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Reconstructing subsistence practices of southwestern Ontario Late Woodland Peoples (A.D. 900-1600) using stable isotopic analyses of faunal material

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A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

RECONSTRUCTING SUBSISTENCE PRACTICES OF SOUTHWESTERN ONTARIO LATE WOODLAND PEOPLES (AD 900–1600) USING STABLE ISOTOPIC ANALYSES OF FAUNAL MATERIAL

(Integrated Article)

by

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Abstract

Stable carbon–, nitrogen–, and oxygen–isotope analyses of animal bones and teeth from 28 archaeological sites are used to reconstruct human subsistence behaviour, i.e., increased maize horticulturalism, during the Late Woodland period (A.D. 1000–1650) in southwestern Ontario. The isotopic data provided dietary, seasonal, and geographic information, which was analysed within archaeological, symbolic, and ecological contexts and used to reconstruct the diets, hunting patterns, and animal processing practices of two neighbouring groups, the Ontario Iroquoian and Western Basin peoples.

Paleodietary and seasonality analyses focused on the following species: canids (domestic dogs, foxes, and wolves), wild turkeys and white-tailed deer, though additional fauna (including black bears, raccoons, and squirrels) were also analysed. Bone (n=324) and dentine (n=11) collagen provided dietary information, specifically concerning access to maize and trophic position. The carbon– and nitrogen–isotope composition of modern plants (n= 8) and animals (n=87) was used to expand the local food web and understand abilities of modern animals to access crops. Structural carbonate isotopic analyses for archaeological (n=126) and modern (n=28) individuals provided additional information about trophic position, post–mortem alteration, and geographic affiliation. Serially sampled enamel was analysed for several deer and a dog, and was successfully paired with x–radiographs to create an enamel formation sequence, which enables reconstruction of short term (seasonal) diets.

The domestic dog isotopic data expanded our understanding of human dietary change over the Late Woodland period for both Ontario Iroquoian and Western Basin peoples, including different emphases on protein sources (i.e., fish). Wild fauna, particularly foxes, wild turkeys, raccoons and squirrels, were able to access maize. The turkey isotopic data suggest a unique hunting strategy at some Ontario Iroquoian sites, i.e., the purposeful discard of maize to create a predictable field hunting zone. An unexpected relationship between the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values of deer appears to reflect a post–mortem processing (i.e., boiling) practice. This thesis has expanded our understanding of Late Woodland diets, horticultural and hunting practices. It has also demonstrated that fauna may be used to reconstruct human behaviour and ideology in lieu of the destructive analysis of human remains.

Keywords

Stable isotopes, bioarchaeology, white-tailed deer, dogs, wild turkey, southwestern Ontario Late Woodland archaeology

Dedication

Dedicated to all the selfless relationships that grow our hearts and expand our minds.

To Kai - my son and soul mate - your happiness is my greatest achievement and your impending birth gave me a deadline that inspired me to finally finish

To Lola - your unyielding loyalty brings me continued happiness and contentment. You truly got me through the ups and downs of thesis research and writing.

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- ☆ Hope Morris.

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Chapter 1

1 Introduction

1.1 Research objectives

In this thesis, stable isotope analyses of archaeological faunal material are used to investigate how Ontario Late Woodland (A.D. 900 to 1650) human activities affected the isotopic composition of animal bones due to increased maize horticulture, hunting locale, season of hunting, and post-mortem treatment. During the Late Woodland period in southwestern Ontario, two neighbouring groups, Ontario Iroquoian and Western Basin peoples, lived contemporaneously until A.D. 1550 with a continuously westward shifting border. The importance of maize to Late Woodland Ontario Iroquoian people has long been understood from archaeobotanical remains and isotopic analyses of human remains (Katzenberg et al. 1995, Harrison and Katzenberg 2003; Schwarcz et al. 1985; van der Merwe et al. 2003; Pfieffer et al. 2014). Until recently, the significance of maize in the diets of Ontario Western Basin peoples was underestimated. The recent analyses of human remains from three sites, Krieger, Great Western Park, and Inland West Pit 9 (Dewar et al. 2010; Spence et al. 2014; Watts et al. 2011), and excavations in the Arkona region Inland West Pit sites (Golder and Associates 2012) suggest heavy investment in maize among Western Basin people in southwestern Ontario.

By A.D. 1000, Ontario Iroquoian populations were growing substantially larger compared to the preceding Middle Woodland period, and associated with increasing sedentism, a pattern that would continue throughout the Late Woodland. Expanding village sites, surrounded by horticultural fields, were in use for fifteen to twenty years and became more heavily fortified. Currently, there is no evidence of the same degree of population increase at Ontario Western Basin sites, nor was there a consistent shift to long-term village life style. Instead, Western Basin sites varied in terms of their size and occupation length. Many sites were occupied seasonally, usually near rivers or lakes during warmer months and further inland during cooler months. Other sites were occupied year round, though the length of occupation was variable. Because of smaller site size and shorter occupation length, the abundance of faunal remains is low and preservation is often poor.

This research pushes the boundaries of interpretations from isotopic analyses of faunal data beyond the reconstruction of food webs by combining isotopic analyses of the organic and mineral phases of bones and teeth to reconstruct both long and short-term behaviour within the archaeological context and human treatment of killed animals (i.e., presence of burning and cut marks). Emphasis has been placed on analysis of canids (wolves, foxes, and domestic dogs), wild turkeys, and white-tailed deer, though black bears, raccoons, groundhogs, grey/black squirrels, rabbits, and some aquatic species along with modern insects and nuts were also analysed to better understand the food web. The isotopic data are considered within the context of available social, economic, and cosmological understandings of animals using ethnohistoric accounts, previous zooarchaeological studies, and ethnographic analogy. Using these integrated data, this dissertation has the following research goals:

(1) to determine which wild animals reflect maize consumption and, therefore, may serve as proxies for landscape change,

(2) to analyse the carbon, nitrogen and oxygen isotopic composition of multiple tissue components (i.e., bone collagen and structural carbonate) of bones and teeth to provide a more complete dietary and geographic profile of the animals,

(3) to determine the dental formation sequence of white-tailed deer, domestic dog, and black bear in order to provide a detailed profile of the early life of animals and enable reconstruction of seasonal dietary patterns,

(4) to compare domestic dog diets, temporally and geographically, with published human data to determine whether dogs can serve as proxies for human diets in southwestern Ontario,

(5) to examine the possible use of oxygen isotope data to reflect the geographic range of animal procurement for both hunted and domestic animals, and

(6) to use carbon and oxygen isotopic data to address possible post-mortem processing of animal remains by humans.

1.2 Stable isotopic analysis of faunal remains

Carbon, nitrogen, oxygen and hydrogen stable isotope analyses have been used extensively by bioarchaeologists to answer questions regarding diet, migration, paleoclimate, and seasonality (see summaries Katzenberg 2007; Schoeninger and Moore 1992; Schwarcz and Schoeninger

1991; White 2004), but as access to human skeletal remains for destructive analysis becomes more and more limited, bioarchaeologists have turned to alternate sources of information. Today, a variety of ecologists, zooarchaeologists and bioarchaeologists have expanded their research to include such analysis of fauna (e.g., Allitt et al. 2008; Balasse et al. 2002; Drucker and Bocherens 2009; Emery 2004; Emery et al. 2000; Fraser et al. 2008, Hobson 1999; Katzenberg 1989; 2006; Kwak and Zedler 1997; White et al 2001; 2004b), which not only act as an alternative to human remains but also provide additional information not previously available from the study of human remains alone. In southwestern Ontario, faunal data have been used primarily to establish a food web for the region (Katzenberg 1989; 2006; Ketchum et al. 2009; Pfeiffer et al. 2014). Although reconstructing the diet of ancient animals to create food webs is needed for interpreting human dietary data and is the most common use of faunal data, animal diets have also been used to: track the introduction of new foods (e.g., Burleigh and Brothwell 1978), identify the domestication of wild species (Balasse and Tresset 2002; Barton et al. 2009; Thorton et al. 2012) and recognize the purposeful feeding of wild species for specific uses, such as ritual sacrifice and feasting (Finucane et al. 2006; White et al. 2001; 2004). Oxygen isotopes have been used to recognize animal migration and long distance trade (Britton et al. 2009; Hobson 1999), explore seasonal patterns of animal resource exploitation (Balasse et al. 2003; Kirsawnow et al. 2008) and reconstruct paleoclimate (Ayliffe and Chivas 1990; Fricke and O'Neil 1996; Stuart Williams and Schwarcz 1997). Faunal data are used in this dissertation for all of the above purposes and to address specific questions regarding behaviours of southwestern Ontario Woodland peoples.

1.3 Stable isotopes

Stable isotopes are naturally occurring variants of an element that differ in number of neutrons and, therefore, atomic mass. Variations in the ratios of one isotope to another are due to their difference in mass, which cause isotopic fractionation during biogeochemical processes (e.g. photosynthesis). The relative abundance of isotopes can be measured using a stable-isotope ratio mass spectrometer and are reported as ratios of heavy to light isotopes in units of per mil (‰) as expressed in the standard δ–notation:

$$\boldsymbol{\delta = (R_{sample}/R_{standard}) / R_{standard}} \qquad \textbf{[Equation 1.1]}$$

where $R = {}^{13}C/{}^{12}C$, ${}^{15}N/{}^{14}N$ or ${}^{18}O/{}^{16}O$ (McKinney et al. 1950:730). Carbon isotopic compositions are standardized to Vienna PeeDee Belemnite (VPDB) (Coplen 1996; 2011). Nitrogen isotopic compositions are standardized to AIR (Mariotti 1983). Oxygen isotopic compositions are standardized to Vienna Standard Mean Ocean Water (VSMOW) (Coplen 1996; 2011).

1.3.1 Carbon-isotope systematics

Carbon isotope ratios of preserved tissues can be used to explore diets of ancient organisms by identifying the consumption of varying plant types (C_3, C_4 and CAM) and as an indicator of degree of carnivory (DeNiro and Epstein 1978; van der Merwe 1982). Identifying the type of plants consumed by an organism is based on differences in the three photosynthetic pathways used by plants. C_3 plants are the most common and include most vegetables, fruits, nuts, trees, wheat and barley. They photosynthesize using a 3–carbon pathway, and have low $\delta^{13}C$ values (~–34 to –23‰, average –26.5‰) (O'Leary 1988; van der Merwe 1982). C_4 plants, including maize and several other tropical grasses, are more adapted to hot climates (Beadle 1939; Matsuko et al. 2002). They photosynthesize using a 4–carbon pathway and are relatively ${}^{13}C$–rich (~–16 to –9‰, average –12.5‰) (O'Leary 1988; van der Merwe 1982). Because these photosynthetic types have a bimodal distribution of $\delta^{13}C$ values, isotopic analysis has been useful for tracking the spread of maize into North America (Allegreto 2007; Boyd et al. 2008; Katzenberg et al. 1995; Schoeninger 2009; Schurr and Redmond 1991; van der Merwe 1982; Vogel and van der Merwe 1977). A third plant type, Crassulacean Acid Metabolism (CAM), which includes cacti and succulents, has isotope compositions that cover the range of C_3 and C_4 plants (van der Merwe 1982), but they were not a component of Ontario ecosystems.

Plant $\delta^{13}C$ values are affected by the composition of CO_2 in the atmosphere. Due to the burning of fossil fuels and deforestation, addition of low-${}^{13}C$ CO_2 since the start of the Industrial Revolution, a phenomenon known as the Suess Effect, has resulted in steadily decreasing $\delta^{13}C$ values of modern atmospheric CO_2. As a consequence, the $\delta^{13}C$ values of modern plants and animals are isotopically lighter (i.e., have lower δ–values) than archaeological ones (Friedli et al. 1986; Verburg 2007; Yakir 2011). Thus all $\delta^{13}C$ values of modern plants and animals mentioned in this text have been corrected by +1.65‰ to account for the Suess Effect (Yakir 2011). None of

the animal remains from the Late Woodland or earlier have been adjusted. The isotopic composition of plants can also be affected by micro-atmospheric environments, such as closed canopy forests, in which CO_2 recycling from decomposing leaf litter is relatively depleted of ^{13}C (Drucker and Bocherens 2009; van der Merwe and Medina 1989; 1991). The lower $\delta^{13}C$ plant values produced are passed on to herbivores consuming plants in closed canopies and are reflected in their $\delta^{13}C$ collagen and structural carbonate values (Cormie and Schwarcz 1994; Drucker and Bocherens 2009).

Because of macronutrient partitioning, dietary carbon is differentially fractionated by different tissues, including the organic (i.e., collagen) and inorganic (i.e., structural carbonate) components of bone and teeth. The carbon-isotope composition of bone and dentine collagen ($\delta^{13}C_{col}$) predominately reflect the protein portion of the diet, while their structural carbonate ($\delta^{13}C_{sc}$) reflects the whole diet, i.e., protein, lipid and carbohydrates (Ambrose and Norr 1993; Clementz et al. 2009; Krueger and Sullivan 1984; Lee-Thorp et al. 1989; Kellner and Schoeninger 2007). Because of this macronutrient partitioning between tissue fractions, the difference between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ (i.e., $\Delta^{13}C_{sc-col}$) or the carbonate-collagen spacing, can be used as an approximate indicator of degree of carnivory. In herbivores, there is an estimated +5‰ increase from diet to collagen, and approximately +12‰ increase from diet to structural carbonate resulting in $\Delta^{13}C_{sc-col}$ mean spacing of ~ +7‰ (Clementz et al. 2009; Krueger and Sullivan 1984; Lee Thorp and van der Merwe 1987). However, there may be a larger increase from diet to structural carbonate (i.e., +12.0 to +14.1‰) for large herbivores (Kellner and Schoeninger 2007; Cerling and Harris 1999). Small trophic increases in $\delta^{13}C_{col}$ (by ~ +1.2–2.0‰) and $\delta^{13}C_{sc}$ (by ~+3‰) between predator and prey (i.e., carnivores) have also been reported, as well as between mothers and breastfeeding infants (Ambrose and Norr 1993; Bocherens and Drucker 2003; Fogel et al. 1989; Fuller et al. 2006; Herring et al. 1998; Krueger and Sullivan 1984; Richards et al. 2002; Tuross and Fogel 1994). The $\delta^{13}C_{col}$ value of breastfeeding juveniles primarily reflects the lipid and carbohydrate-rich (lactose) portion of the breast milk, as breast milk is protein poor (Whitney and Rolfes 2002; Williams et al. 2005). Because lipids have low $\delta^{13}C$ values, the $\delta^{13}C_{sc}$ values of breastfeeding juveniles may be lower than their mothers (Wright and Schwarcz 1998).

1.3.2 Nitrogen-isotope systematics

Nitrogen is also incorporated into the tissues of organisms through dietary sources and provides an additional means to infer an organism's place within the food chain (DeNiro and Epstein 1981). Nitrogen isotopic compositions of bone and teeth are used in paleodiet studies primarily to differentiate consumption of terrestrial versus marine or aquatic food sources (Schoeninger et al. 1983; Schoeninger and DeNiro 1984), and to identify the trophic position of an organism. The nitrogen isotope composition (δ^{15}N) of animal collagen reflects the source of nitrogen at the base of the food web e.g., nitrogen fixing plants (legumes) or fertilized plants. The δ^{15}N values of plants will vary by their environmental context (i.e., soil conditions and climate) and how they incorporate nitrogen. For example, legumes, which fix atmospheric nitrogen, tend to have very low δ^{15}N values (DeNiro and Epstein 1981). Plants in southwestern Ontario exhibit a wide–range of δ^{15}N values (–9 to +3‰) (Longstaffe, *unpublished data*).

