietary reconstructions in regard to the possibility of using dog remains as a proxy material for human bone. Chapter Four provides an overview of the CSA's development, reasons for its use and predictions of where future growth and innovation is likely to occur. Using data from an exhaustive literature review, Chapter Five provides the first cross-contextual comparison of the degree to which dog diets reflect human diets independent of temporal, environmental, or cultural association. In that context, hypotheses previously offered to explain observed similarities and differences between human and dog isotope values are evaluated. Chapter Five also offers original insights into the analogical nature of CSA applications and a categorical framework for structuring CSA inferences to strengthen their underlying analogical arguments. Finally, Chapter Six provides a case study demonstrating how CSA inferences can be effectively structured and supported from the perspective of an analogical inference in order to most clearly lay out the ways in which dogs are considered to act as human dietary analogs. The following discussions summarize and offer future directions for each of these contributions.

The CSA began its unassuming development in 1978. During the early 1980s the CSA was further developed in a passive, unintentional way when domesticated dogs, apparently analyzed as parts of faunal assemblages, began showing similarities with their human keepers. Later research actively commented on this trend. Seminal papers in 1988 and 1999 provided the cornerstones of using stable carbon and nitrogen isotope information from dog bone collagen as

a proxy for human remains. Following these pioneering works, in the early 2000s CSA studies began to proliferate. This increase in CSA application probably reflects multiple factors. As CSA applications became more common in the literature the approach's developing credibility and familiarity likely encouraged the bone chemistry community's acceptance of its feasibility. Additionally, increasing concern among a variety of groups with the destructive analysis of human remains has been a strong driving force behind recent CSA applications. Future CSA analysts may also cite preservation of human remains and growing interest in the lives of ancient dogs as reasons for applying the CSA. Furthermore, other kinds of bone and tooth chemistry work on dogs and humans has provided preliminary indications that information from dog stable oxygen, sulfur, and strontium isotope signatures could provide a proxy for ancient human mobility in addition to diet. Further analyses, focused on assessing these possibilities, may provide archaeologists with complementary techniques for accessing information about past human life ways without destroying human remains.

The relatively large number of studies including stable isotope information from dog and human bone collagen now available has allowed for the assessment of the degree to which human and dog diets show isotopic convergences in a variety of archaeological contexts. In general, mean values for dog diets fall within 2‰ and 3‰ of associated humans for both stable carbon and nitrogen stable isotope ratios suggesting that dogs in most contexts can be used to provide rough proxies for humans. At the same time, variability in this dataset warns that caution must be taken when transposing dog stable isotope data to associated humans. CSA applications can be separated into two types based on the kind of analogical inference employed – either direct or indirect analogies. Particularly in cases where a direct analogy is used, it is important to substantiate the analogical argument by discussing the ways in which dog diets are thought to be

like or unlike those of their human keepers. The cross-contextual comparison of human and dog dietary similarities also met with difficulty when attempting to identify trends in human-dog dietary convergences between related archaeological contexts, likely owing to variability in the dimensions of comparison and the depth and quality of available contextual information provided by each study on the nature of human-dog relations. This analysis urges researchers to analyze larger groups of dogs and to make practical efforts to improve contextual information provided on human and dog relations during future dog and human paleodietary reconstructions.

Stable carbon and nitrogen isotope data from dog and human bone collagen at maritime-oriented Late Archaic sites along the northeastern coast of North America provided an ideal context in which to test a direct analogy CSA application in a relatively controlled manner. A consideration of available information on environmental, cultural and biobehavioral factors that could influence human-dog dietary convergences provided a platform for more confident interpretation of human and dog stable isotope signatures. Stable isotope data obtained from dogs at the MAI and Moorehead occupations of the Port au Choix and Nevin sites, respectively, were compared to previously analyzed humans from each site. These comparisons show a strong similarity. Based on that similarity, the stable carbon and nitrogen isotope values of dog bone collagen at the Moorehead occupation of the Turner Farm site were transposed to their archeologically unavailable human keepers to allow for reconstruction of human diet at that site during the Late Archaic. This case study ties the theoretical considerations of earlier chapters together to provide an example of how CSA applications can make stronger efforts towards substantiating and clarifying their conclusions. Further well-contextualized case studies may also be beneficial to our understanding of how dogs can act as dietary analogs for humans in two important ways. Firstly, similar studies in other environments, time periods and cultural contexts

may help explain variation in human-dog dietary relationships and identify the contexts in which the CSA is most likely to be applicable. Second, case studies comparing humans' and dogs' dietary signatures at the finer grained scale of individual amino acids that compose bone collagen may provide a more detailed understanding of the ways in which dogs and humans share similar diets.

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Tables

Table 3.1 Stable isotope ratio and elemental concentration standards used in analyses.

Standard ID	$\delta^{15}N_{air}$	%N	$\delta^{13}C_{VPDB}$	%C
IAEA-N-1 ($(NH_4)_2SO_4$)	+0.43 ± 0.07 [1]	21.2		
IAEA-N-2 ($(NH_4)_2SO_4$)	+20.32 ± 0.09 [1]	21.2		
USGS-25 ($(NH_4)_2SO_4$)	-30.25 ± 0.38 [1]	21.2		
USGS-26 ($(NH_4)_2SO_4$)	+53.62 ± 0.25 [1]	21.2		
USGS-24 (graphite)			-16.05 ± 0.11 [2]	100.00
IAEA-CH-6 (sucrose)			-10.45 ± 0.13 [2]	42.11
MUN-CO-1 ($CaCO_3$)			-21.01 ± 0.10	12.00
MUN-CO-2 ($CaCO_3$)			-40.11 ± 0.15	12.00
Sulfanilamide		16.27		41.85
MUN Sulfanilamide		16.27		41.85
BBOT		6.51		72.53
Bovine Liver SRM1577b	+7.65 ± 0.25	10.19 ± 0.16	-21.59 ± 0.25	49.13 ± 1.02
B2155 (protein)	+5.97 ± 0.08 [4]	13.32 ± 0.40 [3]	-27.03 ± 0.13 [4]	46.5 ± 0.78 [3]

[1]Coplen et al. 2002, [2]Coplen et al. 2006, [3]Elemental microanalysis certificate of analysis, [4]updated using latest revised values. Table provided by Dr. Alison Pye.

Table 4.1 List of studies including human and dog $\delta^{13}C$ and/or $\delta^{15}N$ values indicating general similarities (within 2-3‰ of associated human data clusters in both $\delta^{15}N$ and $\delta^{13}C$) across various cultural and temporal contexts. Studies from all regions indicating more disparate stable isotope values between humans and dogs are also included.

Region	References
Africa	Mosothwane 2010:132
Americas	Allitt et al. 2008; Berón et al. 2009; Berry 1992; Black 2003; Burleigh and Brothwell 1978; Cannon et al. 1999; Chilton et al. 2001; Coltrain 2009; Corr et al. 2009; DeBoer and Tykot 2007; Gerry 1993:200, 216, 1997; Gerry and Krugger 1997:201, 202; Hogue 2003, 2006; Guiry 2009; Guiry and Grimes 2010; Katzenberg 1988, 1989, 2006:266; Katzenberg and Kelly 1991:212; Rick et al. 2011; Tankersley and Koster 2009; White 2004; White et al. 1993, 2001, 2004:156, 2006:145
Asia	Atahan et al. 2011; Barton et al. 2009; Bocherens et al. 2000, 2006; Choy and Richards 2009, 2010; Choy et al. 2010; Chu 1994:39; Hollund et al. 2010; Katzenberg et al. 2010:185; Kusaka et al. 2008; Losey et al. 2011; Pechenkina et al. 2005; Webber et al. 2009
Europe	Bocherens et al. 2007; Borić and Miracle 2004; Bösl et al. 2006; Le Bras-Goude and Claustre 2009; Chenery et al. 2011; Craig et al. 2009; Eriksson et al. 2008; Fischer et al. 2007a, b; Fornander et al. 2008; Fuller et al. 2010; Hakenbeck et al. 2010; Hedges et al. 2008; Herrsher and Bras-Goude, 2010 ; Honch et al., 2006; Jay and Richards, 2006, 2007:174; Jørkov et al. 2010; Keenlyside et al. 2009; Kosiba et al. 2007; Lightfoot et al. 2009; Lösch et al. 2006; Müldner and Richards 2005, 2007; Murray and Schoeninger 1988:164; Noe-Nygaard 1988, 1995:245; Petrousta and Manolis 2010; Prowse et al. 2004; Redfern et al. 2010; Richards et al. 2003; Schulting and Richards 2000:57, 2002, 2009; Stevens et al. 2010; Van Strydonck 2005
Oceania	Allen and Craig 2009; Craig 2007, 2009:225; Jones and Quinn 2009; Valentine et al. 2006
Studies with disparate values	Borić et al. 2004; Byers et al. 2011; Dürrwächter 2006; Jones and Quinn 2009; Thompson et al. 2005, 2008; Richards et al. 2009

Table 5.1 Background information on studies contributing human and dog bone collagen $\delta^{13}C$ and $\delta^{15}N$ data in Figure 5.1 and 5.2. Asterisks under "Difference in mean dog & human values" indicate that a statistically significant difference was observed during a One Way ANOVA and *Post Hoc* Bonferroni test (2σ) comparing all groups of humans and dogs. Dog and human $\delta^{15}N$ values from Cannon and colleagues (1999) could not be compared.