With each trophic level (i.e., shift from diet to consumer tissue), $\delta^{15}N_{col}$ values increase by +2 to +5‰, depending on species. The $\delta^{15}N_{col}$ values for a particular individual may, therefore, be used to identify the trophic level of a particular organism (Chisholm et al. 1982; DeNiro and Epstein 1981; Schoeninger and DeNiro 1984). The trophic level increase in $\delta^{15}N_{col}$ values from diet to the tissues of consumers includes breastfeeding juveniles who are one trophic level higher than their mothers in the food chain (Fogel et al. 1989; Williams et al. 2005; White et al. 2004a). As aquatic systems tend to have more trophic levels, $\delta^{15}N_{col}$ values may also be used to differentiate marine and freshwater resource consumers from terrestrial resource consumers (Schoeninger et al. 1983; Schoeninger and DeNiro 1984). The $\delta^{15}N_{col}$ values of an organism may also be affected by climatic conditions (e.g. aridity) and physiological stress (e.g. long-term disease or starvation) (Ambrose 1991; Hobson et al. 1993).

1.3.3 Previous food-web carbon- and nitrogen-isotope studies in Ontario

Figure 1.1 illustrates the carbon and nitrogen isotopic compositions of modern and archaeological plants from northeastern North America from published sources and the current study (Table 1.1). Indigenous southwestern Ontario plants, including most edible roots, berries, tubers and leaves are almost exclusively C_3 plants (Allegreto 2007; Katzenberg et al. 1995; Schwarcz et al 1985). While there are a few natural C_4 plant species found in pre-contact

Ontario, such as amaranth and possibly some varieties of chenopodiums, they were not cultivated extensively and may, in the case of amaranth, even be toxic in very high quantities (Oleszek et al. 1999). It is, therefore, unlikely that these plants contributed substantially to either human (Schwarcz et al. 1985) or wild animal diets. Maize would have been the only readily available, edible C_4 plant in southwestern Ontario during the Late Woodland, with a distinct $\delta^{13}C$ value (–9.1±0.3‰) (Schwarcz et al. 1985). It has been identified archaeologically at southwestern Ontario sites as early as A.D. 200 (Allegreto 2007; Boyd et al. 2008; Cappella 2005; Crawford and Smith 1996; Crawford et al. 2006; Katzenberg 2006). By A.D. 1200 maize horticulture was practiced extensively and successfully across much of the region (Katzenberg 2006; Cappella 2005; Crawford and Smith 1996; Crawford et al. 1997). Most of the isotopic information on the timing of maize introduction and its spread has come from human remains found in pre-contact southwestern and central Ontario, and the Western Lake Erie region (Allegretto 2007; Katzenberg 1989; Katzenberg et al. 1995; Katzenberg 2006; Schwarcz et al. 1985; van der Merwe et al. 2003; Harrison and Katzenberg 2003; Pfeiffer et al. 2014; Stothers and Bechtel 1987; Watts et al. 2011; Dewar et al. 2010). Isotopic studies of the regional archaeological fauna and flora are scarcer, and were conducted primarily for the purpose of reconstructing food webs to use in the interpretation of the isotopic data for humans (Katzenberg 1989; Katzenberg 2006; van der Merwe et al. 2003). There are no previously published archaeological Ontario insect studies. Accordingly, modern grasshoppers and crickets were analysed for this study because they are a food source for many of the animals in the food web (e.g. wild turkeys and canids) (Eaton 1992; Kleinman 1967) and may have been maize-pests (Starna et al. 1984) (Table 1.2 and Figure 1.1). Unpublished plant data from southwestern Ontario provide modern C_3 plant values for grasses, trees, shrubs (Longstaffe, *unpublished data*), nuts and berries (this study). Suess Effect-corrected carbon isotopic data for modern plants are used to help complete the southwestern Ontario food web.

Table 1.1: Isotopic data for modern[1] and archaeological plants from the Eastern Woodland region southwestern Ontario.

	δ^{13}C ‰ (VPDB) ±SD (range)	δ^{15}N ‰ (AIR) ±SD (range)	N	References
Archaeological Maize	– 10.8±0.5 (–11.7 to –9.6)	–	16	Tieszen and Fagre 1994
Archaeological Maize, SW Ontario	–9.1±0.3 (–9.8 to –8.7)	–	10	Schwarcz et al. 1985
Modern Maize, Illinois	–10.1±0.1	1.66±1.4	3	Lavin et al. 2003
Modern C_3 plants, Pinery Provincial Park, Ontario	–28.3±2.0	–4.1±02.0	140	Longstaffe, unpublished
Modern nuts London, Ontario	–26.9±1.6 (–81.3 to –26.7)	–1.8±3.5 (–8.2 to 2.4)	8	This study

[1] The δ^{13}C values of modern plants have been corrected by +1.65‰ to account for the Suess Effect.

Table 1.2: Isotopic data for Late Woodland archaeological fauna (bone collagen), published and this study.

	$\delta^{13}C_{col}$ ‰ (VPDB)±SD (range)	$\delta^{15}N_{col}$, ‰ (AIR) ±SD (range)	n	References
Beaver	–21.8±1.2 (–23.6 to –19.5)	4.6±1.5 (1.4 to 6.7)	20	Katzenberg 1989; 2006; This study
Birds (Aquatic and Terrestrial)	–20.4±1.5 (–22.2 to –17.6)	6.3±1.9 (3.8 to 9.4)	11	Katzenberg 1989; 2006; This study
Black Bear	–20.9±0.9 (–22.9 to –19.4)	5.3±0.6 (2.7 to 6.6)	39	Katzenberg 1989; 2006; This study
Canids	–14.3±3.4 (–22.1 to –9.3)	9.5±1.3 (5.3 to 11.4)	103	Katzenberg 1989; 2006; Booth et al. 2011; This study
Cottontail	–22.9±3.0 (–27.4 to –19.4)	3.7±0.8 (2.1 to 4.7)	8	This study
Freshwater Fish	–19.6±2.5 (–24.9 to –11.5)	8.5±2.0 (3.6 to 12.0)	71	Katzenberg 1989; 2006; van der Merwe et al. 2003; This study
Gray/black Squirrel	–19.6±0.6 (–20.5 to –18.5)	5.0±0.8 (3.8 to 6.7)	13	This study
Muskrat	–21.3±1.4 (–23.0 to –20.4)	6.3±1.4 (4.7 to 7.3)	3	This study
Porcupine	–20.5±0.8 (–21.4 to –19.9)	5.0±0.6 (4.4 to 5.6)	3	This study
Raccoon	–20.4±2.2 (–24.5 to –14.0)	8.8±2.0 (4.6 to 11.9)	31	Katzenberg 1989; 2006; This study
Small Carnivores	–20.9±2.1 (–23.3 to –19.5)	8.9±0.3 (8.5 to 9.2)	3	This study
Turtle	–23.7±1.2 (–25.1 to –23.0)	5.8±1.3 (5.0 to 7.2)	3	This study
White-tailed deer	–22.6±1.4 (–24.9to –20.2)	5.4±0.9 (2.8 to 8.6)	114	Katzenberg 1989; 2006; This study
Wild Turkeys	–20.5±2.7 (–30.6 to –9.8)	6.3±1.0 (4.0 to 9.3)	76	Katzenberg 1989; 2006; This study
Woodchuck	–24.0±1.7 (–26.5 to –19.4)	3.2±0.9 (1.1 to 5.5)	30	Katzenberg 1989; 2006; This study
Modern Grasshoppers & Crickets[2]	–24.9±3.2 (–28.9 to –15.0)	2.3±1.6 (–0.8 to 6.2)	47	This study

[2]Modern grasshopper and cricket $\delta^{13}C$ data are included, though the data reflects the analysis of whole, freeze-dried insects and not extracted collagen. Insect values are corrected by +1.65‰.

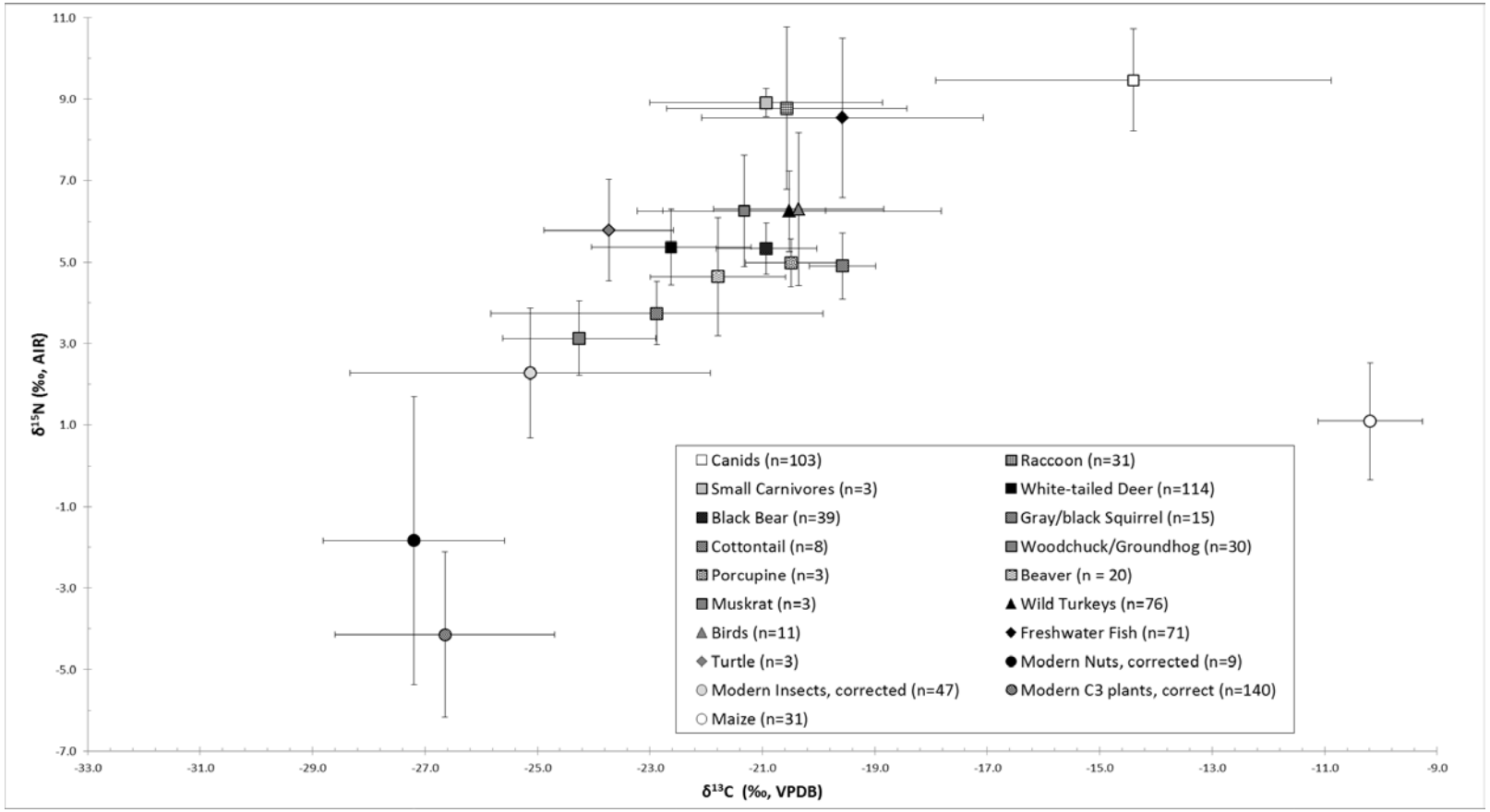

Figure 1.1 Theoretical southwestern Ontario food web based on archaeological bone collagen ($\delta^{13}C_{col}$ and $\delta^{15}N_{col}$, mean±SD‰) data and whole organism, modern plant and insect data ($\delta^{13}C$ and $\delta^{15}N$, mean±SD‰, corrected +1.65‰).[3]

[3] Collagen data are not corrected for trophic level effect. See Tables 1.1 and 1.2 for data sources.

1.3.4 Oxygen-isotope systematics

The $\delta^{18}O$ values of bone and/or tooth bioapatite (structural carbonate or phosphate) can be used to track geographic and climatic variations in precipitation, humidity, latitude, altitude and temperature. Deciphering geographic and climatic variables is possible because the oxygen-isotope composition of skeletal tissue is at equilibrium with body water, which, in turn, is primarily derived from ingested water (Bryant and Froelich 1995; Luz et al. 1984; Luz and Kolodny 1985). Oxygen enters the body from: inhaled atmospheric oxygen, ingested water, and water in food resources, but for most mammals, ingested water is the primary source (Luz et al. 1990). Luz et al. (1990) found a relationship between local meteoric water and the phosphate of white-tailed deer bones collected across much of North America, and the relationship between the $\delta^{18}O$ values of body water and skeletal phosphate is well-established (Longinelli 1984; Luz et al. 1984; Luz and Kolodny 1985). In bone that has not undergone isotopic alteration after death, phosphate and structural carbonate $\delta^{18}O$ values are correlated (Bryant et al. 1996; Iacumin et al. 1996). This suggests that body water and structural carbonate oxygen isotopic compositions should also be correlated, a hypothesis that is tested here by comparing the $\delta^{18}O_{sc}$ values of wild and domesticated animals with the predicted $\delta^{18}O$ values of modern, local precipitation. Bone should provide a lifetime average of the oxygen isotope composition of consumed water, obscuring seasonal fluctuations, while tooth enamel should provide seasonal information related to the time of tissue formation. Intra-species variation has enabled the reconstruction of past climates (Clementz and Koch 2001; Longinelli 1984; Luz et al. 1984; Sponheimer and Lee–Thorp 1999; Kirsanow et al. 2008), seasonality (Balasse et al. 2003), geographic movement (Britton et al. 2009; Hobson 1999; Schwarcz et al. 1991) and transitions from breastfeeding to weaning (White et al. 2004a; Williams et al. 2005; Wright and Schwarz 1998). Because species-specific variations in $\delta^{18}O$ can also be caused by differences in body size, physiology and drinking/feeding ecology (i.e. obligate drinkers versus drought–tolerant species) (Bryant et al. 1996; Bryant and Froelich 1995; Daux et al. 2008; Kirsanow and Tuross 2011), isotopic research designs need to be controlled by species.

Latitude, altitude, humidity and temperature all affect the oxygen isotopic composition of precipitation as it moves across continents (Ayliffe and Chivas 1990; Fricke and O'Neil 1999). For example, as evaporated water condenses and precipitates as rain or snow, the distance it has traveled inland from the ocean, away from the equator and/or with increasing altitude contributes to preferential loss of ^{18}O, resulting in precipitation that is increasingly depleted of ^{18}O, a phenomenon known as the Rayleigh Distillation Effect (Dansgaard 1964; Craig and Gordon 1965). Although there are differences in the effects of evaporation among potential water sources for animals (i.e., puddles, small streams, Great Lakes, plant water), the $\delta^{18}O$ values of animal tissue may still provide an indirect link to the $\delta^{18}O$ value of local meteoric water.

Southwestern Ontario is a relatively small region, with minimal oxygen isotopic variation due to distance from the ocean or altitude. There is, however, latitudinal and longitudinal variation in $\delta^{18}O$ values across southwestern Ontario (Longstaffe 2013, *personal communications*). The precipitation data from sixteen stations spanning from Illinois to Quebec (IAEA/WMO 2013; Longstaffe *unpublished data*) show a decrease in the heavy isotope (^{18}O) in precipitation moving across the Great Lakes region from west to east, resulting in an approximately 2‰ geographic difference in $\delta^{18}O$ values likely due to temperature differences and the influx of air masses of different origin at different times of the year (Edwards et al. 1996; Larson and Longstaffe 2007). The precipitation station isotopic data were used to predict the annual precipitation $\delta^{18}O$ values for the locations of Western Basin and Iroquoian sites examined in this study (Figure 1.2).[4]

Over the past several thousand years there have been climatic events that may have affected the seasonal and annual local meteoric water $\delta^{18}O$ values. For example between approximately A.D. 800 and 1200 there was the Medieval Warming Period (MWP),

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[4] Predicted $\delta^{18}O$ values of past, local precipitation for the archaeological sites mentioned in text (Figure 1.3) were interpolated using a Kriging analysis based on the $\delta^{18}O$ values of local precipitation collected and analysed from sixteen water stations (six stations from IAEA/WMO 2013; ten stations from Longstaffe *unpublished data*). An ordinary, spherical Kriging analysis was performed with no special parameters. Only the Great Lakes region bounded by Lake Erie to the south, the western tip of Lake Ontario to the east, Lake St. Clair and the southeast tip of Lake Huron to the west and area south of Georgian Bay to the north (see Figure1.2 area of interest box) are considered in the proceeding discussions.

followed by the Little Ice Age (LIA) starting around A.D. 1450 and continuing through to the early 1800s (Bernabo 1981; Campbell and Campbell 1989; Foster 2012; Gajewski 1988; Mullins et al. 2011; Viau and Gajewski 2012). During the MWP there may have been an annual temperature increase of up to +0.1°C in most of this region, which likely resulted in slightly higher δ^{18}O values for meteoric water. During the LIA, there was likely a temperature decrease between 0.2 to 0.3°C resulting in slightly lower δ^{18}O values (Viau and Gajewski 2012). Deer in this study come from sites dated to between 3500 to 400 years BP, so some may have been affected by the MWP and beginning of the LIA. Nonetheless, Edwards et al. (1996) suggest that the temperature and precipitation patterns of the Great Lakes region from 4000 B.P. onward appear to have been relatively stable despite annual temperature changes (also see Bernabo and Webb 1977 for stability in pollen record 2000–500 BP).

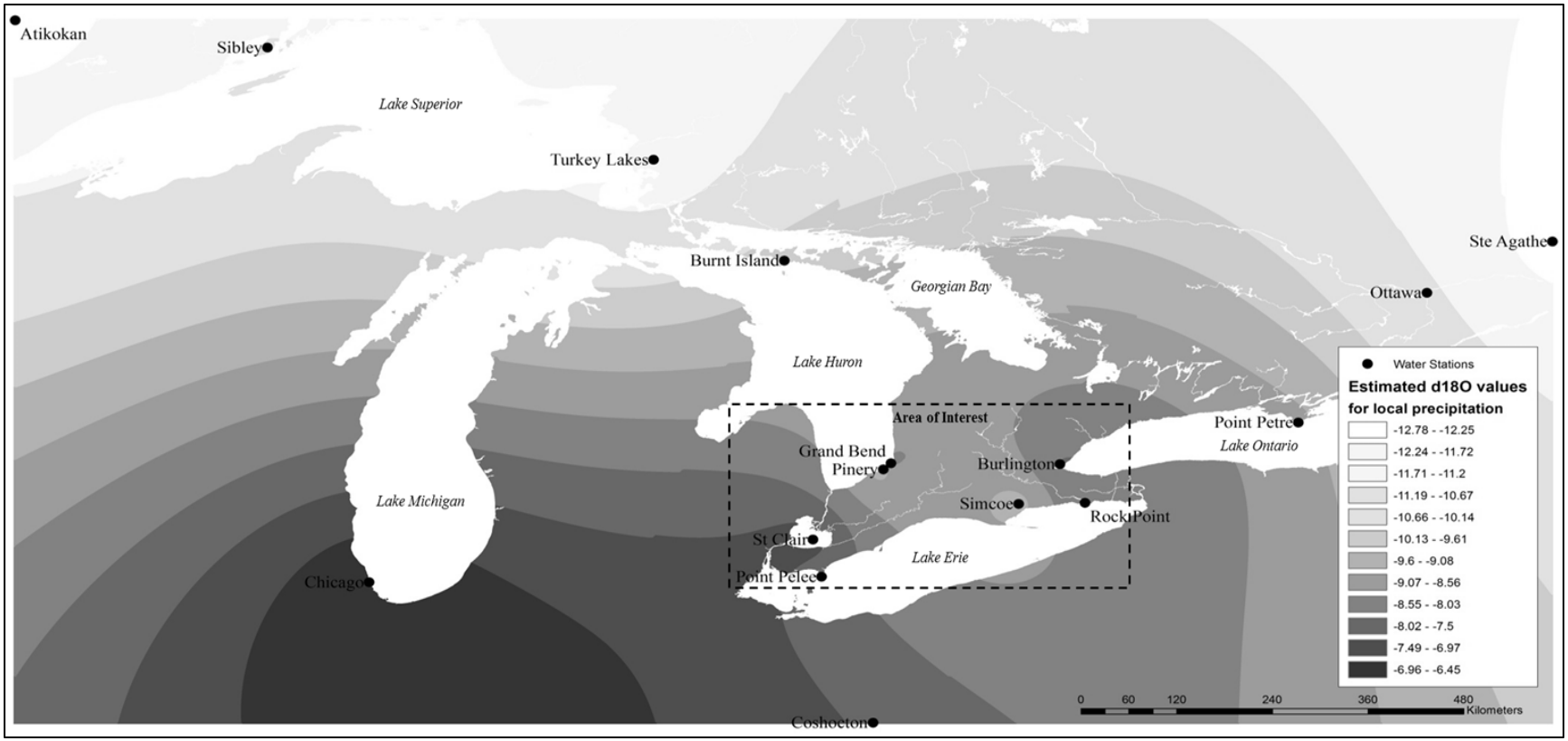

Figure 1.2: Interpolated regional $\delta^{18}O$ values based on the $\delta^{18}O$ values of local precipitation collected and analysed from sixteen water stations (IAEA/WMO 2013; Longstaffe *unpublished data*). [5] The box delineates the study area.

[5] All maps in the thesis were created by Zoe Morris in ArcGIS® software by ESRI, North American Datum (NAD) 1983, using the following data layers: World Country Boundaries, Source: ArcWorld Supplement; Canada Provincial Boundaries, Source: DMTI Spatial Inc.; United States of America State Boundaries, Source: ESRI, derived from Tele Atlas; Hydrology (Rivers and Lakes), Source: CanMap Water, DMTI Spatial Inc., 2011.

1.4 Research context: Late Woodland SW Ontario

Southwestern Ontario is loosely associated with the larger Northeastern Woodland archaeological cultural area extending through southern Quebec, Ontario, and the Maritimes in Canada and US Atlantic and Midwest states. The southwestern Ontario Woodland region is bounded by Lake Erie to the south, Lake Huron and Lake St. Clair to the west and Lake Ontario to the east, within the northern limit of the Carolinian forest. Archaeologists have typically divided the material remains in this region into two groups; ; the Ontario Iroquoian[6] and Western Basin peoples. These two cultural groups inhabited this region contemporaneously and within shifting borders. Table 1.3 summarizes the phases of Ontario Iroquoian and Western Basin cultural traditions, which are identified primarily by pottery styles. Despite their proximity, there are differences in the subsistence and settlement strategies adopted by the Ontario Iroquoians and Western Basin peoples.

Both groups employed a mixed subsistence strategy, incorporating domestic plant horticulturalism, with wild plant gathering, and hunting and fishing local faunal resources. White-tailed deer, small mammals, a variety of birds, and freshwater fish were all important dietary components throughout the Late Woodland time period. The emphasis on particular hunted and fished species, however, differed by cultural group and time period (Foreman 2011; Murphy and Ferris 1990; Prevec and Noble 1983; Stewart 2000; Warrick 2000). Settlement patterns for both groups are variable, though after A.D. 1000, generally Ontario Iroquoian sites appear to be occupied year round, while Western Basin sites are less consistent in terms of season of occupation, patterns of annual re–use, and length of occupation. The variation in settlement style had previously led researchers

[6] The term Iroquoian is used in this dissertation to describe Iroquoian-speaking peoples living in the lower Great Lakes region prior to and following European contact. The term Iroquois specifically refers to peoples of the historic Five Nations of New York State, including Onodaga, Oneida, Mohawk, Seneca and Cayuga (Smith 1990:279; Trigger 1978:3). The Ontario Western Basin (herein referred to as Western Basin) name and sequence was adapted from Fitting (1965) and Stother (1975) by Murphy and Ferris (1990:189) to recognize the distinct cultural tradition present in the southwestern-most corner of Ontario, though it also extended into southeastern Michigan and northwestern Ohio.

to assume that the more sedentary Ontario Iroquoian people were more heavily reliant on domestic crops, particularly maize, compared to their Western Basin neighbours. Recent isotopic data for Ontario Western Basin peoples suggest a similar pattern of maize consumption (Dewar et al. 2010; Spence et al. 2014; Watts et al. 2011). The seasonal occupation evident at many Western Basin sites has created speculation as to where and how Western Basin people were growing large quantities of maize and, therefore, the use of additional proxies for landscape use warrant further investigation.

Table 1.3: Cultural stages of southwestern Ontario.

Pre–A.D. 200		
Archaic	~8000–800 B.C.	Ellis et al. 1990
Early Woodland	~900 – 0 B.C.	
Middle Woodland	300 B.C. to A.D. 500	
Ontario Iroquoian		
Princess Point Phase	A.D. 700–1000	Fox 1990
Early Ontario Iroquoian Period	A.D. 900–1300	Williamson 1990
Middle Ontario Iroquoian Stage	A.D. 1300–1450	Dodd et al. 1990; Finlayson 1998
Late Iroquoian/Neutral	A.D 1450–1650	Lennox and Fitzgerald 1990
Ontario Western Basin		
Riviere au Vase Phase	A.D. 600–900	Murphy and Ferris 1990
Younge Phase	A.D 800–1200	
Springwells Phase	A.D 1200–1400	
Wolf Phase	A.D. 1400–1550	

1.5 Research sample

Faunal samples were procured from twenty–eight previously excavated archaeological sites from southwestern Ontario (Appendix A). The samples ranged temporally from the Late Archaic Davidson site, dated to 3500 B.P, to contact period Neutral sites, dating into the mid–1650s. The majority of the sites, however, date between A.D. 1000 and 1650. Sixteen Ontario Iroquoian sites were sampled, including two Princess Point sites, as well as nine Western Basin sites. Three sites dating prior to as the entry ofmaize into the region are used as baselines for C_3-only resource availablity (Figure 1.3).

The bulk bone collagen of 324 individuals and bulk dentine from 11 individuals (n=38 teeth) were analysed (Appendix B and H). The bulk bone structural carbonate was analysed for a subset of the individuals (n= 126 animals) (Tables 1.4 and 1.5, Appendices D and I). Serially sampled enamel was analysed for 14 archaeological individuals (n=105 tooth sections). Collagen and structural carbonate were analysed for an additional dataset of modern white-tailed deer (n=16, n=14 respectively) and wild turkey (n=19, n=14 respectively) from known recovery/hunting locations (Appendices C and E). Bulk dentine (n=9 teeth) and enamel serial sections were completed for two modern deer (n=27 teeth sections) (Appendices H and I). The carbon and nitrogen isotopic compositions of modern crickets (n=17), grasshoppers (n=30), and plants (n=12), including seeds and fruit, were also analysed to help round out the southwestern Ontario food web (Appendix F and G, respectively).

Table 1.4: Total number of collagen and structural carbonate samples from archaeological animals (excluding canids, wild turkeys and white-tailed deer).

SPECIES	COLLAGEN		STRUCTURAL CARBONATE	
	Ontario Iroquoian A.D. 900–1600	Western Basin A.D. 900–1600	Ontario Iroquoian A.D. 900–1600	Western Basin A.D. 900–1600
Beaver	3	-	-	-
Birds (Aquatic and Terrestrial)	4	1	-	-
Black Bear	14	5	5	2
Cottontail	8	-	-	-
Freshwater Fish	-	1	-	-
Gray/black Squirrel	14	-	1	-
Muskrat	2	1	-	-
Porcupine	2	1	-	-
Raccoon	13	16	3	1
Small Carnivores (i.e., mink and skunk)	2	1	-	-
Turtle	3	-	-	-
Woodchuck	16	-	1	-
TOTAL	**81**	**25**	**10**	**3**

Table 1.5: Total number of collagen and structural carbonate samples from modern and archaeological canids, wild turkey and white-tailed deer.

COLLAGEN	Pre–horticulture pre A.D. 200	Ontario Iroquoian A.D. 900–1600	Western Basin A.D. 900–1600	Modern
Canids	3	58	15	-
Wild Turkeys	2	44	15	19
White-tailed deer	8	52	21	16
TOTAL (253)	**13**	**154**	**51**	**35**
STRUCTURAL CARBONATE	**Pre–horticulture pre A.D. 200**	**Ontario Iroquoian A.D. 900–1600**	**Western Basin A.D. 900–1600**	**Modern**
Canids	4	49	7	-
Wild Turkeys	-	12	1	14
White-tailed deer	6	22	10	14
TOTAL (141)	**10**	**85**	**18**	**28**

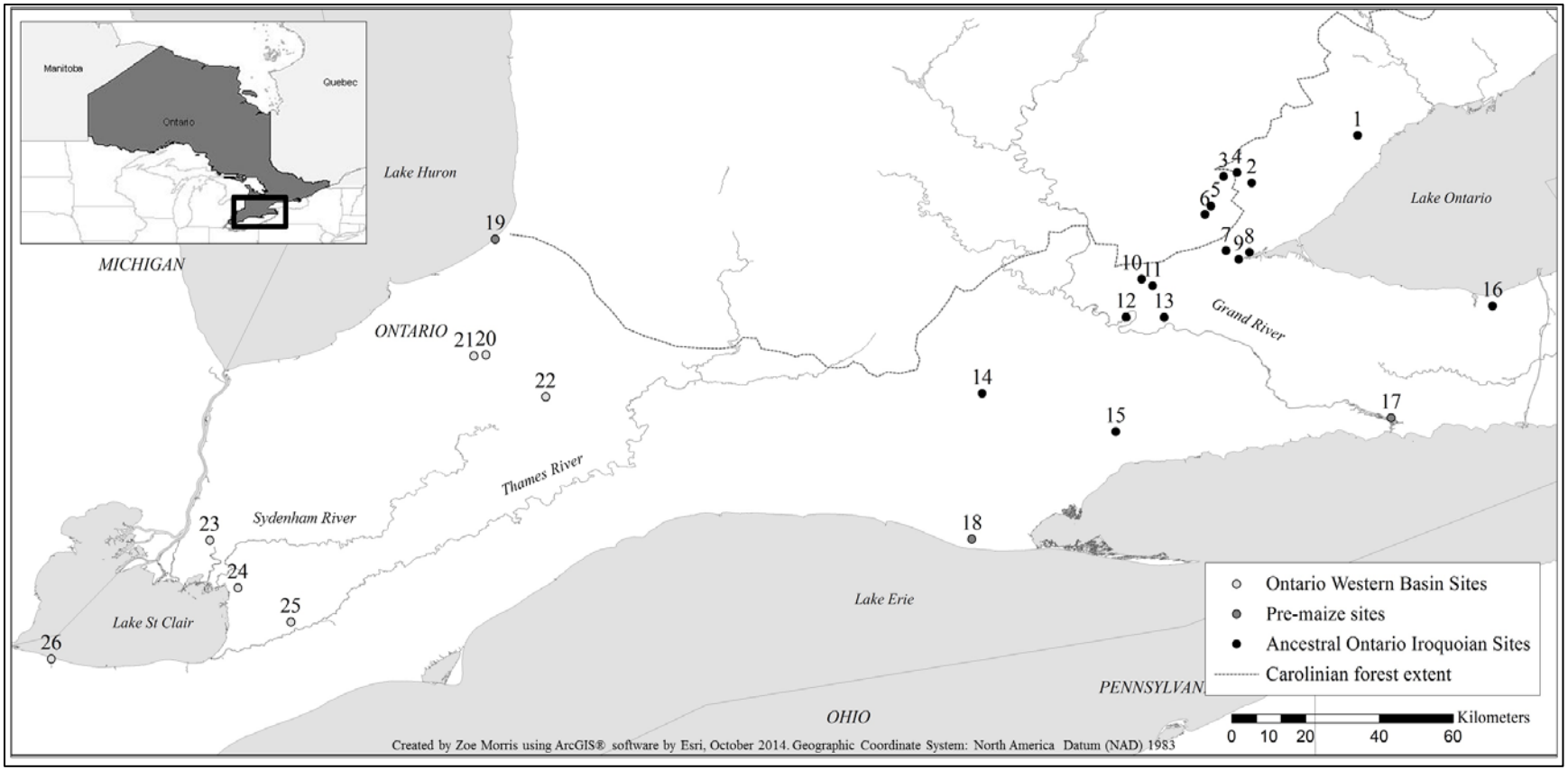

Figure 1.3: Map of southwestern Ontario including all archaeological sites from which faunal samples were selected.