Source	Location	Notes	Dog (n)	Hum. (n)	Dog mean values (‰)	Humans mean values (‰)	Difference in mean dog & human values
Allen and Craig 2009	Aitutaki, S. Cook Is.	Some dog values derive from dentine.	11	8	$\delta^{13}C$ -14.05 ±2.08 $\delta^{15}N$ 12.35 ±1.35	$\delta^{13}C$ -14.83 ±1.15 $\delta^{15}N$ 11.46 ±0.41	$\delta^{13}C$ 0.78‰ $\delta^{15}N$ 0.89‰
Barton et al. 2009	N.W. China	Dogs included are associated with general phase from which human values are given.	6	6	$\delta^{13}C$ -9.90 ±1.91 $\delta^{15}N$ 8.40 ±0.57	$\delta^{13}C$ -9.78 ±2.96 $\delta^{15}N$ 9.72 ±0.79	$\delta^{13}C$ -0.12‰ $\delta^{15}N$ -1.32‰
Borić et al. 2004	Serbia		10	31	$\delta^{13}C$ -19.82 ±1.26 $\delta^{15}N$ 10.56 ±0.68	$\delta^{13}C$ -19.38 ±0.48 $\delta^{15}N$ 14.31 ±0.78	$\delta^{13}C$ -0.4.3‰ *$\delta^{15}N$ -3.76‰
Cannon et al. 1999	W. Canada	Human $\delta^{13}C$ values from Chisholm et al. (1983) and $\delta^{15}N$ values from unpublished data (Schwarcz et al. n.d., as per Cannon et al. (1999: 404). No standard deviation given.	15	13	$\delta^{13}C$ -13.02 ±0.56 $\delta^{15}N$ 16.56 ±0.67	$\delta^{13}C$ -13.15 ±0.47 $\delta^{15}N$ 19.00	$\delta^{13}C$ 0.12‰ $\delta^{15}N$ -2.44‰
Craig et al. 2009	S. Italy		6	116	$\delta^{13}C$ -18.52 ±0.37 $\delta^{15}N$ 8.53 ±0.50	$\delta^{13}C$ -19.44 ±0.25 $\delta^{15}N$ 8.65 ±1.33	$\delta^{13}C$ 0.92‰ $\delta^{15}N$ -0.12‰
Eriksson 2004	Gotland, Sweden		13	20	$\delta^{13}C$ -14.49 ±0.93 $\delta^{15}N$ 13.54 ±0.60	$\delta^{13}C$ -15.12 ±0.51 $\delta^{15}N$ 15.60 ±0.55	$\delta^{13}C$ 0.63‰ *$\delta^{15}N$ -2.06‰
Eriksson et al. 2008	Öland, Sweden	Individuals from Köpingsvik shown.	9	15	$\delta^{13}C$ -14.62 ±0.28 $\delta^{15}N$ 14.54 ±0.32	$\delta^{13}C$ -14.55 ±0.46 $\delta^{15}N$ 16.72 ±0.71	$\delta^{13}C$ -0.07‰ *$\delta^{15}N$ -2.18‰
Fuller et al. 2010	Ibiza, Spain		23	21	$\delta^{13}C$ -18.78 ±0.31 $\delta^{15}N$ 10.33 ±0.63	$\delta^{13}C$ -18.09 ±1.31 $\delta^{15}N$ 10.88 ±1.02	$\delta^{13}C$ -0.70‰ $\delta^{15}N$ -0.55‰

Table 5.1 Continued.

Source	Location	Notes	Dog (n)	Hum. (n)	Dog mean values (‰)	Humans mean values (‰)	Difference in mean dog & human values
Gerry 1993	W. Honduras	Only individuals from Copán shown here. Human data may include very young individuals.	9	15	$\delta^{13}C$ -8.90 ±0.83 $\delta^{15}N$ 5.62 ±0.91	$\delta^{13}C$ -10.00 ±1.09 $\delta^{15}N$ 7.62 ±0.73	$\delta^{13}C$ 1.10‰ *$\delta^{15}N$ -2.00‰
Herrscher and Le-Bras Goude 2010	S. France	Individuals from Cugnaux shown.	5	8	$\delta^{13}C$ -20.26 ±0.27 $\delta^{15}N$ 9.40 ±0.51	$\delta^{13}C$ -20.46 ±0.41 $\delta^{15}N$ 9.98 ±1.19	$\delta^{13}C$ 0.20‰ $\delta^{15}N$ -0.58‰
Jay and Richards 2006	E. UK		6	56	$\delta^{13}C$ -20.77 ±0.60 $\delta^{15}N$ 7.68 ±1.23	$\delta^{13}C$ -20.56 ±0.31 $\delta^{15}N$ 9.72 ±0.60	$\delta^{13}C$ -0.20‰ *$\delta^{15}N$ -2.03‰
Jay and Richards 2007	N.E. UK	Individuals from Broxmouth shown.	5	9	$\delta^{13}C$ -20.72 ±0.30 $\delta^{15}N$ 9.66 ±0.32	$\delta^{13}C$ -20.74 ±0.15 $\delta^{15}N$ 10.67±0.47	$\delta^{13}C$ 0.02‰ $\delta^{15}N$ -1.01‰
Lightfoot et al. 2009	S. UK	Individuals from the Roman Period shown.	5	5	$\delta^{13}C$ -20.24 ±0.21 $\delta^{15}N$11.02 ±1.07	$\delta^{13}C$ -19.64 ±0.34 $\delta^{15}N$ 10.98 ±2.01	$\delta^{13}C$ -0.60‰ $\delta^{15}N$ 0.04‰
Müldner and Richards 2007	UK	Individuals from the Wharram Percy Site shown. Human data from Richards et al. (2002).	6	28	$\delta^{13}C$ -20.55 ±0.50 $\delta^{15}N$ 8.37 ±1.00	$\delta^{13}C$ -19.7 ±0.30 $\delta^{15}N$ 9.40 ±0.80	$\delta^{13}C$ -0.85‰ $\delta^{15}N$ -1.03‰
Rick et al. 2011	W. US		5	14	$\delta^{13}C$ -11.52 ±0.87 $\delta^{15}N$ 17.86 ±0.68	$\delta^{13}C$ -13.51 ±0.82 $\delta^{15}N$ 17.13 ±1.50	*$\delta^{13}C$ 1.99‰ $\delta^{15}N$ 0.73‰

Table 6.1 Maritime Archaic Indian human data from the Port au Choix site reproduced from Jelsma (2000:288, Table 7.31)

Burial Cluster	NP No.	Sex	Age	$\delta^{13}C$	$\delta^{15}N$	C/N	Laboratory	Sample no.
A	1A	M?	Old adult	-14.00	19.95	--	Oxford	PAC 1A
A	1B	M	22-30	-14.56	19.54	--	Groningen	18532
A	A3	?	12 to 21	-14.70	19.20	2.9	Oxford	PAC 3
A	A4	F?	Adult	-13.57	20.34	--	Oxford	PAC 4
A	A8	M	45-70	-13.48	20.34	--	Oxford	PAC 8
A	A9	?	22-30	-14.17	19.34	--	Oxford	PAC 9
A	A10	F	45-70	-14.31	19.40	--	Groningen	18533
A	A12	M	>65	-14.52	18.28	--	Groningen	18534
B	B16A	F	22-30	-13.20	20.99	--	Oxford	PAC 16A
B	B18A	M	45-70	-14.08	20.09	--	Groningen	18535
B	B18B	F	22-30	-13.00	20.99	--	Oxford	18B
B	B25	M	22-30	-13.49	20.48	--	Groningen	18536
B	B27A	M	45-70	-13.52	20.18	--	Oxford	PAC 27A
B	B29	M	22-30	-13.70	20.70	2.9	Oxford	PAC 29
B	B30C	M	45-70	-13.88	20.04	--	Groningen	18537
B	B31	M	25-50	-15.30	17.30	3.0	Oxford	PAC 31
C	C32	M	22-30	-13.30	21.10	2.9	Oxford	PAC 32
C	C34	M	25-50	-13.75	20.01	--	Oxford	PAC 34
C	C35A	M	45-70	-16.07	16.44	--	Groningen	18538
C	C36A	F?	6 to 12	-13.80	20.76	--	Groningen	18539
C	C37A	M	25-50	-13.21	20.70	--	Oxford	PAC 37A
C	C37B	F	25-50	-14.10	20.10	2.9	Oxford	PAC 37B
C	C40A	M	25-50	-15.25	17.32	--	Groningen	18540
C	C44A	M	22-30	-13.60	19.20	2.8	Oxford	PAC 44A
C	C46A	M?	Adult	-13.55	19.79	--	Oxford	PAC46A
C	C47A	M	45-70	-13.60	20.70	2.8	Oxford	PAC 47 A
C	C49A	F	22-30	-12.68	21.00	--	Oxford	PAC 49A
C	C50A	M	22-30	-13.70	19.40	2.8	Oxford	PAC 50A
C	C50B	M	25-50	-14.10	18.50	2.8	Oxford	PAC 50B
C	C52A	F	22-30	-13.00	20.50	2.8	Oxford	PAC 52

Table 6.2 Moorhead human data from the Nevin site published graphically in Bourque and Krugger (1994:202, 203, Figures 13-4 and 13-5). Numerical data is unpublished and has been reproduced here Dr. Bruce Bourque's permission.

Feature No.	Cat No.	Sex	Age	$\delta^{13}C$	$\delta^{15}N$	Lab. No.
4A	NEV 6876	Male	Old Adult	-13.1	18.4	CCNR-59013
Unknown	NEV 6886	Unknown	Unknown	-12.9	17.6	CCNR-59016
1	NEV 6878	Male	Adult	-15.3	16.2	CCNR-59014
9-3	NEV 6875	Female	Adult	-15	14.5	CCNR-59012
8	NEV 6873	Unknown	Adult	-14	18.7	CCNR-59011
3	NEV 6872	Female	Juvenal	-13.4	18.2	CCNR-59010
4B	NEV 6870B	Female	Adult	-13.2	18.1	CCNR-59008
10	NEV 6869	Male	Adult	-12.2	18.5	CCNR-59007
5-5	NEV 6871	Male	Adult	-13	19.1	CCNR-59009
5-3/4	NEV 6879	Female	Juvenal	-12.9	18.9	CCNR-59015

Table 6.3 Mean stable isotope values from unpublished faunal data from the Turner Farm site provided by Dr. Bruce Bourque. Fauna derive from Moorehead and later occupations.