Ancestral Ontario Iroquoian Sites: 1. Lightfoot; 2. Pipeline; 3. Rife; 4. Crawford Lake; 5. Bogle II; 6. Hamilton; 7. Winking Bull; 8. Old Lilac Garden; 9. Princess Point; 10. Cleveland; 11. Fonger; 12. Porteous; 13. Walker; 14. Van Besien, 15. Slack-Caswell; 16. Thorold. Pre-maize Sites: 17. Cranberry Creek; 18. Bruce Boyd; 19. Davidson. Ontario Western Basin Sites: 20. Figura; 21; Inland West Pit Sites, Loc. 3, 9 and 12; 22. Montoya; 23. Dobbelear; 24. Liahn I; 25. Roffelson; 26. Silverman.

1.6 Organization of this dissertation

The dissertation body is organized into three substantive chapters, which will eventually be published in peer-reviewed journals. Each chapter deals with a different group of animals and includes relevant background, research questions and methodology specific to that set of animals. In Chapter 2 the isotopic data of wild and domestic canids are used to reconstruct the diets of canids, which include probable wolves, a group of large canids, foxes, and domestic dogs. The domestic dog results are compared to published human data for Ontario Iroquoian and Western Basin sites through time in order to determine whether dogs can serve as proxies for southwestern Ontario humans. In Chapter 3 the bone collagen and structural carbonate of wild turkeys recovered from Ontario Iroquoian sites are compared to a set of modern wild turkeys from known locations as well as archaeological turkeys from sites in the southeastern and southwestern United States and Mexico. The unique pattern of maize access noted for the Ontario Iroquoian wild turkeys is hypothesized as purposeful feeding. In Chapter 4 radiographic data are used to reconstruct the dental formation sequence of white-tailed deer, which is corroborated with the analysis of oxygen–isotope data from enamel serial sections from ten deer mandibles. The same serial sections are also used to explore the diet and ecology of the first year of life. Compared with models from modern deer collagen and structural carbonate analyses, archaeological deer are not consuming significant quantities of maize and show an unusual relationship between bone collagen and structural carbonate. The lack of maize consumption indicates that these deer were hunted, and a specific *post–mortem* treatment of deer is hypothesized to explain the unusual collagen–structural carbonate results. In each chapter, the oxygen isotopic composition of carbonate ($\delta^{18}O_{sc}$) for each type of animal is compared with the predicted and/or measured oxygen isotopic composition of local precipitation (Figure 1.2) in order to determine whether the isotopic composition of the animals reflects their recovery locations/sites or if they have been obtained from a distant region. Chapter 5 summarizes all of the findings and suggests future directions for expanding this research.

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Chapter 2

2 Domestic and wild canids

2.1 Introduction

"Men should be good to their dogs, for kindness is due to those that aid us, and if they are unkind, there may be a penalty. There is an abyss between us and the land of souls, and over this two dogs hold a log in their teeth. Over this log, if fortunate, the soul passes to the happy hunting grounds. If voices are heard saying, 'He fed us, he sheltered us, he loved us,' then the dog at each end grips hard with his teeth, holding the log with all his might and the soul passes safely over. But if the voices say, 'He starved us, he beat us, he drove us away,' then, when he is halfway over, the dogs let go, and he falls into depths of woe." An Onodaga Story, Brehm 2011:365 from Bear c. 1932

During the Late Woodland period (A.D. 900–1600) two contemporary cultural traditions, Western Basin and Ontario Iroquoian existed along a shifting frontier in southwestern Ontario. Both traditions involved a mixed subsistence economy, based on hunting, fishing, gathering and cultivation of crops that were both introduced (maize, squash, beans) and locally domesticated (e.g., sunflower, tobacco). Archaeological evidence has suggested that during the Late Woodland, Ontario Iroquoian people emphasized maize horticulturalism and consequently occupied village sites for longer periods than their Western Basin neighbours (Murphy and Ferris 1990; Warrick 2000; Williamson 1990). In contrast, archaeological evidence has led to the belief that Ontario Western Basin people de-emphasized maize cultivation because of their seasonal mobility, economic and settlement flexibility (Murphy and Ferris 1990). Recent isotopic analyses of human remains from southwestern Ontario has, however, revealed that Western Basin individuals in Ontario were consuming amounts of maize comparable to their Ontario Iroquoian contemporaries (Dewar et al. 2010; Spence et al. 2010; Watts et al. 2011). Because human remains are rarely accessible for analysis, the animals with which they interacted are used here to investigate their usefulness as dietary proxies and to examine patterns of landscape use and subsistence activity.

The relationship between humans and animals provides insight into human cultural choices (both economic and symbolic), ecological relationships and landscape use (Comaroff and Comaroff 1990; Ingold 1994; Russell 2012; Shipman 2010). Dogs, and their closely related canid cousins, are a particularly interesting group of animals because of their varied and, at times, distinctive association with humans (Morey 2006; 2010; Clutton-Brock 1994). In this paper, the diets of domestic dogs and humans are compared and patterns of horticultural land-use and hunting choices related to wild canids are reconstructed isotopically to determine the nature of relationships among Late Woodland dogs, foxes and wolves and the humans who incorporated their remains into the archaeological record.

Cultural norms and taboos often dictate human-animal relations, which are complicated by individual preference and environmental/climatic contexts. Dogs have long been integrated into human society, fulfilling a range of roles including hunting companions, components of ritual and medicine, sacrificial objects, food, pets, village and crop guards, tolerated scavengers and even bed-warmers (Brizinski and Savage 1983; Coppinger and Coppinger 2001; Hriscu et al. 2000; Kerber 1997; Morey 2010; Olsen 1985; Olsen 2000; Russell 2012; White 2004; Zeuner 1963). Social influences on the relationship between humans and canids will also have biological consequences, such as changes in diet that should be reflected in the stable isotopic composition of both species.

The carbon, nitrogen and oxygen isotopic compositions of collagen and structural carbonate of canid bones (wolves, foxes and domestic dogs) recovered from fourteen Ontario Iroquoian and six Western Basin sites (A.D. 900 – 1650) as well as three sites pre-dating the entry of maize to the region (Figure 2.1) are used to determine whether the isotopic variability of animals reflects distinct human cultural practices. Interpretive frameworks include the use of: (1) diets of domesticated dogs as proxies for human subsistence practices in southwestern Ontario, (2) comparison of human hunting behaviours using the diets and deposition patterns of non–domestic canids, and (3) oxygen isotopic composition of canid bones to explore their usefulness as proxies for geographic movement (e.g. trade of dogs or range of hunting territories).

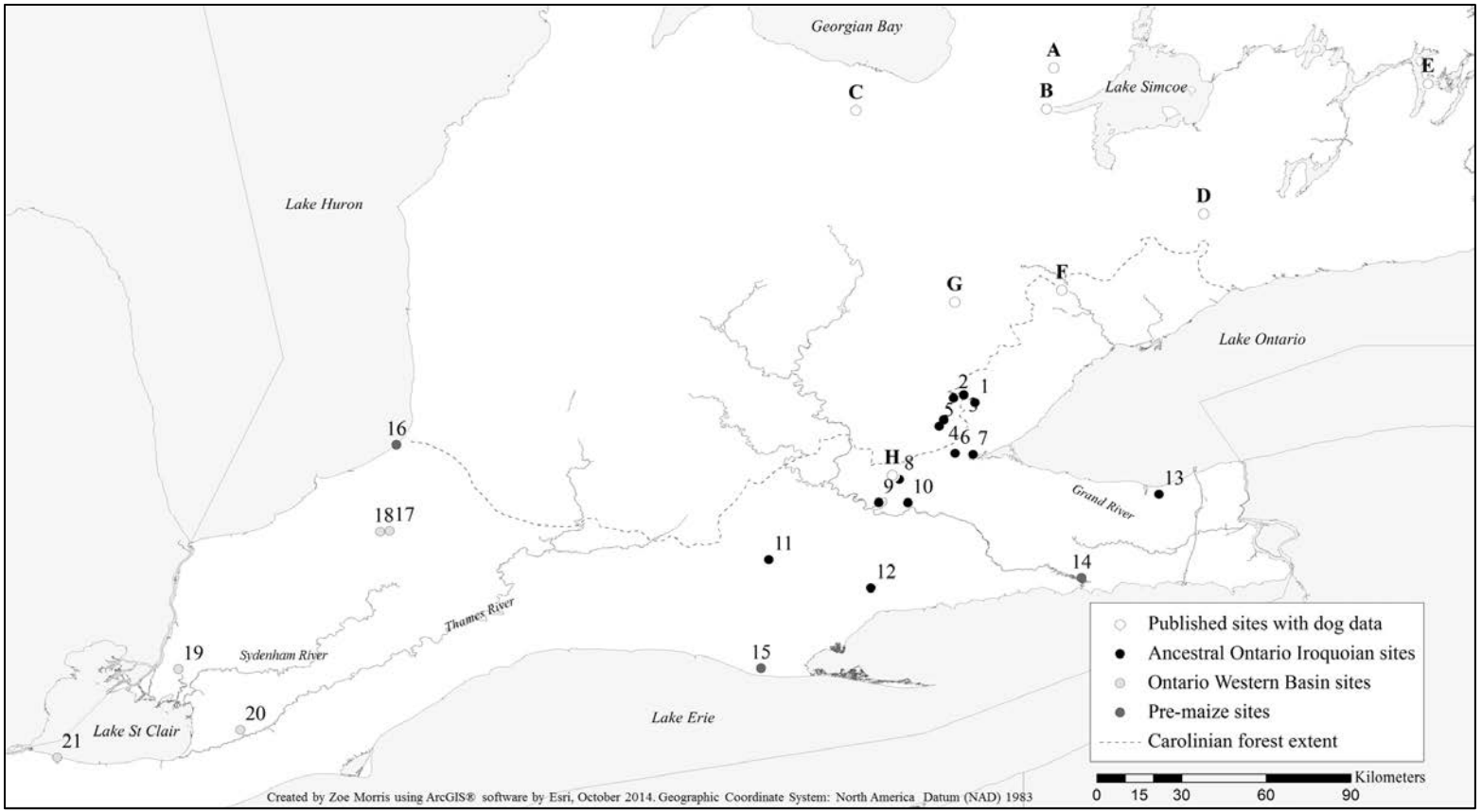


Figure 2.1: Map of southwestern Ontario with all sites with canid isotope data mentioned in the text, including previously published isotopic data (Booth et al. 2011; Conolly et al. 2014; Katzenberg 1989; 2006).[7]

[7] Ancestral Ontario Iroquoian Sites: 1. Pipeline; 2. Rife; 3. Crawford Lake; 4. Bogle II; 5. Hamilton; 6. Winking Bull; 7. Old Lilac Garden; 9. Fonger; 9. Porteous; 10. Walker; 11. Van Besien, 12. Slack-Caswell; 13. Thorold. Pre-maize Sites: 14. Cranberry Creek; 15. Bruce Boyd; 16. Davidson. Ontario Western Basin Sites: 17. Figura; 18; Inland West Pit Sites, Loc. 9 and 12; 19. Dobbelear; 20. Roffelson; 21. Silverman. Sites with previously published dog isotope data: (A.) Ball; (B). Holly; (C.) Kelly-Campbell. (D.) Draper; (E.) Jacob's Island; (F.) Seed; (G.) Wallace (H.) Cleveland.

2.1.1 History of dogs in North America

The association of dogs with humans spans continents and millennia, and is a diverse and complicated relationship. It is generally accepted that dogs are the first and most successful domesticated species (Coppinger and Coppinger 2001; Clutton–Brock 1989; Wang and Tedford 2008), and are present on every continent occupied by humans by 4000 B.P. (Crockford 2000).

There is debate regarding the timing of the domestication of *C. familiaris*. Some genetic evidence suggests domestication occurred 100,000 years ago (Wayne 1993; Wayne and Lehman 1992; Vilà et al. 1997). Raiser (2004:222-3) argues that the dog-wolf split at that time was unrelated to human actions but set the stage for the domestication of dogs approximately 15,000 years ago. Recent genetic data along with archaeological and morphological evidence support the more recent domestication date (Benecke 1987; Morey 2006; Morey 2010: 81; Savolainen et al. 2002). It is possible that a subspecies of wolf emerged over 80,000 years earlier but Vilà et al. (1997) note that the morphological changes evident in the zooarchaeological record were only manifested with the emergence of agriculture.

The social, hierarchical structure of wolf packs has been cited as key reason for their domestication (Coppinger and Copping 2001; Morey 2010; Schwartz 1997), though the mechanism for domestication is unclear. Hypotheses include: (1) hunting cooperation between humans and wolves stemming from competition within the same ecological niches, and resulting in mutually beneficial reduction of competition through cooperation (Clutton-Brock 1981; Cummins 2002; Morey 1990; 2010; Schwartz 1997; Zuener 1963), (2) “pet-keeping” of young wolf pups as companions (Clutton-Brock 1989; Morey 2004; Zuener 1963), and (3) a symbiotic relationship between canids and humans derived from tolerated scavenging and protection of crops and/or villages (Coppinger and Coppinger 2001; Russell 2002; Zeuner 1963).

Regardless of the timing and reason for dog domestication, as ancient humans crossed from the Old World into the New World during the Late Pleistocene, they were accompanied by domesticated dogs (Fiedel 2005; Wang and Tedford 2008).

Mitochondrial DNA from Alaskan and Central American dogs demonstrates that New World dogs originated from several lineages of Old World dogs (Leonard et al. 2002). Humans and dogs spread rapidly and successfully across many parts of North, Central and South America (Lupo and Janetski 1994; Raiser 2004; Schwartz 1997). The earliest remains of domestic dogs in North America are found in the northwest at Old Crow in the Yukon Territory dated to 11,450–12,660 B.P. and in Fairbanks, Alaska, dated to 10,000 B.P. (Beebe 1980; Olsen 1985). By 7000 B.P., dogs are found in Illinois (Morey and Waint 1992), Wyoming (Walker and Frison 1982), Idaho (Yohe and Pauesic 2000, Haag 1970, Lawrence 1967; 1968) and as far south as Arizona (Warren 2000). While dogs are presumed to be present in Ontario during the Paleo–Indian Phase (pre–10,000 B.P.), preserved dog remains are not found until the Ontario Archaic period (10,000–3000 B.P.) (Birzinski and Savage 1983; Oberholtzer 2002).

2.1.2 Dogs and other canids in the Great Lakes region

"The dogs in this country howl rather than bark, and all have upright ears like foxes, but in other respects all are like the moderate–sized mastiffs of our villagers. They are used instead of sheep to be eaten at feast, they bring the moose to bay and discover the animals' lair, and they cost their master very little... On different occasions I have been present at feasts of dog. I freely admit that at first it was abhorrent to me, but I had not eaten of the meat twice before I found it good, with a taste rather like pork; moreover (like pigs) their [dog's] most usual fare is nothing but the refuse they find in the streets and on the roads. They [dogs] also very frequently put their pointed nose into the savages' pot of sagamité: but it is not thought to be less' clean on that account"
Wrong 1939:226 from Sagard's 1632 The Long Journey into the Country of the Huron

Domesticated dogs (*C. familiaris*), gray wolves (*C. lupus*) and foxes (*V. vulpes* and *U. cinereoargenteus*) co-habited southwestern Ontario prior to European contact, but coyotes (*C. latrans*) were absent in the region until two centuries after Europeans arrived (Geese and Bekoff 2004; Gomper 2002). Figure 2.2 provides the taxonomic relationships for extant canids in southwestern Ontario. Allen (1920) documented seventeen breeds of indigenous dogs present in the New World. In the Northeastern Woodland region, the "Larger or Common Indian Dog" (see also, the "North American" dog, "*C. canadensis*"

identified by Richardson 1829:80–2) was present (Allen 1920:457; Cummins 2002; Richardson 1829) and was significantly smaller than the Inuit dogs to the north (Allen 1920:462; Richardson 1829 80–82). The smaller “Short–legged Indian Dog” may also be present in Ontario as remains of this variety were found in Ohio (Allen 1920). The possibility of wolf–dog hybrids exists according to some accounts (Barton 1805; Richardson 1829) as all members of the genus *Canis* are inter–fertile (Schwartz 1997).