Common Name	Taxon	n	Mean $\delta^{13}C$	Mean $\delta^{15}N$
Cod	*Gadus* sp.	9	-13.21 ± 1.72	15.04 ± 1.09
Swordfish	*Xiphias gladius*	12	-11.93 ± 0.59	9.16 ± 0.74
Flounder	Paralichthyidae	4	-10.33 ± 0.90	13.66 ± 0.89
Sculpin	*Myoxocephalus* sp.	3	-9.86 ± 1.40	14.09 ± 0.55
Sea mink	*Neovision macrodon*	7	-9.66 ± 1.09	15.38 ± 0.57
Common mink	*Neovision vision*	5	-11.65 ± 0.51	15.30 ± 0.27
Black bear	*Ursums americanus*	9	-23.08 ± 1.23	5.25 ± 1.63
White-tailed deer	*Odocoileus virginianus*	6	-22.37 ± 1.14	6.03 ± 2.01

Table 6.4 Stable isotope data from domesticated dog and *Canis* specimens from the Moorhead occupation at the Turner Farm site. Asterisks beside MARC numbers indicate that values provided are averaged from duplicate analyses.

MARC ID	Cat. No.	Taxon	Name	Element	Age	Context	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	Collagen Yield
1018*	D1199	*Canis famiaris*	Dog	Ulna?	Unknown	Burial, Feature 43	-12.63	16.81	40.04	14.22	3.29	10.36%
1019	N/A	*Canis famiaris*	Dog	Femur	Infant	Burial, Feature 28	-13.23	18.98	46.06	16.26	3.31	14.48%
1020*	D1179	*Canis famiaris*	Dog	Long Bone	Juvenile?	Burial, No feature no.?	-12.67	17.86	34.72	12.35	3.29	10.38%
1021	B724	*Canis* sp.	Dog	Mandible	Juvenile?	Midden	-18.36	8.68	34.85	12.33	3.3	4.36%
1022	B694	*Canis* sp.	Dog	Ulna	Unknown	Midden	--	--	--	--	--	1.65%
1023	B425	*Canis* sp.	Dog	Mandible?	Unknown	Midden	-21.2	6.91	37.31	13.34	3.27	6.19%
1024	B668	*Canis* sp.	Dog	Long bone	Unknown	Midden	-12.28	17.04	30.73	11.1	3.24	11.10%
1025	B465	*Canis* sp.	Dog	Cranial	Unknown	Midden	-21.4	3.28	39.26	13.98	3.28	5.42%
1026	55A	*Canis* sp.	Dog	Unknown	Unknown	Midden	-12.62	17.16	29.69	10.46	3.32	9.88%
1027	C217	*Canis* sp.	Dog	Mandible	Unknown	Midden	-12.34	16.06	41.03	14.78	3.24	9.85%
1028	C218	*Canis* sp.	Dog	Mandible	Juvenile?	Midden	-13.08	14.74	40.35	14.4	3.28	5.29%
1029	C-81	*Canis* sp.	Dog	Femur	Unknown	Midden	-21.43	3.39	42.22	14.87	3.32	2.69%

Table 6.5 Stable isotope data from domesticated dog, *Canis* and other faunal specimens from the Moorhead occupation at the Nevin site. Asterisks beside MARC numbers indicate that values provided are averaged from duplicate analyses.

MARC ID	Cat. No.	Taxon	Common Name	Element	Age	Context	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	Yield
1039	600, 3/587	*C. famiaris*	Dog	Mandible	Juvenile?	Burial #1	-12.73	16.40	42.63	14.83	3.36	5.48%
1040	601, 356-12	*C. famiaris*	Dog	Mandible	Juvenile?	Burial #2	-12.02	15.49	43.32	15.17	3.34	8.61%
1041*	604,	*C. famiaris*	Dog	Mandible	Adult	Burial #4	-12.29	16.04	36.23	12.89	3.29	11.14%
1042	602, 153-15	*C. famiaris*	Dog	Mandible	Adult	Burial #3	-11.17	15.93	35.97	12.28	3.42	4.36%
1043	20-13	*Canis* sp.	Canid	Calcaneus	Adult	Midden	-12.84	15.90	35.74	12.69	3.29	11.08%
1044	228-2	*Canis* sp.	Canid	Calcaneus	Adult	Midden	-11.95	16.83	32.02	11.30	3.31	9.17%
1045	228-5	*Canis* sp.	Canid	Calcaneus	Adult	Midden	-12.50	16.59	36.90	12.90	3.34	8.44%
1046	355-24	*Canis* sp.	Canid	Calcaneus	Adult	Midden	-13.55	13.75	37.51	13.32	3.29	11.39%
1047	383-5	*Canis* sp.	Canid	Calcaneus	Adult	Midden	-14.19	14.31	41.01	14.43	3.32	9.96%
1048	20-12	*Lontra canadensis*	River otter	Femur	Adult	Midden	-13.10	15.14	43.78	15.82	3.24	17.76%
1049	335-1	*P. vitulina*	Harb. seal	Humerus	Adult	Midden	-13.76	15.51	40.39	13.65	3.46	3.70%
1050	335-9	*.P vitulina*	Harb. seal	Humerus	Adult	Midden	--	--	--	--	--	1.71%
1051	335-4	*Lynx canidensis*	Lynx	Tibia	Adult	Midden	-9.66	19.13	41.34	14.14	3.42	3.39%
1052	355-2	*Alces alces*	Moose	Metatarsal	Adult	Midden	-22.30	0.99	43.80	15.55	3.29	6.61%
1053	355-6	*Ursus americanus*	Black bear	Mandible	Adult	Midden	-19.34	4.25	39.10	13.99	3.27	10.85%
1054	355-11	*Odocoileus virginianus*	White-tailed deer	Astragalus	Adult	Midden	-23.12	9.40	34.40	11.73	3.43	0.27%
1055	20-14	*Castor canidensis*	Beaver	Humerus	Juvenile	Midden	-22.18	4.51	44.12	15.03	3.43	4.49%
1056	228-20	*Procyon lotor*	Racoon	Metacarpal (1st)	Adult	Midden	-10.81	17.86	44.49	15.00	3.47	7.18%

Table 6.6 Stable isotope data from domesticated dogs from the MAI cemetery and faunal specimens from a later cemetery at the Port au Choix site. Asterisks beside MARC numbers indicate that values provided are averaged from duplicate analyses.

MARC ID	Cat. No.	Taxon	Common Name	Element	Age	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C:N	Yield
238	N/A	Aves	Bird sp.	Maxilla	Unknown	-15.71	18.85	44.58	15.19	3.43	10.80%
239	N/A	Aves	Bird sp.	Premandible	Unknown	-15.49	18.82	45.67	15.25	3.50	16.97%
240	N/A	Aves	Bird sp.	Long Bone	Unknown	-15.04	17.68	42.88	14.51	3.45	4.77%
244	N/A	Aves	Bird sp.	Long Bone	Unknown	-13.24	14.92	45.81	16.21	3.30	14.81%
247	N/A	Aves	Bird sp.	Long Bone	Unknown	-16.54	15.75	45.19	15.68	3.37	19.12%
253	N/A	Aves	Bird sp.	Unknown	Unknown	-18.59	12.67	45.05	15.63	3.37	18.74%
241	N/A	Phocidae	Seal sp.	Unknown	Unknown	-15.47	17.26	41.33	13.90	3.48	3.78%
242	N/A	Phocidae	Seal sp.	Rib	Unknown	-14.63	17.39	38.70	13.08	3.46	2.49%
243	N/A	Phocidae	Seal sp.	Scapula	Unknown	-15.04	14.69	45.16	15.96	3.31	11.65%
249	N/A	Phocidae	Seal sp.	Scapula	Unknown	--	--	--	--	--	0.00%
254	N/A	Phocidae	Seal sp.	Unknown	Unknown	-14.96	15.08	34.23	12.02	3.33	2.27%
245	N/A	Mammalia	Mammal	Unknown	Unknown	-15.16	17.04	31.91	10.76	3.46	2.34%
248	N/A	*R. tarandus*	Caribou	Scapula	Unknown	-18.76	1.98	43.81	14.68	3.49	6.87%
284*	N/A	*O. zibethicus*	Muskrat	Mandible	Unknown	-22.64	3.57	45.61	15.81	3.37	13.89%
471	1787D N2514	*C. familiaris*	Dog 1	Rib	Unknown	-14.62	18.48	45.96	15.15	3.55	18.31%
472	1293 N2358	*C. familiaris*	Dog 2	Rib	Unknown	--	--	--	--	--	9.92%
473*	1293 N2358	*C. familiaris*	Dog 2	Tibia	Unknown	-13.68	17.53	44.14	15.64	3.55	12.17%
474	NP-50B	*C. familiaris*	Dog 3	Femur	Adult	-13.92	17.05	43.41	15.36	3.30	18.13%
475*	NP-50B	*C. familiaris*	Dog 3	Rib	Adult	-13.77	17.40	45.48	16.35	3.25	16.50%
476	NP-50A	*C. familiaris*	Dog 4	Femur	Adult	-13.50	15.75	45.43	16.52	3.21	12.22%
477	NP-50A	*C. familiaris*	Dog 4	Rib	Adult	-13.84	16.94	44.61	16.22	3.22	17.95%
237*	NP-50A	*C. familiaris*	Dog 4	Rib	Adult	-13.92	17.62	44.68	16.09	3.25	20.47%

Figures

Figure 4.1 Studies (see Table 4.1) including bone collagen $\delta^{13}C$ and/or $\delta^{15}N$ data from associated dogs and humans.