As the only domesticated animal in pre-contact Ontario (Cummins 2002; Ferris 1989; Thwaites 1896–1901 2), dogs served a variety of roles among the indigenous peoples of the Great Lakes. They were companions and protectors (Cummins 2002; Richardson 1829; Thwaites 1896–1901 23), hunting partners (Thwaites 1896–1901 1; 2; 60; Barton 1805) and components of ritual and feasts (Birzinski and Savage 1983; Oberholtzer 2002; Thwaites 1896–1901; 20). The role of dogs among Iroquoian groups, such as the Huron, is well-established in ethnohistoric accounts (Harrington 1921; Katzenberg 1989; Katzenberg 2006; Oberholtzer 2002; Wrong 1939) but the role dogs played among Ontario Western Basin peoples is not as well understood.

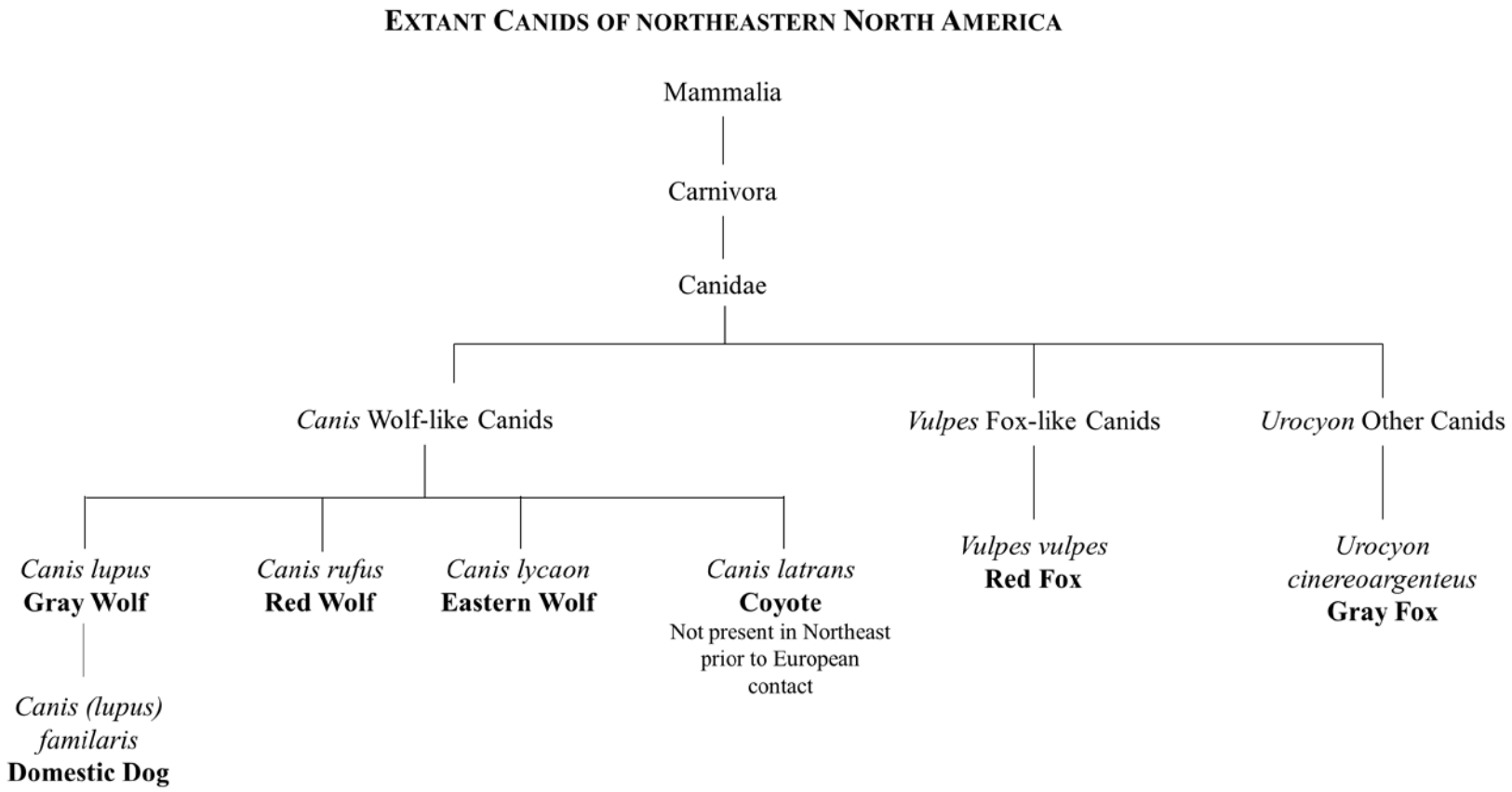


Figure 2.2: Taxonomic relationships of canids present in southwestern Ontario.

Dogs around the world are often both simultaneously revered and a practical food source (Schwartz 1997; Morey 2010). Schwartz (1997:62) attributes the "mystification" of dog consumption to the social nature of dogs and the personal bonds they form with humans compared with other modern domesticates. Globally dogs are also the most common animals used in sacrifice, and there is extensive ethnohistoric and archaeological evidence of dog consumption among Eastern Woodland groups, often within a ritualized context (Blau 1964; Brizinkski 1979; Brizinski and Savage 1983; Oberholtzer 2002; Thwaites 1896–1901 23; Wrong 1939). Sagard describes their consumption as well as the purposeful fattening of dogs for ceremonies:

"But they will only feed dogs, and sometimes young bears for important feasts, because their flesh is very good; and, in order to have it ready they fatten them…. they give them the remains of their sagamite [a stew of corn and grease] *to eat."* (Wrong 1939:220).

Further, dog consumption in this area was often associated with specific events, such as marriage (Wrong 1939; Schwartz 1997; 2002), departure for hunts, voyages or battle (Cummins 2002; Kurath et al. 2009), and for healing the sick and injured (Thwaites 1896–1901:43; 60; Wrong 1939). Archaeologists now anticipate the presence of dog burials (often attributed to ritual or social contexts) on Late Woodland sites because they are so ubiquitous (Smith 2000).

Great Lakes mythologies provide further insight into the ambiguous ideological role of dogs (i.e., wild versus tame) (Schwartz 1997). By occupying the liminal space between the forest and village, dogs were regarded as ideal mediators between the worlds of man and animals because they possessed both human and animal traits (Engelbrecht 2003; Cantwell 1980). For example, some mythologies describe dogs as having souls that pass into the afterlife (Schwartz 1997). For these reasons, among the Iroquois, dogs could be substituted for humans in ceremonial sacrifices (Russell 2012), and the dog sacrifices of both the Algonkian and Iroquoian peoples were always made to the "Great Spirit" (Obeholtzer 2002:9). Numerous sacred legends from the northeastern region include dogs, foxes and wolves (Brehm 2011; Bruchac 1995; Engelbrecht 2003; Kurath et al. 2009), and clan names and effigies provide further evidence of the symbolic significance

of canids in Great Lakes spiritualism (Dawson 1966; Ellis 2002; Lennox 2004; Mathews 1980; Parmalee and Stephens 1972; Parmenter 2010). For example there is the thieving (or resourceful) fox in Ho–chunk, Ojibwe and Anisinâbe legends (see for example the stories by Hágaga, Wâsāgunäckang and Johnston collected by Brehm 2011). Wolves are often described as the wild analogs of dogs and are fiercely loyal to humans as exemplified by stories of the Anisinâbe, Ojibwe and Winnebago (see for example Brehm 2011). The story of "How Graywolf Became Guardian of the World" (Smith 1997) is an illustration of the sacred place of wolves as the protagonist that is simultaneously wild and connected with humans: "*Gray wolf is free, and his call is always heard the world over, for he is the mightiest wolf of them all. He is the protector of the human race*" (Brehm 2011:364–5). Russell (2012) noted that the ideological value of wolves may account for their rarity in the archaeological record, as there are often taboos against killing them, except for symbolic purposes, or for self-protection or protection of food resources. Understanding the spiritual and practical roles of canids among Late Woodland people is critical for interpreting patterns of food access, hunting choice and discard practices (i.e., purposeful burial versus placement in middens).

Published faunal data demonstrate the limited role of foxes and gray wolves as hunted species (Foreman 2011; Lennox 1977; Stewart 1991; 2000). The majority of canid remains found at Ontario Iroquoian and Western Basin sites are *C. familiaris* (domestic dogs) or *Canis sp*., and the majority of *Canis sp*. remains are probably domestic dogs (Foreman, personal communication 2013). Foxes are more ubiquitous than wolves at Ontario Iroquoian sites but are relatively rare at Western Basin sites. No known wolves have been recorded in the Western Basin faunal assemblage data.

2.1.3 Dogs as proxies for human diet

Burleigh and Brothwell (1978) were the first to use isotopic analyses of domesticated dog remains as proxies for human diet. They noted an unexpected enrichment in carbon-13 in 3000 year old Peruvian dog hair and suggested the dogs had consumed large quantities of maize, positing that dogs, humans and other fauna could be used as supportive evidence of maize cultivation in the past. Since 1978, stable isotopic analyses of dogs have successfully provided evidence of: production of maize and other plant domesticates

(Allitt et al. 2008; Bentley et al 2005; 1978; Hogue 2003; 2006), trends in marine subsistence economy (Cannon et al. 1999; Clutton–Brock and Noe–Nygaard 1990; Fischer et al. 2007; Guiry and Graves 2013; Rick et al. 2011; Schulting and Richards 2002) and canid-human relations, e.g., ritual uses of dogs (Booth et al. 2011; White 2004a; White et al. 2001, 2004b). Guiry (2012:352) recently coined the term, *"canine surrogacy approach (CSA),"* by which he asserts that isotopic analyses of dogs can provide an analog for human subsistence practices that is either direct (e.g. dogs are "source" information regarding human diet) or indirect (e.g., dogs provide evidence of specific food procurement behaviour, such as maize cultivation). The assumptions underlying the belief that dogs can serve as proxies for human diet are: (1) dogs and humans are metabolically similar and incorporate isotopes in a similar manner, and (2) dogs would have accessed the same foods as their human companions either as scavengers of food waste or human faeces (coprophagy), or through purposeful feeding by humans (Alitt et al. 2008; Cannon et al. 1999; Guiry 2012; Katzenberg 1989: Tankerslay and Koster 2009). Intentional feeding of dogs may imply: (1) care and affection of a companion "pet", guardian and/or hunting partner, (2) fattening for use as food, or (3) preparation for specific ritual or ceremonial contexts, whether or not the dog was to be eaten (Olsen 2000; White et al. 2001). Currently there are no studies examining the metabolic comparability of human and dog isotopic fractionation and incorporation of isotopes into tissues so it is not possible to directly assess this assumption. The assumption that dogs have access to human food should be established for each archaeological context independently.

2.2 Materials and methods

2.2.1 Stable isotopes

As an organism interacts with its environment by drinking and eating, it incorporates the stable isotopic composition of ingested substances into its tissues. The stable isotopic compositions of animal tissues are expressed as δ–values in per mil (‰), using the formula (after McKinney et al. 1950:730):

$$\boldsymbol{\delta = (R_{sample}/R_{standard}) / R_{standard}} \textbf{ [Equation 2.1]}$$

where $R = {}^{13}C/{}^{12}C$, ${}^{15}N/{}^{14}N$ or ${}^{18}O/{}^{16}O$. Carbon isotopic compositions are standardized relative to Vienna PeeDee Belemnite (VPDB) (Coplen 1996; 2011). Nitrogen is standardized relative to AIR (Mariotti 1983). Oxygen is expressed ${}^{18}O/{}^{16}O$ ratio and is standardized to the Vienna Standard Mean Ocean Water (VSMOW) (Coplen 1996; 2011). An expanded description of stable carbon, nitrogen, and oxygen isotope analysis is proved in Chapter 1, Section 1.3.

2.2.2 Canid identification

Samples were selected from previously excavated faunal collections housed at various institutes from across southwestern Ontario (D.R. Poulton & Associates Inc.; Department of Anthropology, McMaster University; Department of Anthropology, The University of Western Ontario; Ontario Museum of Archaeology see Appendix A for site descriptions). Specimen identification was completed by the author, Dr. Lindsay Foreman and Dr. Lisa Hodgetts using the Zooarchaeology Reference Collection, Department of Anthropology, The University of Western Ontario. The comparative collection includes a modern adult male husky (~ 35kg) as well as an adult male red fox, an adult coyote, and an adult, male gray wolf. Morphology was the primary method for evaluating species identification but size was used as an additional means to support identification. Figure 2.3 illustrates the variation in morphology and size among domestic dogs, foxes and wolves.

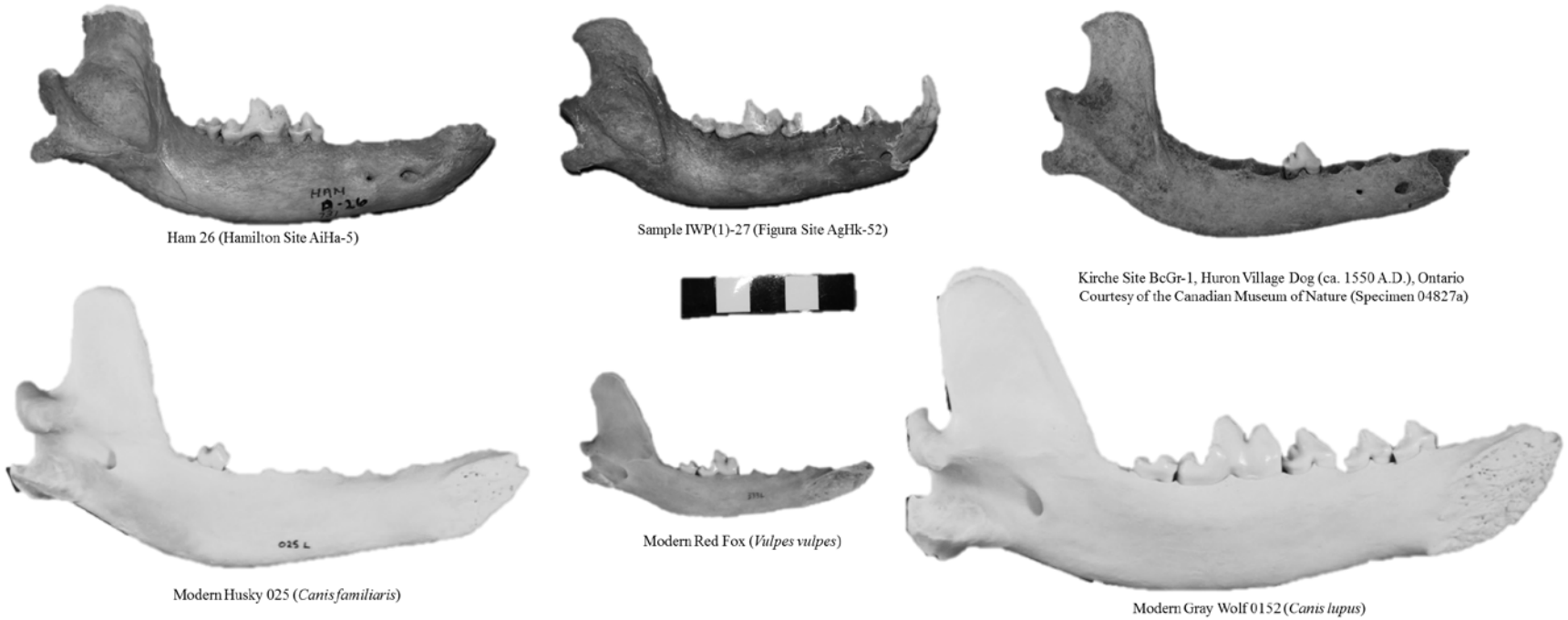


Figure 2.3: Comparison of dog mandibles used for canid identification.