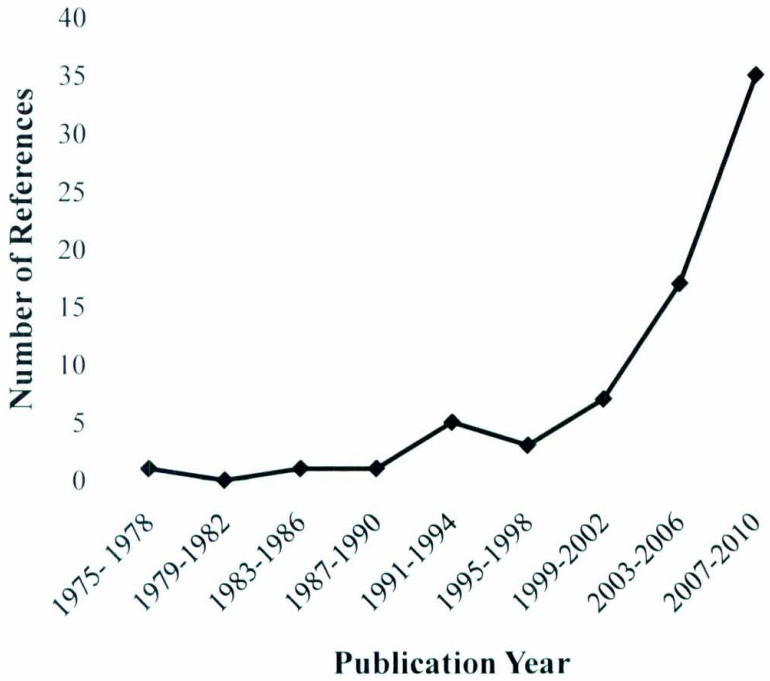


Figure 4.2 All studies (see table 4.1) with similar dog and human stable isotope values (i.e. $\delta^{13}C$ and/or $\delta^{15}N$ data within 2-3‰) shown by broad geographical region. Studies containing dissimilar dog and human isotope data are also show for comparison.

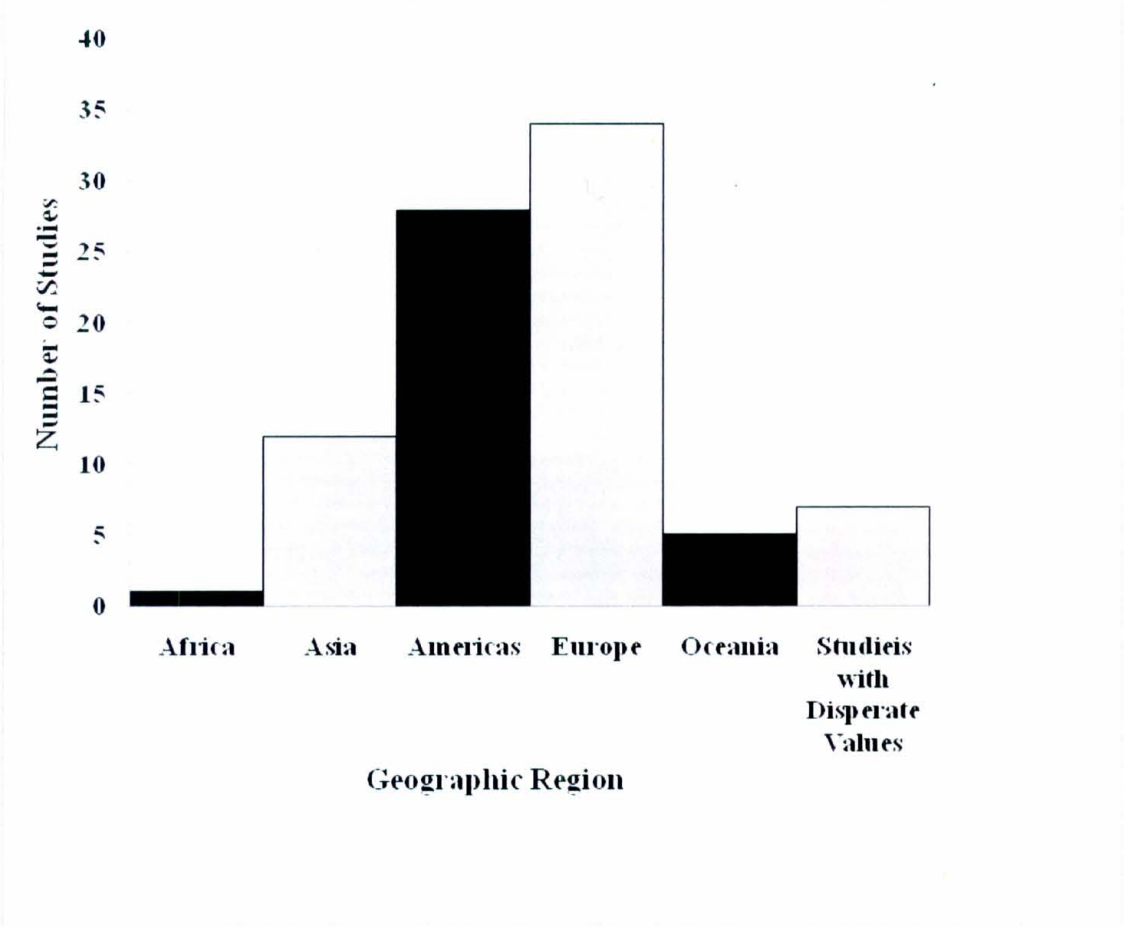


Figure 5.1 Human (diamonds) and dog (triangles) $\delta^{13}C$ and $\delta^{15}N$ data means. Error bars show one standard deviation. Table 5.1 provides background information on each study. Available collagen quality indicators including collagen yield and atomic C:N (Van Klinken 1999) were considered in data selection.

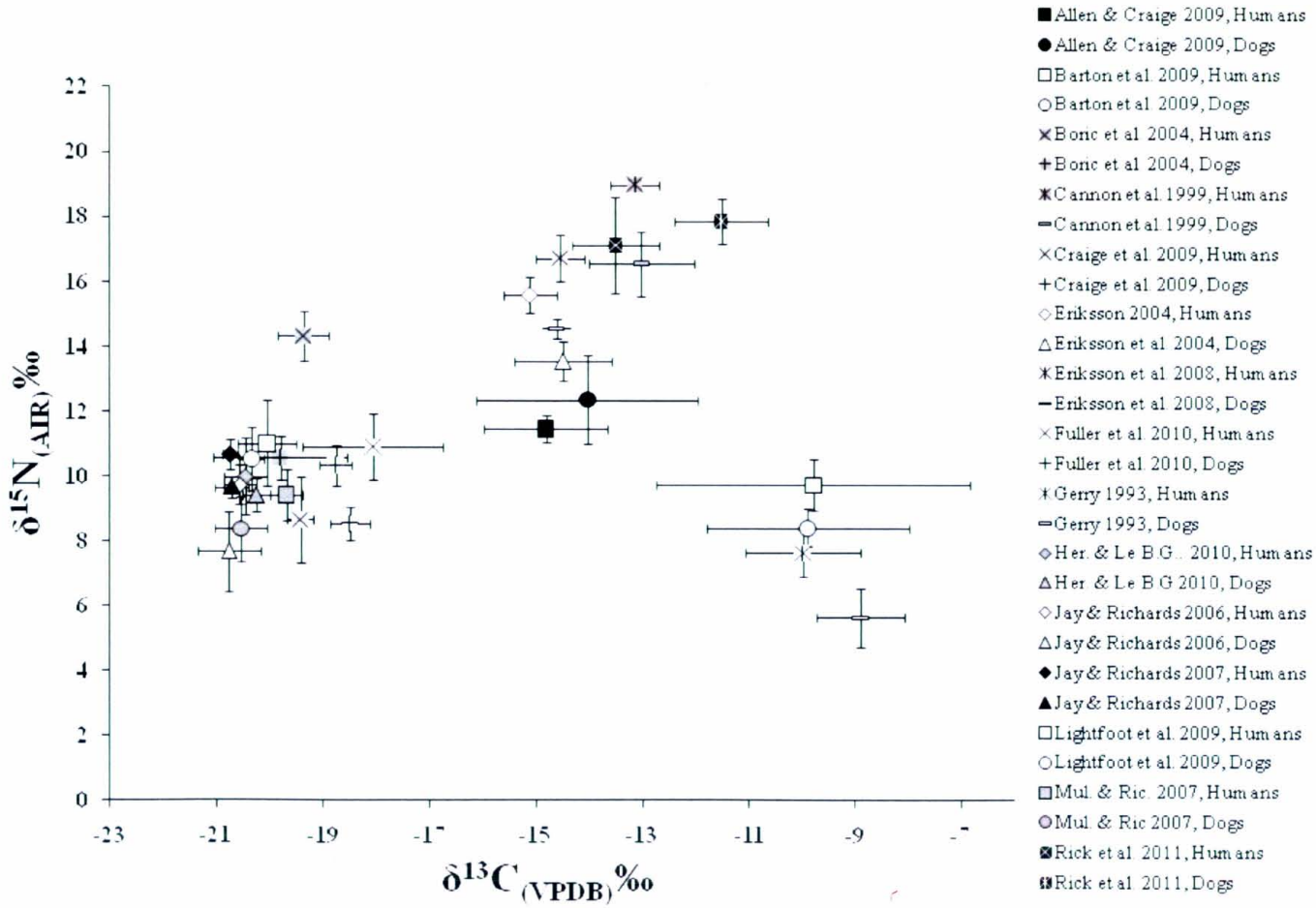


Figure 5.2. Human mean $\delta^{13}C$ and $\delta^{15}N$ values subtracted from those of associated dogs. Table 5.1 provides background information on each study. Error bars show one standard deviation.

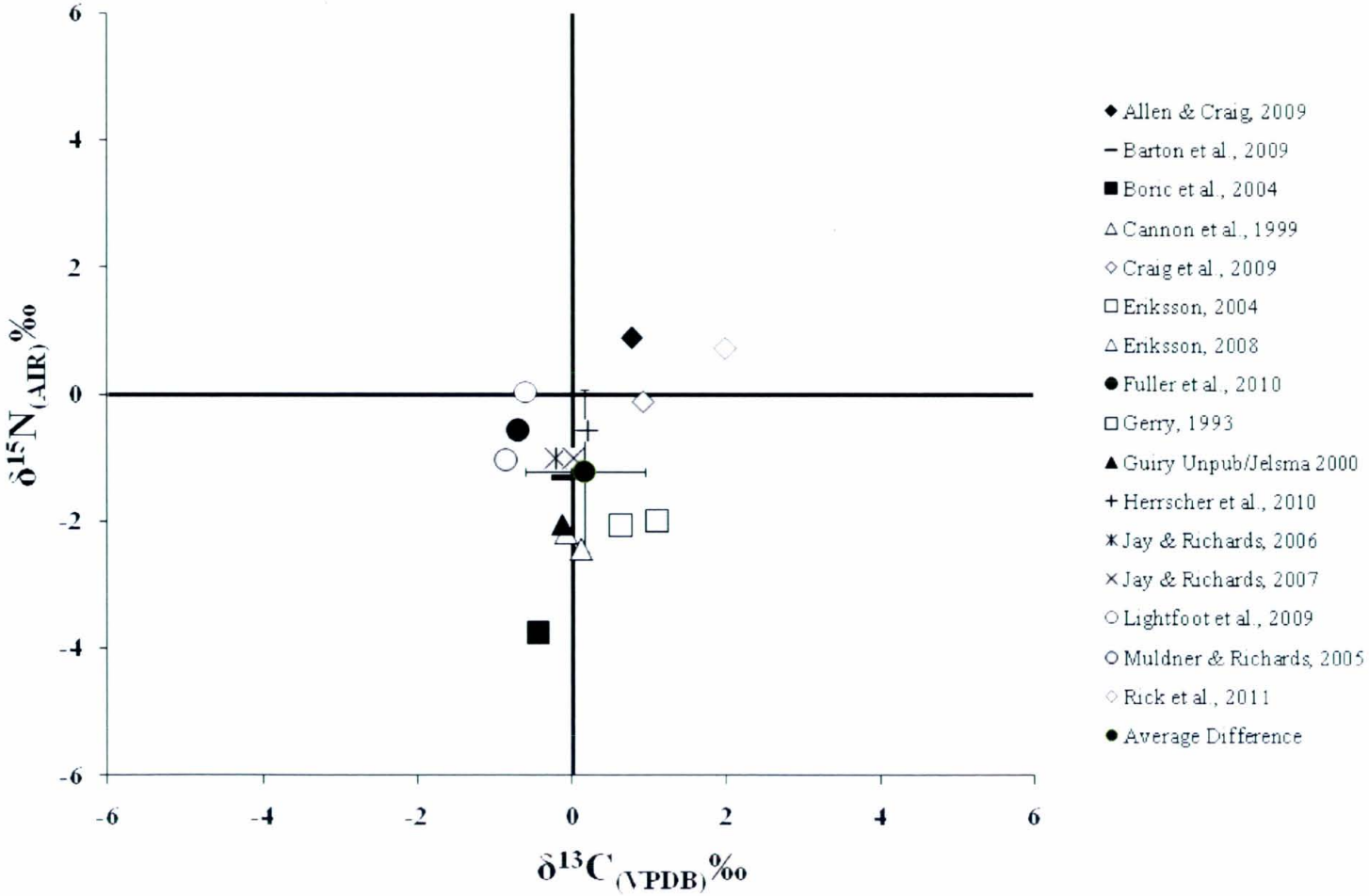


Figure 6.1 Stepwise map series locating the Port au Choix site in global context. Red squares link the map series (from top to bottom and left to right). Modified from Google.ca maps.

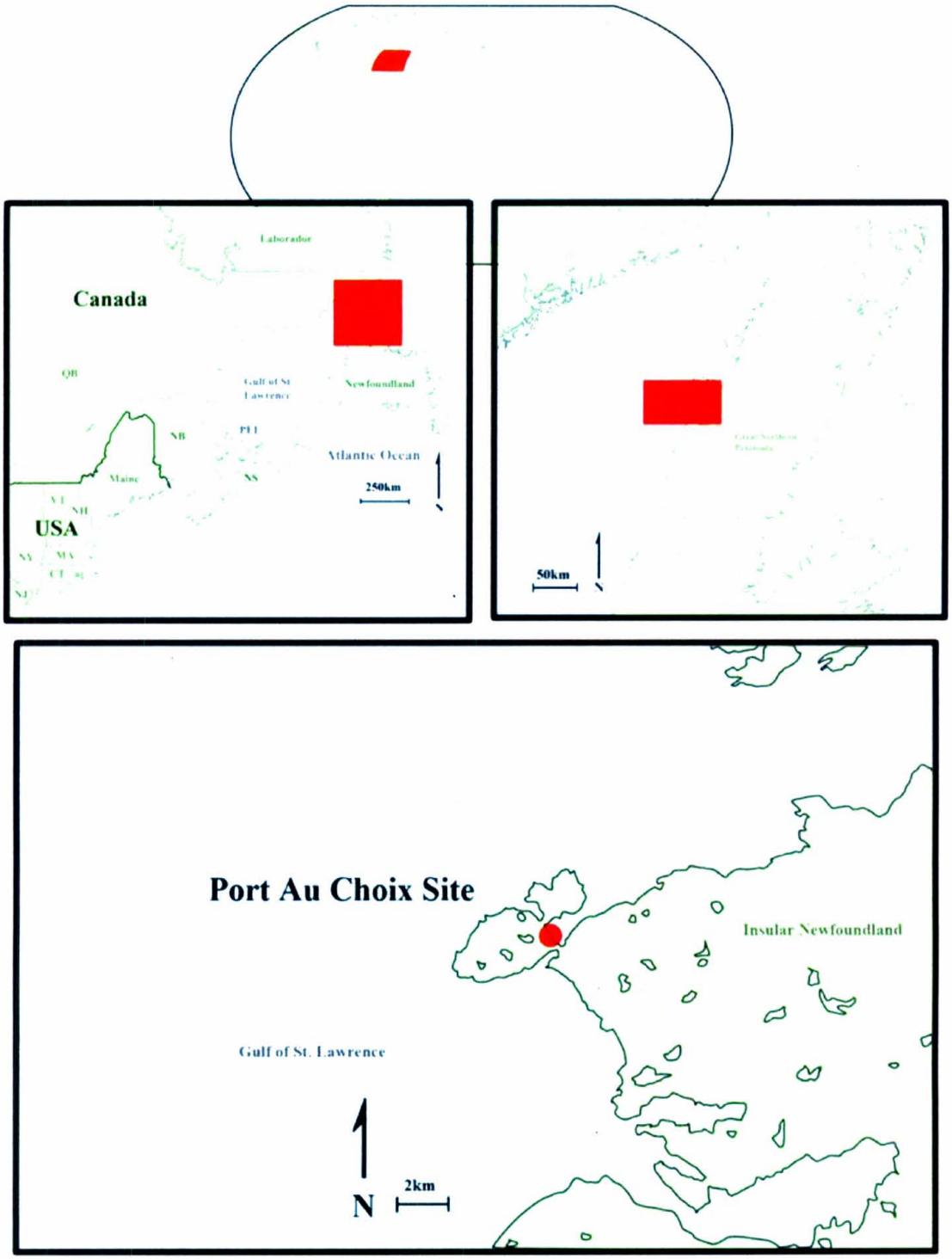


Figure 6.2 Stepwise map series locating the Nevin site in global context. Red squares link the map series (from top to bottom and left to right). Modified from Google.ca maps.