Above: Archaeological samples including the largest canid mandible analysed in this study (Hamilton 26), and a typically–sized mandible (IWP(1)–27). The Kirche Site dog mandible[8] is from a contemporary Late Woodland site and is comparable in size to canids identified as *Canis familiaris*. Below: modern fox, husky and gray wolf used for comparative purposes[9].

[8] Image courtesy of the Canadian Museum of Nature.

[9] Images courtesy of the Department of Anthropology, The University of Western Ontario.

Due to the fragmentary nature of many of the remains examined and morphological similarities among different canid species, identification of species was made cautiously and conservatively. The archaeological record of the Late Woodland and preceding periods could include several canids: the domestic dog (*C. familiaris*), the gray wolf (*C. lupus*), the red fox (*V. vulpes*) and common gray fox (*U. cinereoargeneus*). Although the size of pre–contact, Ontario dogs appears to be slightly larger than that of full-sized, male foxes (Allen 1920; Cummins 2002; Richardson 1829), distinguishing large domesticated dogs from wolves can be particularly challenging (Morey 2010).

For this study, the category of domestic dog (*C. familiaris*) was reserved for well-preserved samples that usually had a mandible with teeth. The forty-four *C. familiaris* samples range in size from slightly larger than the modern, male red fox to approximately 2/3rd the size of the adult husky, which corresponds well with the predicted size range for both the "Common Indian Dog" described by Allen (1920) and the Neutral dog described by Prevec and Nobel (1983). All juvenile remains were categorized as *Canis sp.* due to problems of differentiating the various canid species (Coppinger and Coppinger 2001), with the exception of Pip(2)–028, an older juvenile, which was categorized as a *Canis sp.* (lg.). Table 2.1 summarizes the canid samples collected and analysed for this study.

Large *Canis sp*. was used to describe all remains larger or comparable in size to modern, adult male huskies ("*Canis sp.* (lg.) dog, hybrid or wolf"). The "Canid cf. sm. dog or fox" category was reserved for samples that were either small dogs or foxes and was usually comprised of long bone fragments. "Canid cf. fox" was used to designate foxes primarily identified by mandibles. Canid remains identified only as *Canis sp.* (no size designation) were comparable in size to the *C. familiaris*, but due to their fragmentary nature could not be definitively identified as to species. These canid remains were in almost all cases probably *C. familiaris.*

Seventy-four specimens were selected for isotopic analysis (Table 2.1). An additional three adult specimens analysed by Booth et al. (2011) from the Cleveland (n=2) and Holly (n=1) sites are included in the discussion. While the majority of the specimens analysed in this study represent fragmentary remains recovered from midden or pit

features, some may represent purposeful or ritual burials. Those special case burials (for example; complete burials or burials associated with pottery) are noted in the Appendices. Published archaeological dog data (Allitt et al. 2008; Conolly et al. 2014; Katzenberg 1989; Katzenberg 2006) and modern canid isotopic data (Fox-Dobbs et al. 2007; Lavin et al. 2003; Urton and Hobson 2007) are also used for comparison in the discussion (Table 2.7 A and B). Appendices B and D summarize the results and descriptions for all canids analysed in this study.

Table 2.1: Summary of canids sampled and analysed for this study.

	Pre–horticulture 3500 B.C. – A.D. 200 (sites n=3)	**Western Basin A.D. 900–1600 (sites, n=6)**	**Ontario Iroquoian A.D. 900–1600 (sites, n=14)**
***C. familiaris* (Domestic Dog)**	1	7	33
***Canis sp.*(dog or hybrid)**	0	6 juvenile	10 adult, 2 juvenile
***Canis sp. lg.* (Gray Wolf, Hybrid or lg. Dog)**	1	0	2 adult, 1 juvenile
Canid (sm. Dog or Fox)	0	0	4
Canid cf. fox (red or gray)	0	1	6
TOTAL	**2**	**8 (6 juveniles)**	**55 (3 juveniles)**

2.2.3 Bulk bone sampling

Samples were selected based on availability and varied by bone type (e.g. mandible, tibia), side (left or right), preservation state and size (complete or fragmentary). In the case of complete bones or large bone fragments, a piece of the bone (approximately 500mg) was removed using a handheld Dremel. All efforts to preserve the integrity of the remaining bone for future study were made. All bones were gently cleaned with a brush and distilled water and allowed to dry overnight at room temperature.

Trabecular bone was separated from the cortical bone using clean dental instruments. The remaining 300–500mg piece of cortical bone was crushed with a porcelain mortar and pestle and put through a set of sieves. Powdered bone was collected at three intervals: (1) 180 to 850 μm (for collagen analysis), 2) 63 to 180 μm (for carbonate analysis) and (3) 45 to 63 μm (for FTIR analysis).

2.2.4 Stable isotopic analysis

All isotopic analyses were conducted at the Laboratory for Stable Isotope Science, in the Department of Earth Sciences at The University of Western Ontario.

2.2.4.1 Collagen extraction protocol ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$)

Bone collagen analysis involved multiphase tissue preparation to remove lipids, inorganics and humics. The protocol used is a modification of Longin's (1971) collagen extraction method (Szpak et al. 2009). Crushed bone samples were weighed and placed in vials. A 2:1 chloroform:methanol solution was used to extract lipids (adapted from the method of Bligh and Dyer 1959; Kates 1986). The inorganic portion of the bone or tooth was removed by treating the samples with 0.50M HCl at room temperature. The slow demineralization of the bioapatite took several days. Bone samples were deemed demineralized when fragments felt gelatinous and formed pseudomorphs. Once the demineralized tissue was rinsed, humic acids and soil contaminants were removed using multiple 0.1M NaOH washes.

The extracted collagen was then made water–soluble by heating the samples in slightly acidic water in order to produce a collagen "gelatin" (Chisholm 1989:14). The water–soluble collagen was carefully transferred into clean vials and dried. The dried collagen was weighed to provide collagen yield. The extracted collagen was weighed (0.390 ± 0.01 mg) into 3.5 x 5.0 mm tin capsules, which were introduced into the Costech Elemental Combustion System (ECS 4010) coupled to the Delta V Plus Isotope Ratio Mass spectrometer for isotopic measurements.

The collagen provided $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values as well as the carbon and nitrogen content, which was used to calculate its C:N ratio. The $\delta^{13}C_{col}$ values were calibrated to Vienna Pee Dee Belemnite (VPDB) using the standards USGS-40 (accepted value, –26.39‰), and USGS-41(accepted value = +37.63 ‰). The $\delta^{15}N_{col}$ values were calibrated to AIR using USGS-40 and USGS-41 (accepted values = –4.52 ‰ and +47.57 ‰, respectively), following Coplen (1994) and Coplen et al. (2006). An internal laboratory standard, Keratin (#90211, MP Biomedicals), was analysed approximately every fifth sample to determine the accuracy and precision of the collagen analysis. Both were very good. The accepted keratin value for $\delta^{13}C_{col}$ is –24.04‰, which compares well with the mean $\delta^{13}C_{col}$ value of –24.07 ± 0.08‰ (n=72) obtained here; for $\delta^{15}N_{col}$ the accepted value for the keratin is 6.36‰, compared to the mean $\delta^{15}N_{col}$ value of 6.29 ± 0.17‰ (n=71) obtained here. Duplicates (i.e., replicate analyses of the same collagen extraction) and method duplicates (i.e., a different extraction and analysis of collagen on the same sample) were performed on ~10% of all samples. Method duplicates provided reproducibility values of ± 0.07‰ for $\delta^{13}C_{col}$ and ± 0.05‰ for $\delta^{15}N_{col}$. The analytical precision for $\delta^{13}C_{col}$ duplicates was ±0.03‰, and for $\delta^{15}N_{col}$ was ±0.05‰.

2.2.4.2 Carbonate extraction protocol ($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$)

It was necessary to first determine whether or not tissue samples from all the animals (i.e., including both mammals and birds) should be pre-treated to remove secondary carbonates and organic matter. In order to determine this, Pre-treated versus untreated data were compared for fifteen bone pairs (n=30), three antler pairs (n=6), and fifty-four enamel pairs from twelve individuals (n=108). Pre-treatment of the structural carbonate was necessary because some samples showed the presence of secondary carbonates.

Therefore all bone and enamel samples were pretreated using the protocols developed by Lee-Thorp (1989) to remove organic material and secondary carbonates. Successful removal of the secondary carbonates was confirmed by FTIR analysis.

The two-step process involved the removal of organic matter using an excess of 1% reagent grade sodium hypochlorite, reacted with the powdered tissue at room temperature for 72 hours with bone and 24 hours with enamel. Samples were then rinsed multiple times with Millipore water to remove the sodium hypochlorite solution. Next, samples were reacted with 0.1 M acetic acid for 4 hours at room temperature in order to remove diagenetic (secondary) carbonates. The samples were again washed multiple times with Millipore water and then freeze-dried overnight to remove the remaining moisture. The pretreated samples were weighed (approximately 0.8–1.0mg) into Multiprep sample vials and the isotopic composition of the structural carbonate was analysed using a Micromass Multiprep autosampler attached to a VG Optima dual–inlet IRMS, following Metcalfe et al. (2009).

The $\delta^{13}C_{sc}$ values were calibrated to Vienna Pee Dee Belemnite (VPDB), following Coplen (1994), using the NBS–19 standard (accepted value of 1.95 ‰) and Suprapur (accepted value of –35.28 ‰). The $\delta^{18}O$ values were calibrated to Vienna Standard Mean Ocean Water (VSMOW), following Coplen (1996), using NBS-19 and NBS-18 standards (accepted values of 28.60 ‰ and +7.20 ‰, respectively). An internal laboratory calcite standard, World Standard 1 (WS-1), was analysed approximately every fifteenth sample in order to assess the accuracy and precision of the carbonate analyses. The mean $\delta^{13}C_{sc}$ value of 0.80 ± 0.18‰ (n=33) and the mean $\delta^{18}O_{sc}$ value of 26.24 ± 0.17‰ (n=32) compared favourably to the accepted WS-1 values of 0.76‰ and 26.23‰, respectively. Carbonate pre-treatment duplicates and method duplicates were conducted ~10% of the canid samples with a mean reproducibility of ±0.09‰ for $\delta^{13}C_{sc}$ and ±0.17‰ for $\delta^{18}O_{sc}$. The analytical precision for $\delta^{13}C_{sc}$ was ± 0.06‰ and for $\delta^{18}O_{sc}$ was ± 0.10‰.

2.2.4.3 Fourier transform infra-red spectroscopy (FTIR)

Prior to pre-treatment, Fourier transform infra-red (FTIR) spectroscopy was conducted for all canid bone samples whose structural carbonate isotopic composition was to be

analysed. FTIR spectroscopy provided crystallinity indices (CI), carbonate/phosphate (C/P) ratio and a peak profile that was used to detect contaminants or recrystallization, (e.g., peaks at 1096cm^{-1} may indicate introduction of francolite, caused by a substitution in the hydroxyl sites by fluorine) (Nielsen-Marsh and Hedges 2000; Shemesh 1990; Weiner and Bar-Yosef 1990; Wright and Schwarcz 1996). A high CI may indicate isotopic alteration (Surovell and Steiner 2001; Weiner and Bar-Yosef 1998).

Crushed bone powder (~2mg) was mixed with 200mg potassium bromide and heated in a 90 °C oven for at least 24 hours. The powder was then formed into a disk under pressure and analysed using a Bruker Vector 22 Spectrometer. TheCI, C:P ratios, and peak profiles were provided for each sample by the FTIR analysis. The expected CI for archaeological bone may reach as high as 3.5 and 4.2 (Stuart-Williams et al. 1998; Weiner and Bar-Yosef 1990). Tooth enamel has a higher expected CI index than bone (Wright and Schwarcz 1996). The generally accepted C:P ratio range for unaltered bone is 0.3 to 0.6 (King et al. 2011; Nielsen-Marsh and Hedges 2000; Pucéat et al. 2004; Wright and Schwarcz 1996).

2.3 Results

2.3.1 Sample integrity

Post-mortem alteration of collagen was evaluated using collagen yield and carbon:nitrogen (C:N) ratios of the bone samples (Table 2.3). Fresh, modern bone contains approximately 22% collagen by weight (Van Klinken 1999), and samples yielding less than 1% are generally considered to be too degraded to give reliable results (Van Klinken1999; Ambrose 1993). The mean collagen yield was 12.1±6.1% (range 1.7 to 22.2%). Only one canid sample, Cra-10, was excluded because of low collagen yield (0.6%). All samples fell within the 2.9 to 3.6 range for C:N ratio recommended by DeNiro (1985) (mean = 3.3±0.1, range 2.6 to 3.6).

Post-mortem alteration of the inorganic portion of bone (bioapatite) was assessed using FTIR spectroscopy, percentage of bioapatite by weight and percentage of CO_3 (as CO_2) by weight (Table 2.3).

The FTIR analysis determined that the canid mean CI (2.74±0.16), and range (2.46 to 3.26) are comfortably below the accepted upper limit (Table 2.2), and so re-crystallization is not indicated for any samples. The mean C:P ratio for the canid bone samples was within the accepted range of 0.3 to 0.6 (0.53±0.33, range = 0.32 to 0.88) but some canids (n=20) had C/P ratios >0.6. These samples were not rejected, however, because their CI did not indicate re–crystallization and there is no evidence of contaminants or recrystallization in their FTIR peak profiles. Further, a C:P comparison between untreated and pretreated bone samples (n=26 canid sample pairs) showed that pre-treatment lowered the C:P ratio for over 92% of the canids, shifting the mean C:P to a mean of 0.33±0.08 and the range to 0.23 to 0.64 (Table 2.2). Finally, there were no significant correlations between the canid CI values or C:P ratios and $\delta^{13}C_{sc}$ values. No structural carbonate isotopic compositions were rejected based on the FTIR results because: (1) the CI indices were acceptable for all canid samples, (2) there were no unexpected peaks in the FTIR spectrum, and (3) pre-treatment lowered C:P ratios to within the expected range.

Table 2.2: Summary of FTIR Crystallinity Indices (CI) and Carbonate/Phosphate ratios (C/P) for canid bone samples before and after pre-treatment

Canids	n	mean±std dev (range)	
CI Before Pre-treatment	58	2.74	±0.16 (2.46 to 3.26)
CI After Pre-treatment	26	2.83	±0.16 (0.32 to 0.88)
C:P Before Pre-treatment	58	0.53	±0.17 (2.48 to 3.28)
C:P After Pre-treatment	26	0.33	±0.08 (0.23 to 0.64)

Fresh bone has an expected bioapatite [$Ca_{10}(PO_4)_6(OH)_2$]) yield by weight between 70 – 75% (Ambrose 1993; Sillen 1989) to 90% (Lee-Thorp 1989). After removal of the organic portion of the bone, the mean yield by weight for the canid bone was 72.3±7.6% (range 46.3 to 90.7%). For pretreated bone samples the percentage of CO_3 should range from 2.0 to 7.9% (Lee-Thorp 1989; Lee-Thorp and Sponheimer 2003; Wright and Schwarcz 1996) while enamel has a narrower range of 4.5 to 4.1% (Rink and Schwarcz 1995). The mean percentage of CO_3 for canid samples fell within this range with a mean of 5.99±1.22% (range = 2.50 to 7.90%). There were no significant correlations between $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values and percentage of inorganic content by weight or percentage of

CO_3 by weight. Therefore, no isotopic data for structural carbonate samples were rejected.