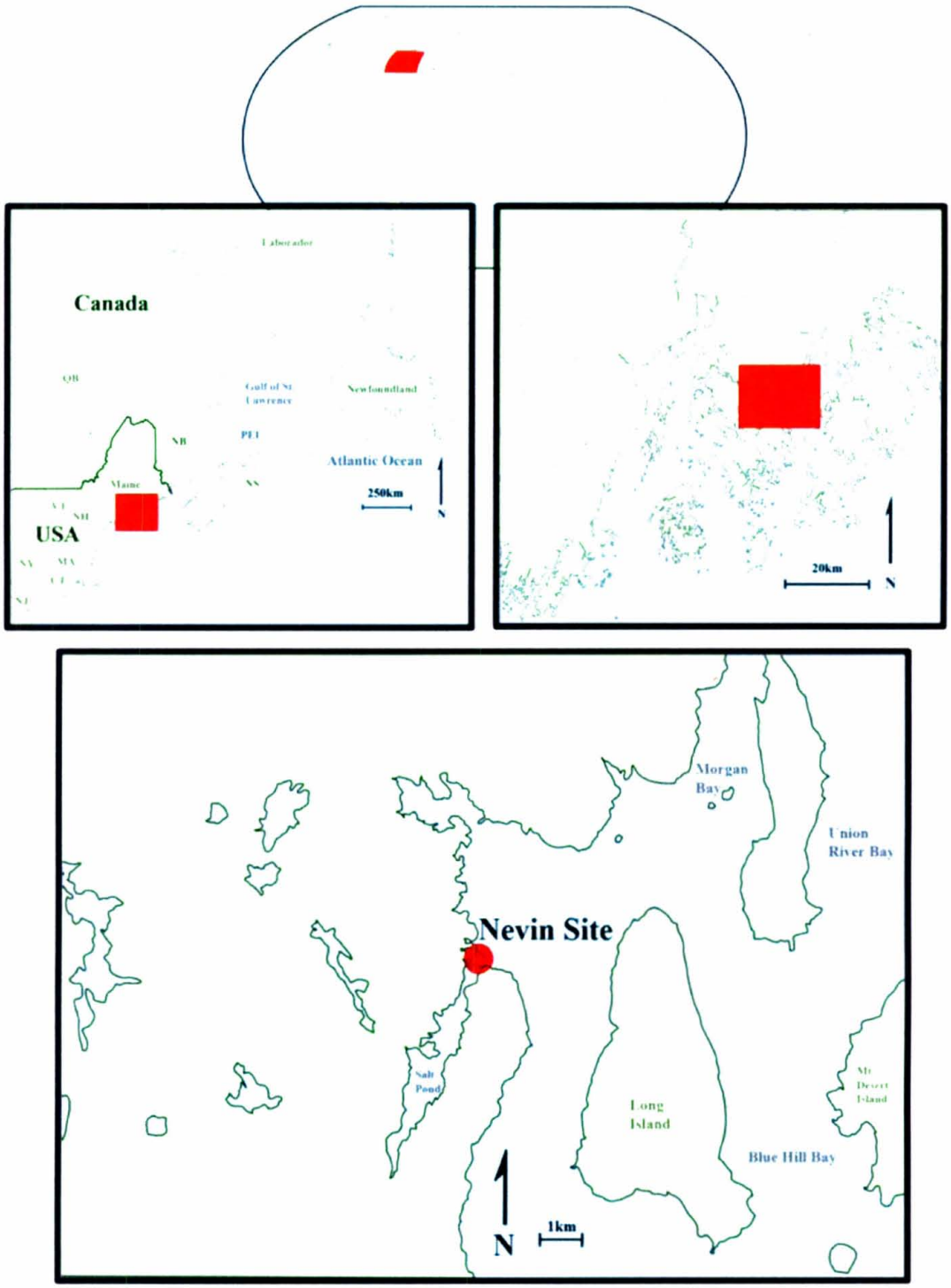


Figure 6.3 Stepwise map series locating the Turner Farm site in global context. Red squares link the map series (from top to bottom and left to right). Modified from Google.ca maps.

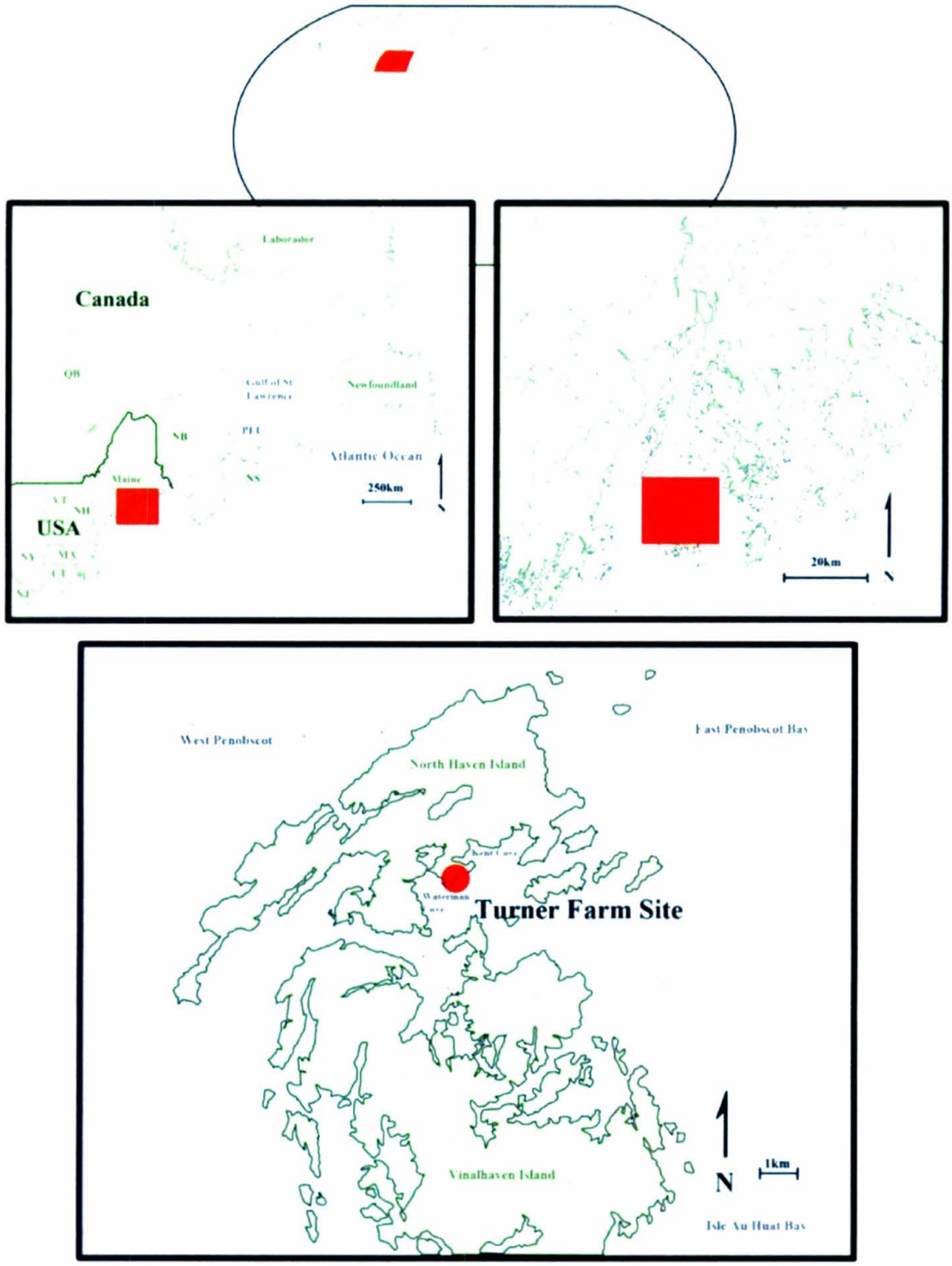


Figure 6.4 Stable isotope data plotted from the Turner Farm site. Faunal data from species other than Moorehead occupation dogs and *Canis* derive from unpublished work and have been provided by Dr. Bruce Bourque.

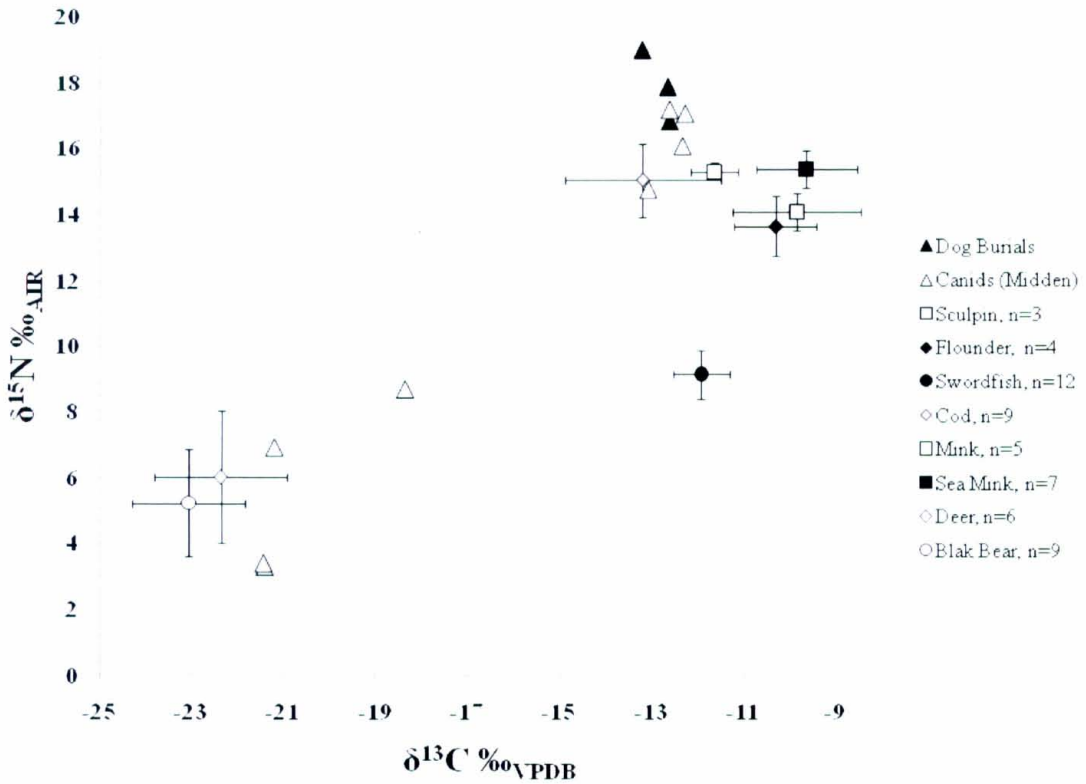


Figure 6.5 Mean stable isotope values plotted from the Turner Farm site. *Canis* specimens have been split into two significantly different groups. Faunal data from species other than Moorehead occupation dogs and *Canis* are unpublished and have been provided by Dr. Bruce Bourque.

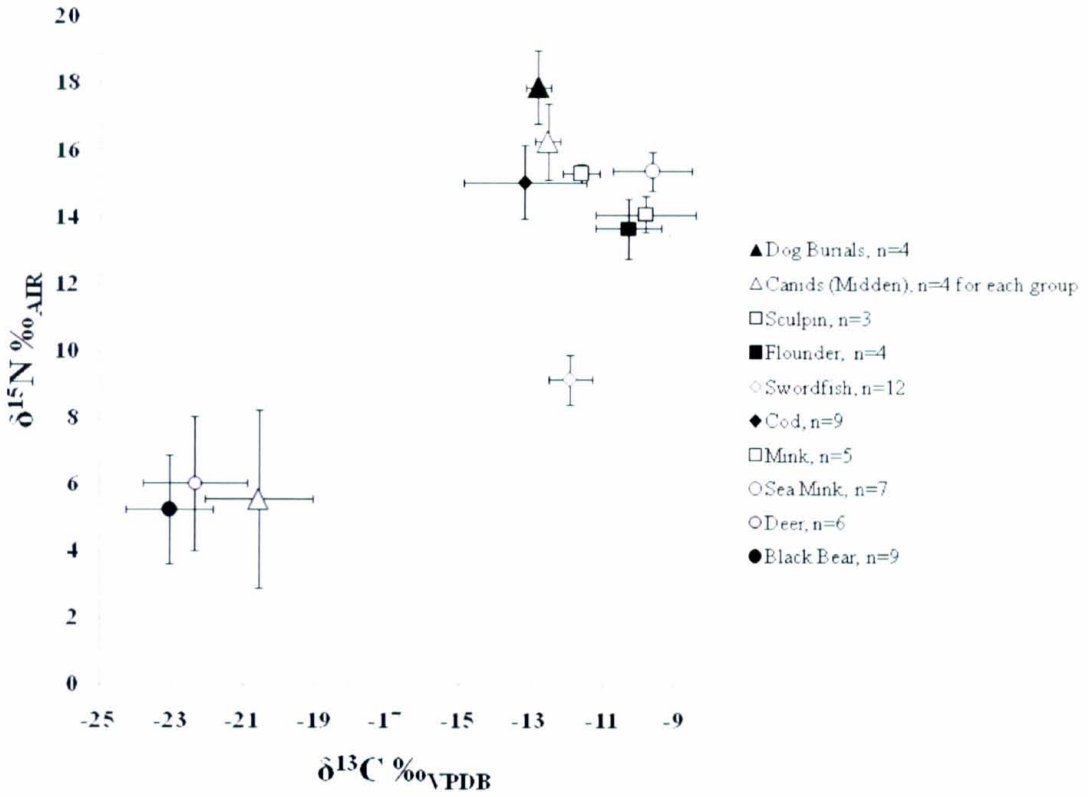


Figure 6.6 Stable isotope values plotted from the Nevin site. *Canis* specimens have been split into two significantly different groups. Human data as well as faunal data from species other than Moorehead occupation dogs and *Canis* are unpublished and have been provided by Dr. Bruce Bourque.

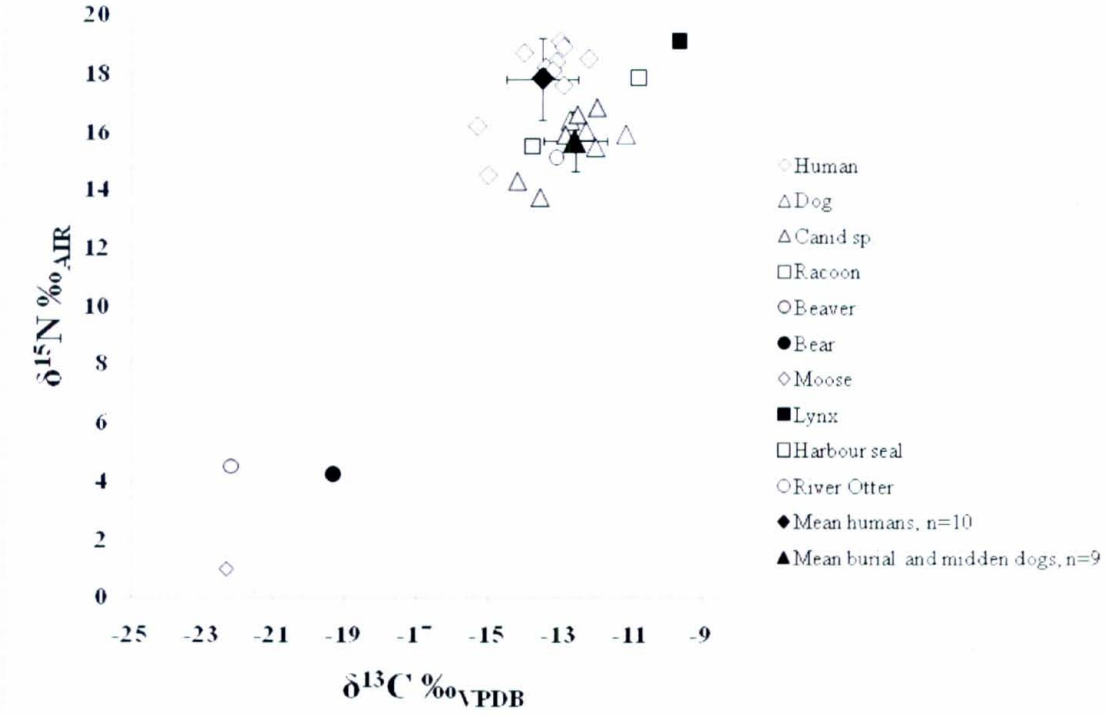


Figure 6.7 Stable isotope values plotted from the Port au Choix site. Humans (Jelsma 2000:288, Table 7.31) and dogs are from the Maritime Archaic Indian cemetery and other faunal specimens from a later cemetery (Locus 5).

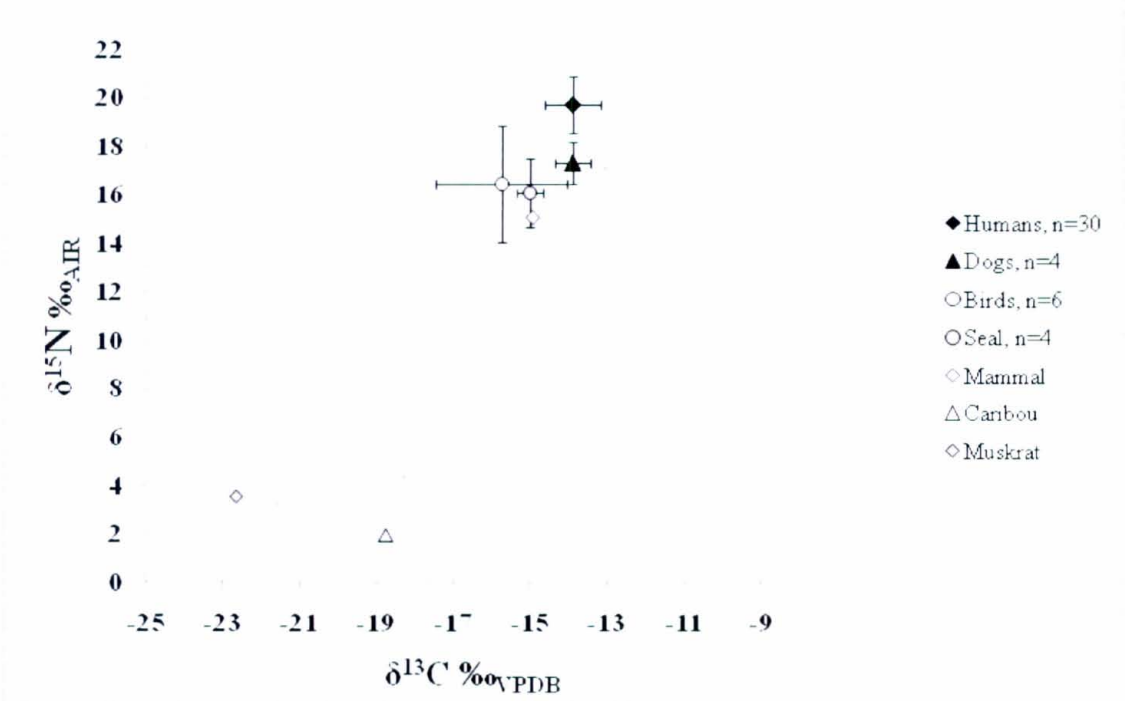


Figure 6.8 Mean stable isotope values for humans, dogs and *Canis* specimens from all sites. Port au Choix site human data is from Jelsma (2000:288, Table 7.31). Human data from the Nevin site is unpublished and was provided by Dr. Bruce Bourque.