2.3.2 Adult canid remains isotope results

The isotopic data for adult and juvenile canids (all identified species together) are summarized in Table 2.4 and a more comprehensive table including site dates and references is presented in Appendices B and D. For the canids from pre A.D. 200 sites, the mean $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values were –21.32±0.76‰ and 9.35±1.37‰ respectively. The mean $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values were –10.21±2.85‰ and 21.39±1.83‰, respectively. The mean $\Delta^{13}C_{sc-col}$ value was +9.87±1.87‰.

The overall mean isotopic compositions for the Ontario Iroquoian canids by species are listed in Table 2.5 and visualized as box plots in Figure 2.4. The Ontario Iroquoian *C. familiaris* had a mean $\delta^{13}C_{col}$ value of –12.57±1.44‰ and a mean $^{\delta 15}N_{col}$ value of 9.46 ±0.74‰. They also had a mean $\delta^{13}C_{sc}$ value of –6.55 ±1.42‰ with a mean $\Delta^{13}C_{sc-col}$ value of +6.84±0.54‰, and the mean $\delta^{18}O_{sc}$ value was 21.08±1.18‰. For the Western Basin sites, the mean δ–values were –14.03±1.45‰ for $\delta^{13}C_{col}$, 10.25±0.76‰ for $\delta^{15}N_{col}$,–6.35±1.00‰ for $\delta^{13}C_{sc}$ and 21.23±1.02‰ for $\delta^{18}O_{sc}$ with a mean $\Delta^{13}C_{sc-col}$ value of +7.48±3.89‰.

Nine Ontario Iroquoian specimens could not be identified beyond Canis sp., though most likely represent *C. familiaris* based on size. Their mean $\delta^{13}C_{col}$ value was –12.04±1.79‰ and the mean $\delta^{15}N_{col}$ value was 9.50±0.56‰. The Canis sp. (n=8) had a mean $\delta^{13}C_{sc}$ of –5.37±1.68‰ and a mean $\delta^{18}O_{sc}$ of 21.29±1.17‰. Six Ontario Iroquoian canids identified as foxes had mean values of –18.81±0.66‰ for $\delta^{13}C_{col}$ and 8.81 ±0.90‰ for $\delta^{15}N_{col}$. Their mean δ–values were –10.20±1.89‰ for $\delta^{13}C_{sc}$ and 20.90±1.20‰ for $\delta^{18}O_{sc}$. The single Western Basin fox had $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of –19.34‰ and 8.74‰, and $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values of –10.37‰ and 20.61‰, respectively. Its $\Delta^{13}C_{sc-col}$ was +8.92‰.

Table 2.3: Summary of sample integrity checks for collagen (C:N ratio and collagen yield) and structural carbonate (bioapatite yield by weight and percentage of CO_3 by weight).

	n_{col}	C:N Ratio (Range)	% Collagen by Weight (Range)	n_{sc}	% Bioapatite by Weight (Range)	% CO_3 by Weight (Range)
Pre A.D. 200, Adults (3 sites)	2	3.03±0.47 (2.59–3.53)	4.1±3.3 (1.7 –6.5)	3	86.5±3.4 (82.6–88.8)	5.64±2.27 (2.50–7.65)
Western Basin Sites, Adults (2 sites)	10	3.34±0.13 (3.19–3.52)	5.6±2.9 (2.2–10.1)	7	78.6±012.6) (61.6±90.7)	5.60±1.44 (3.70–7.62)
Western Basin Sites, Juveniles (4 sites)	6	3.22±0.09 (3.06–3.30)	9.0±3.0 (6.8–11.1)	1	N/A	N/A
Ontario Iroquoian Sites, Adults (2 sites)	55	3.30±0.09 (3.05–3.58)	13.0±6.1 (1.9–22.2)	46	70.7±6.3 (46.3–79.4)	6.05±1.12 (2.71–7.90)
Ontario Iroquoian Sites, Juveniles (13 sites)	3	3.41±0.08 (3.34–3.50)	14.3±2.7 (11.2–16.5)	3	73.9±2.9 (70.7–76.3)	6.37±0.81 (5.47–7.04)

Table 2.4: Summary of collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$) and structural carbonate ($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$) results for all canids.

	n_{col}	$\delta^{13}C_{col}$ (‰, VPDB) (Range)	$\delta^{15}N_{col}$ (‰, AIR) (Range)	n_{sc}	$\delta^{13}C_{sc}$ (‰, VPDB) (Range)	$\delta^{18}O_{sc}$ (‰, VSMOW) (Range)	$\Delta^{13}C_{sc-col}$ (Range)
Pre A.D. 200 Adults	3	–21.32±0.76 (–21.86 to –20.78)	9.35±1.37 (8.38 to 10.31)	4	–10.21±2.35 (–13.31 to –7.72)	20.87±1.96 (18.42 to 22.57)	10.31±1.54 (8.55 to 11.43)
Western Basin Adults	9	–14.56±2.2.17 (–19.34 to –12.00)	10.10±086 (8.74 to 11. 41)	6	–6.92±1.77 (–1037 to –4.98)	21.14±0.96 (19.54 to 22.30)	7.48±3.89 (4.73 to 10.23)
Western Basin Juveniles	6	–14.85±2.69 (–18.54 to –11.12)	11.54±1.67 (8.94 to 13.99)	1	3.47	20.41	7.65
Ontario Iroquoian Adults	55	–13.74±3.19 (–22.13 to –9.30)	9.28±0.92 (5.39 to 11.34)	46	–7.27±2.74 (–15.79 to –3.19)	21.13±1.14 (18.52 to 23.81)	6.56±1.42 (4.11 to 11.18)
Ontario Iroquoian Juveniles	3	–17.00±5.97 (–21.60 to –10.26)	8.08±1.80 (6.04 to 9.46)	3	–9.16±3.93 (–11.48 to –4.63)	21.60±1.34 (20.14 to 22.77)	7.84±2.30 (5.63 to 10.22)

Table 2.5: Summary of collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$) and structural carbonate ($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$) results for adult remains by species.

	n_{col}	$\delta^{13}C_{col}$ (‰, VPDB) (Range)	$\delta^{15}N_{col}$ (‰, AIR) (Range)	n_{sc}	$\delta^{13}C_{sc}$ (‰, VPDB) (Range)	$\delta^{18}O_{sc}$ (‰, VSMOW) (Range)	$\Delta^{13}C_{sc-col}$ (Range)
Western Basin Sites, Adults cf. *C. familiaris*	9	–14.03±1.45 (–16.29 to –12.00)	10.25±0.76 (8.99 to 11.41)	6	–6.35±1.00 (–7.54 to –4.98)	21.23±1.02 (19.54 to 22.30)	7.48±3.89 (4.73 to 10.23)
Western Basin Sites, Adults Canid cf. fox	1	–19.34	8.74	1	–10.37	20.61	8.97
Ontario Iroquoian Sites, Adults, cf. *C. familiaris*	33	–12.57±1.44 (–15.82 to –9.30)	9.46±0.74 (7.87 to 11.34)	27	–6.55±1.42 (–9.32 to –4.42)	21.08±1.18 (18.52 to 23.40)	6.84±0.54 (6.41 to 7.45)
Ontario Iroquoian Sites, Adults, *Canis sp.*	9	–12.04±1.79 (–14.78 to –10.14)	9.50±0.56 (8.13 to 9.98)	8	–5.37±1.68 (–7.49 to – 3.19)	21.29±1.17 (19.81 to 23.81)	6.89±0.81 (6.32 to 7.46)
Ontario Iroquoian Sites, Adults, Canid cf. fox	6	–18.81±0.67 (–19.67 to –17.95)	8.81±0.90 (7.57 to 10.30)	6	10.26±1.82 (–13.03 to –8.58)	20.91±1.18 (19.39 to 22.39)	7.98±1.62 (5.74 to 9.58)
Ontario Iroquoian Sites, Adults, Sm. Canid	4	–15.84±5.29 (–21.22 to –11.19)	9.15±0.95 (7.88 to 10.14)	4	–9.79±5.47 (–15.79 to –4.69)	20.81±0.75 (19.85 to 21.50)	6.04±0.53 (5.43 to 6.50)
Ontario Iroquoian Sites, Adults, *Canis sp.* lg.	2	–21.38±1.06 (–22.13 to –20.63)	7.13±2.16 (5.39 to 8.87)	2	–12.15±1.70 (–13.35 to –10.95)	22.28±1.24 (21.40 to 23.15)	9.23±2.76 (7.28 to 11.18)

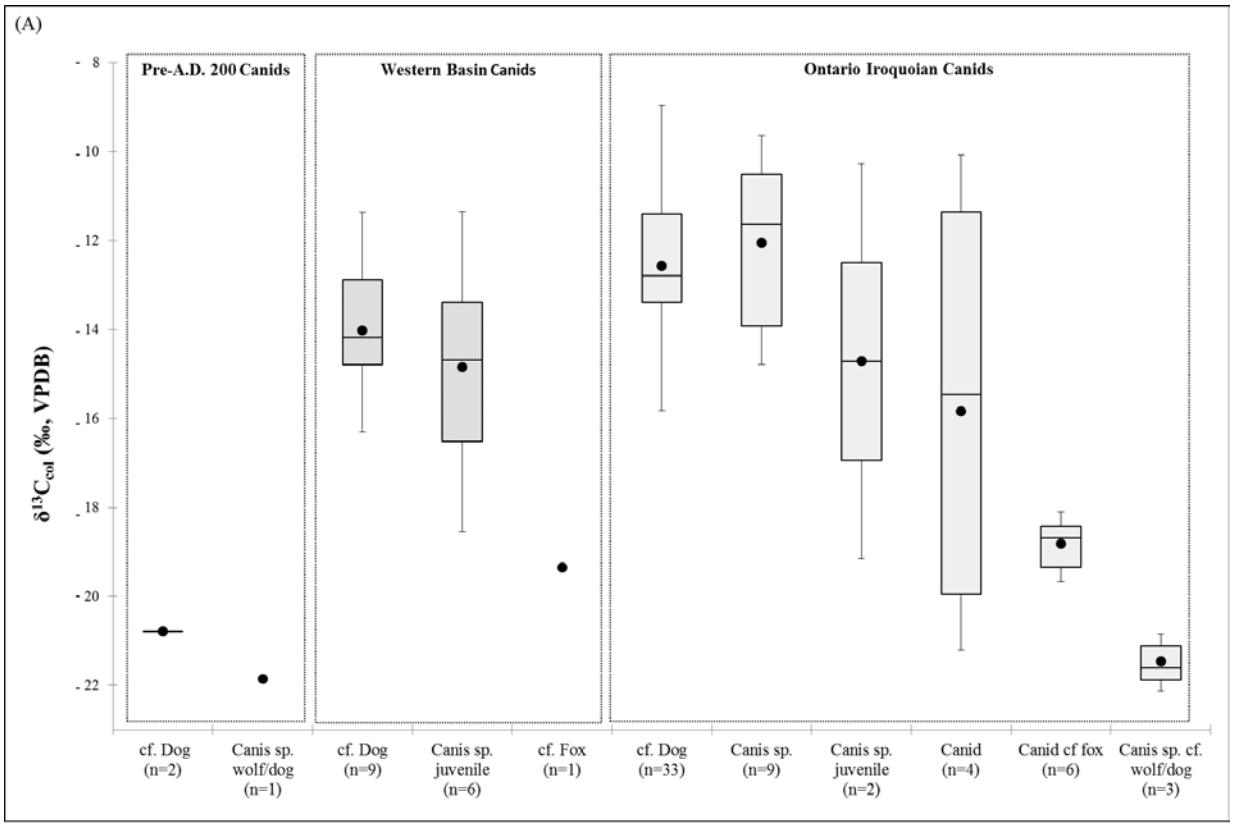
An additional four Ontario Iroquoian canids could not be differentiated as either fox or small dog and had mean values of –15.84 ±5.29‰ for $\delta^{13}C_{col}$ and 9.13±0.90‰ for $\delta^{15}N_{col}$. The four small canids had mean $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values of –9.79±5.47‰ and 20.81±0.75‰.

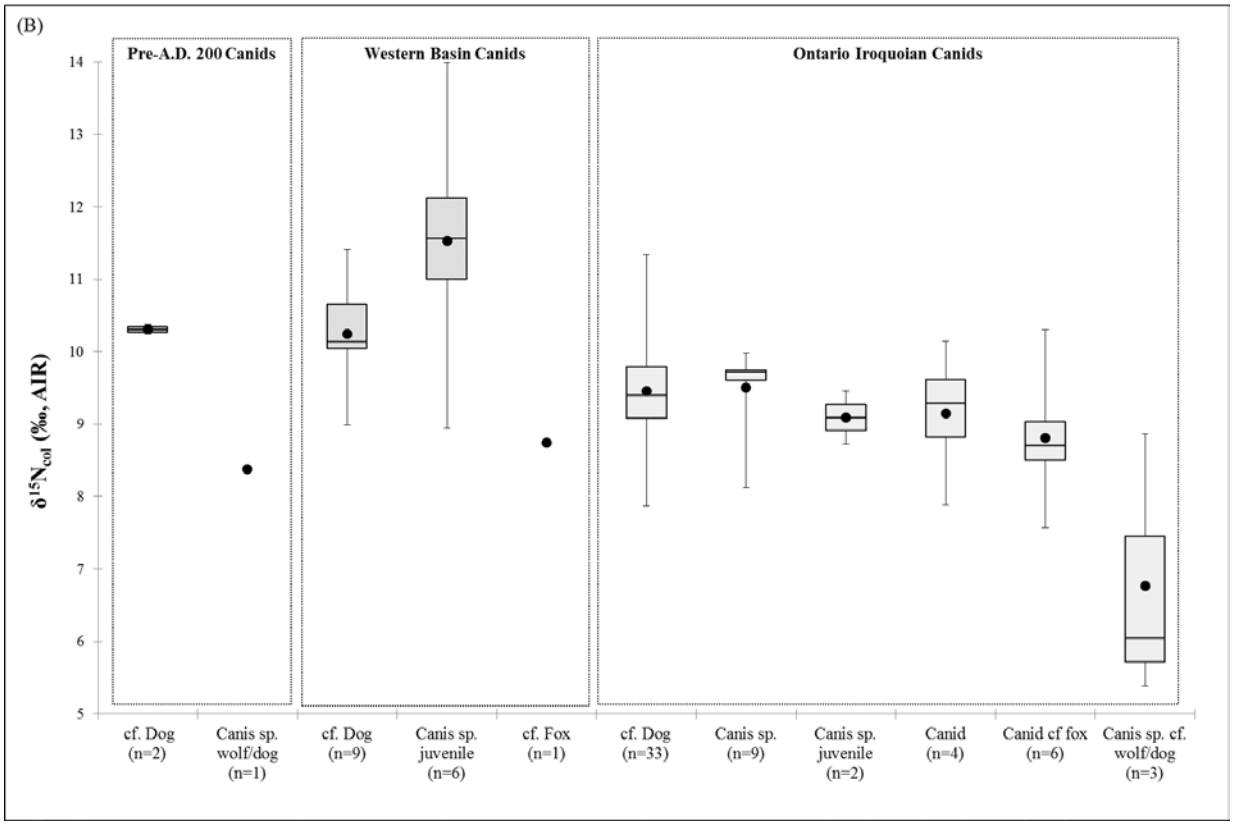
Two fragments from a large *Canis sp*. (large dog, dog–wolf hybrid or wolf based on size) dated to the Late Woodland had $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of –21.38±1.06‰ and 7.13±2.46, and $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values of –12.15±1.70‰ and 22.28±1.24‰.