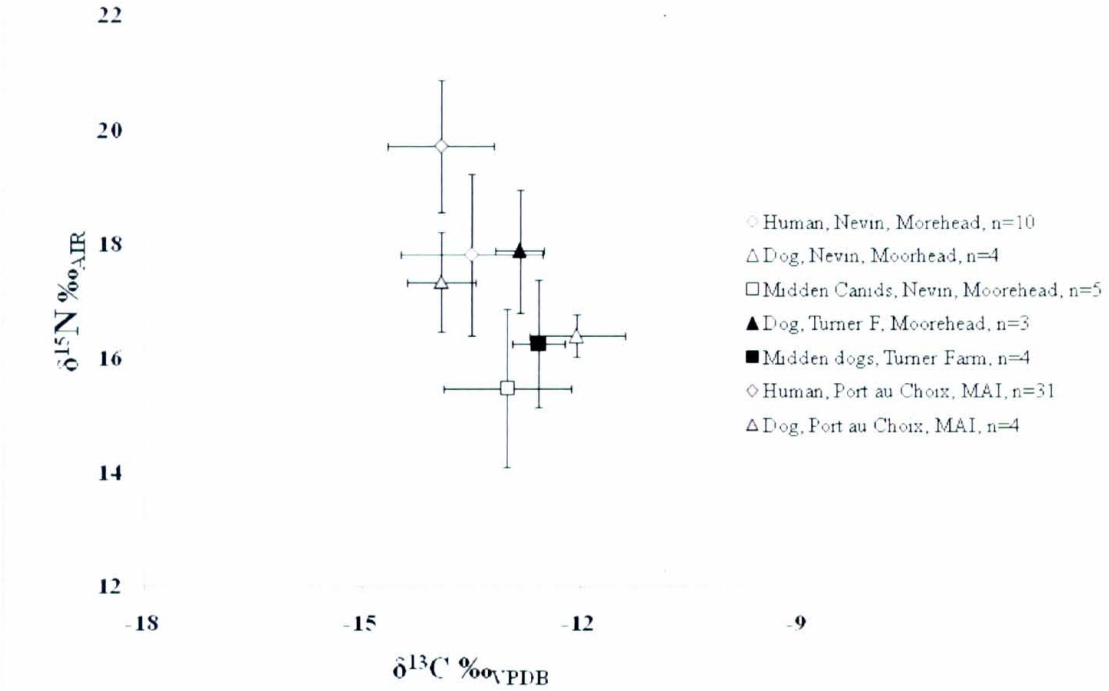


Figure 6.9 Human mean $\delta^{13}C$ and $\delta^{15}N$ values from all sites subtracted from those of associated dogs.

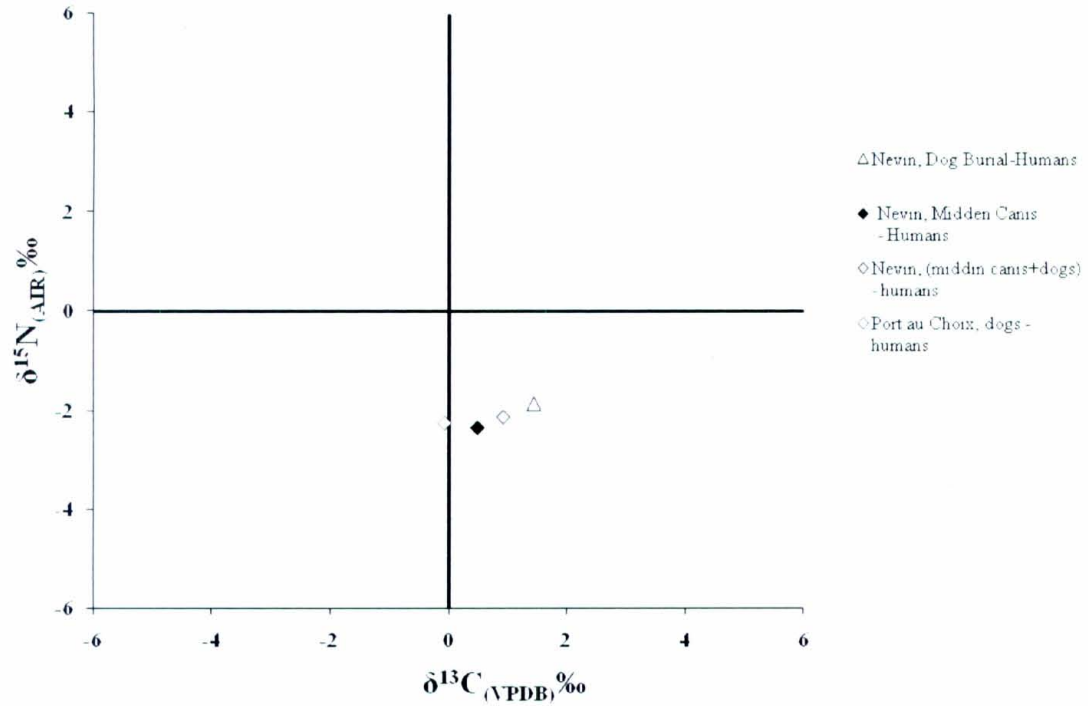
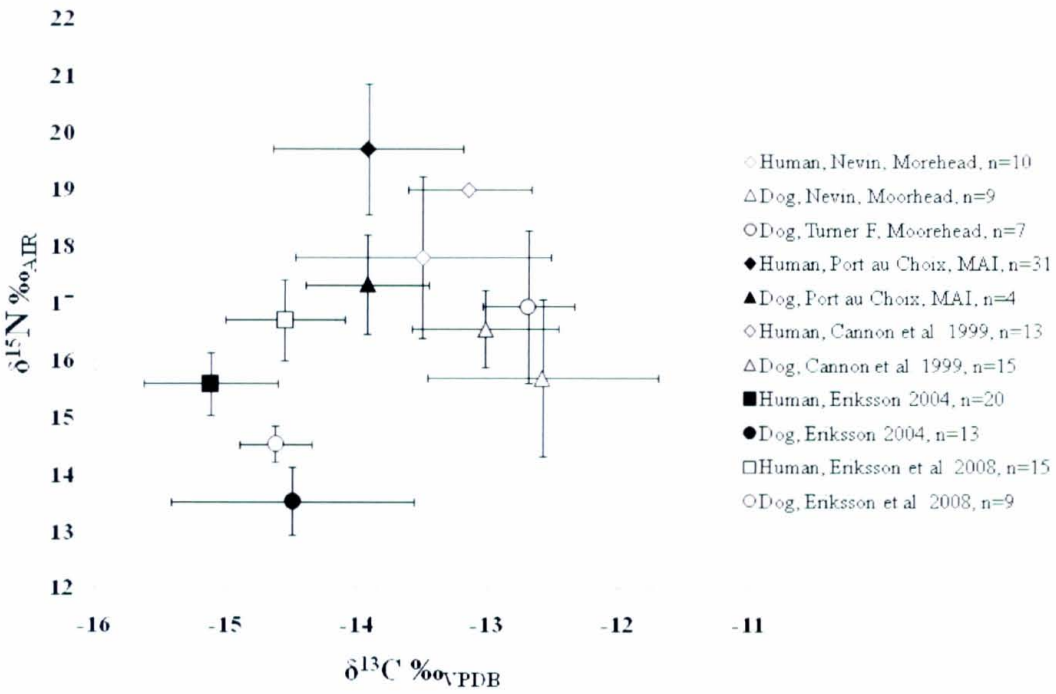


Figure 6.10 Mean human and dog $\delta^{13}C$ and $\delta^{15}N$ values from various maritime oriented hunter-gatherer sites. Port au Choix site human data is from Jelsma (2000:288, Table 7.31). Human data from the Nevin site is unpublished and was provided by Dr. Bruce Bourque. Data from Namu in British Columbia, Canada (Cannon et al. 1999), as well as Gotland and Öland, Sweden (Eriksson 2004; Eriksson et al. 2008) are included for comparison.



Plates

Plate 6.1 Lateral view of dogs showing cranial trauma from Burial 50 at the Port au Choix site. Reproduced from Tuck (1976:241, Plate 49a).

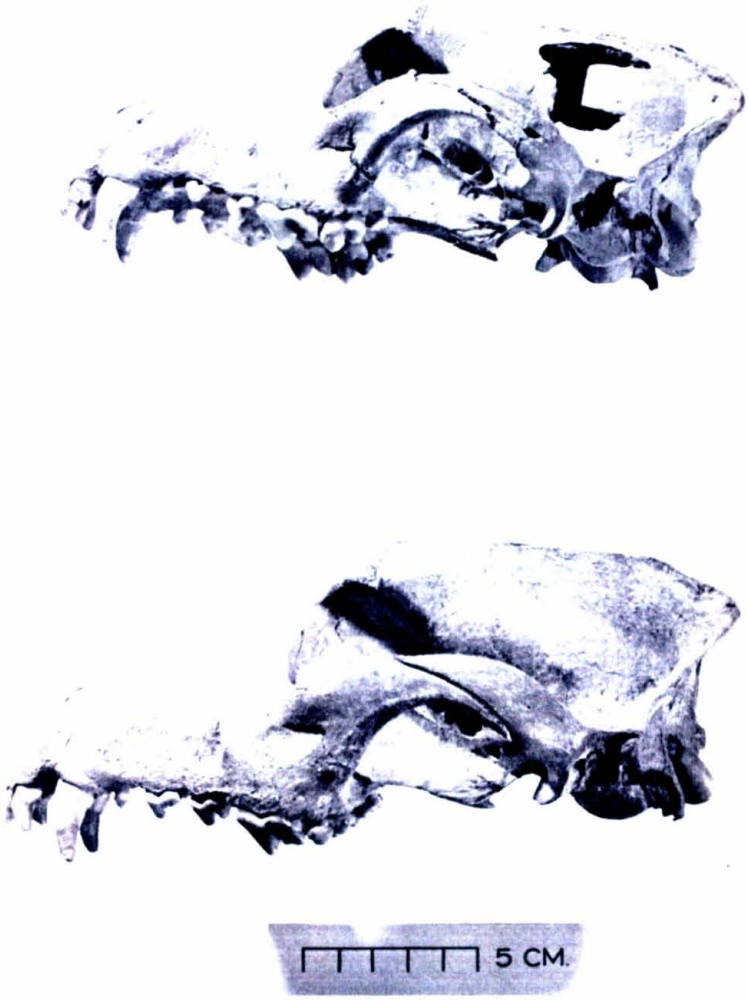


Plate 6.2 Port au Choix site excavation photograph depicting the bed of sand separating dogs from humans in Burial 50. Reproduced from Tuck (1976:202, Plate 10).