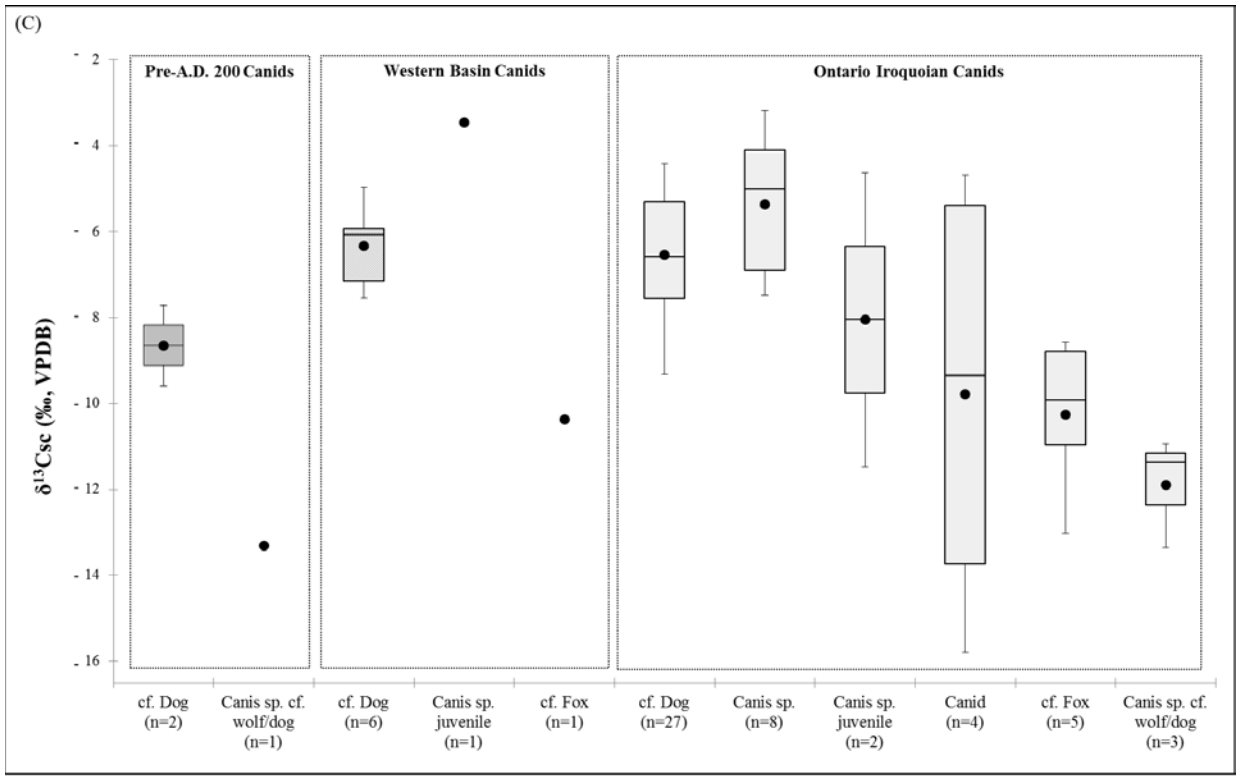
For all the samples there was a significant correlation between $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values (Pearson's r = 0.308, p=0.007) and $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values (Pearson's r = 0.897, p<0.000). Based on a one–way ANOVA, there are significant differences between the cultural groups. A Dunnett T3 reveals that the pre-200 A.D. canid remains have significantly lower $\delta^{13}C_{col}$ values compared to canids from the Late Woodland (A.D. 900 to 1650), Western Basin (p<0.000) and Ontario Iroquoian (p<0.000). The test also demonstrated that the Western Basin adult canids had significantly higher $\delta^{15}N_{col}$ values (Dunnett T3, p=0.003) relative to the adult Ontario Iroquoian canids.

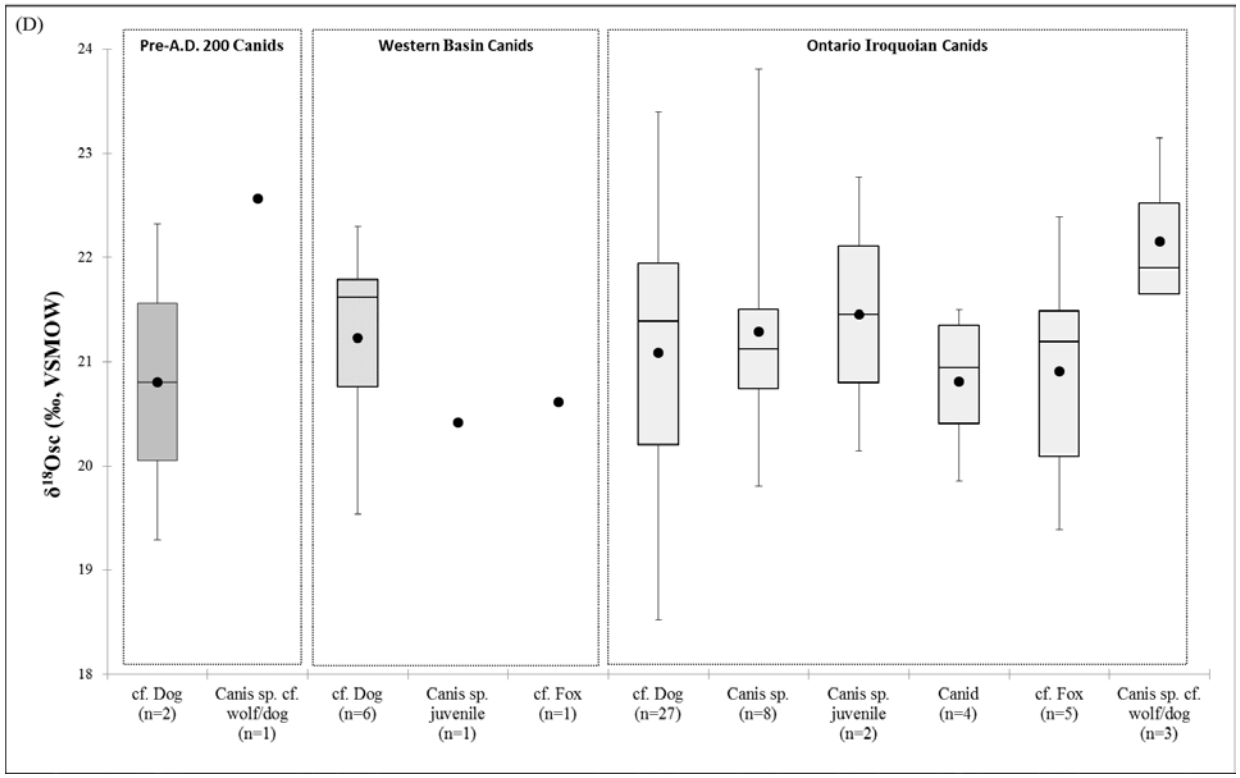
2.3.3 Juvenile canid remains isotope results

Mean $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for the three Ontario Iroquoian juvenile Canis sp. samples were –17.00 ±5.97‰ and 8.08±1.80‰. The mean $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ for the three Ontario Iroquoian juvenile Canis sp. samples was –9.16±3.92‰ and 21.60±1.34‰ (Table 9). Western Basin juvenile canids (n=6) had a mean $\delta^{13}C_{col}$ value of –14.85±2.69‰ and a mean $\delta^{15}N_{col}$ value of 11.54 ±1.67‰. Structural carbonate was examined for only one juvenile (fetal) Canis sp., which had $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values of –3.47‰ and 20.41‰, respectively. The mean $\Delta^{13}C_{sc–col}$ for the Ontario Iroquoian juvenile canids was +7.84±2.30‰ and for the single Western Basin juvenile it was +7.65‰.


(A)
Pre-A.D. 200 Canids
Western Basin Canids
Ontario Iroquoian Canids
δ13Ccol (‰, VPDB)
- 8
- 10
- 12
- 14
- 16
- 18
- 20
- 22
cf. Dog (n=2)
Canis sp. wolf/dog (n=1)
cf. Dog (n=9)
Canis sp. juvenile (n=6)
cf. Fox (n=1)
cf. Dog (n=33)
Canis sp. (n=9)
Canis sp. juvenile (n=2)
Canid (n=4)
Canid cf fox (n=6)
Canis sp. cf. wolf/dog (n=3)


(B)
Pre-A.D. 200 Canids
Western Basin Canids
Ontario Iroquoian Canids
δ15Ncol (‰, AIR)
14
13
12
11
10
9
8
7
6
5
cf. Dog (n=2)
Canis sp. wolf/dog (n=1)
cf. Dog (n=9)
Canis sp. juvenile (n=6)
cf. Fox (n=1)
cf. Dog (n=33)
Canis sp. (n=9)
Canis sp. juvenile (n=2)
Canid (n=4)
Canid cf fox (n=6)
Canis sp. cf. wolf/dog (n=3)


(C)
Pre-A.D. 200 Canids
Western Basin Canids
Ontario Iroquoian Canids
δ13Csc (‰, VPDB)
2
-4
-6
-8
-10
-12
-14
-16
cf. Dog (n=2)
Canis sp. cf. wolf/dog (n=1)
cf. Dog (n=6)
Canis sp. juvenile (n=1)
cf. Fox (n=1)
cf. Dog (n=27)
Canis sp. (n=8)
Canis sp. juvenile (n=2)
Canid (n=4)
cf. Fox (n=5)
Canis sp. cf. wolf/dog (n=3)


(D)
Pre-A.D. 200 Canids
Western Basin Canids
Ontario Iroquoian Canids
δ18Osc (‰, VSMOW)
24
23
22
21
20
19
18
cf. Dog (n=2)
Canis sp. cf. wolf/dog (n=1)
cf. Dog (n=6)
Canis sp. juvenile (n=1)
cf. Fox (n=1)
cf. Dog (n=27)
Canis sp. (n=8)
Canis sp. juvenile (n=2)
Canid (n=4)
cf. Fox (n=5)
Canis sp. cf. wolf/dog (n=3)

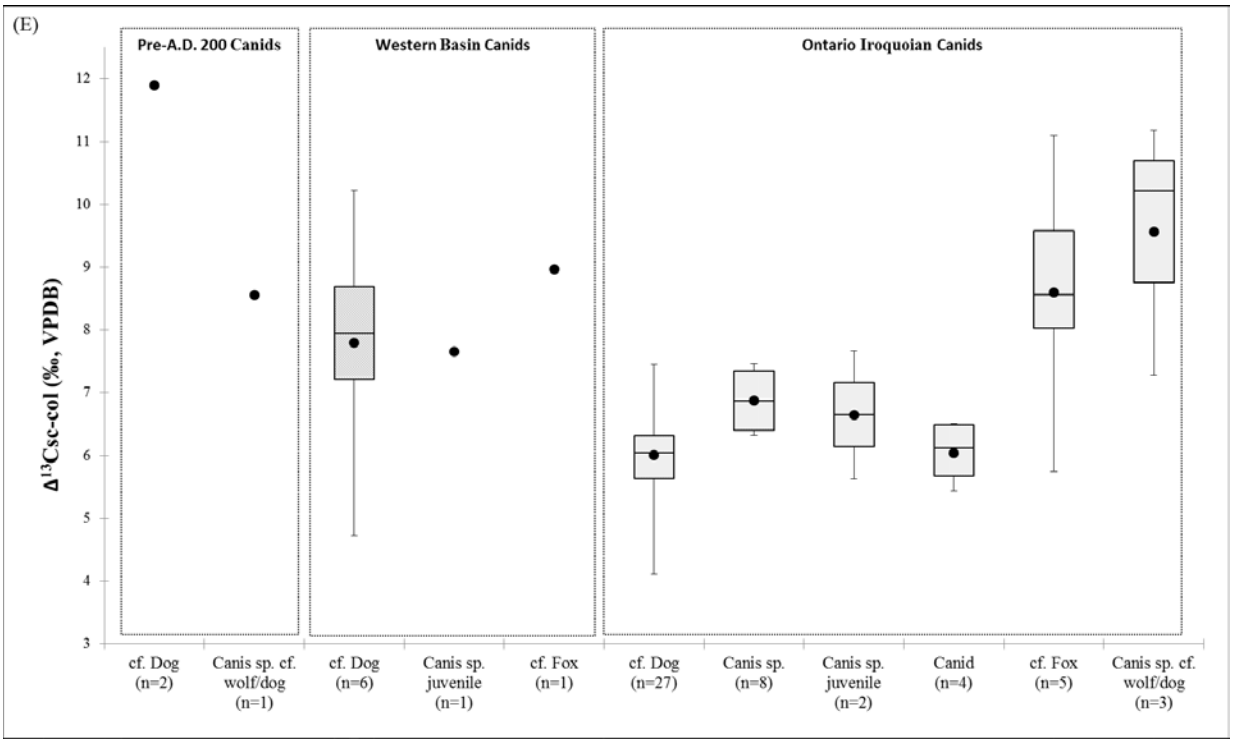


Figure 2.4: Box plot summaries of the stable-isotopic composition of the canids. Box plots (A) $\delta^{13}C_{col}$ values, (B) $\delta^{15}N_{col}$ values, (C) $\delta^{13}C_{sc}$ values,(D) $\delta^{18}O_{sc}$ values and (E) $\Delta^{13}C_{sc-col}$ values.

Table 2.6: Stable isotopic ranges for the distinct canid categories

	$\delta^{13}C_{col}$ (‰, VPDB) range	$\delta^{15}N_{col}$ (‰, AIR) range	$\Delta^{13}C_{sc-col}$
Category A: Domestic Dogs	–16 to –9	8 to 11	+6.4±1.1
Category B: Foxes	–20 to –17	8 to 10.5	+8.0±2.0
Category C: Lg. feral dogs/Wolves	–23 to –20	6 to 10	+9.3±1.7

2.4 Discussion

This discussion is divided into several parts. First, the isotopic data for all adult canids are compared with those from two modern dietary behavioural studies (Figure 2.7) (Urton and Hobson 2006; Lavin et al. 2003) in order to describe and differentiate ecological niches. Second, juvenile remains are examined separately. Third, the isotopic data for adult domesticated dogs are compared to previously published isotopic data for humans in order to determine whether the use of domestic dogs as proxies for human subsistence practices is appropriate for this region. Finally, human–dog relationships are compared with subsistence practices of Late Woodland Western Basin and Ontario Iroquoian peoples within southwestern Ontario.

2.4.1 Identifying canid ecological niches

The variability in collagen isotopic compositions ($\delta^{13}C_{col}$ and $\delta^{15}N_{col}$) of Late Woodland Ontario canids suggests a wide range of dietary strategies (Table 2.5). Ontario mammals with $\delta^{13}C_{col}$ values greater than –210‰ consumed some C_4 foods, while those with values lower than –21‰ have diets consistent with a pure C_3 food web (Katzenberg 2006; Morris *unpublished data, this study*). Osteological and collagen isotope data were used to identify three categories of canids, each of which occupies a distinct ecological and/or dietary niche (Table 2.6, Figure 2.5). Domesticated dogs have the greatest access to maize, followed by foxes, and then feral canids who consumed little or no C_4 foods. The $\delta^{13}C_{sc}$ values (Figure 2.6) provided an additional means of indicating access to C_4 foods and trophic position. There is a significant difference in $\Delta^{13}C_{sc–col}$ values (Figure 2.4 (E), Table 2.6) between domestic dogs (Category A) and both foxes (Category B) and feral dogs/wolves (Category C) (Tukey HSD, $p>0.000$ and 0.006, respectively), which indicates that domestic dogs were also more carnivorous.

2.4.1.1 Category A – domestic dogs

All the canids within Category A are definitively identified as domestic dogs (*C. familiaris*) based on their morphology and isotopic compositions. These dogs are the most isotopically distinct canids analysed for this study. Significantly enriched in ^{13}C

(Tukey HSD, p>0.000), they are all maize consumers. The species identification of domestic dog does not presume that all dogs were "pets" or actively *kept*. Some may have been *strays* who were tolerated in or near villages. Modern wild canids have relatively low $\delta^{15}N_{col}$ values (7.06±2.34‰) (Fox-Dobbs et al. 2007; Schwarcz et al. 1991; Urton and Hobson 2007) compared to the archaeological dogs analysed in this study who, like archaeological dogs in previous studies (9.57±0.78‰) (Katzenberg 1989: 2006), consumed protein from a higher trophic level, such as freshwater fish. Such high trophic level foods would only have been available if they were procured by humans. Wild canids, such as foxes and wolves, rarely have access to freshwater fish in spite of being flexible predators that consume hunted prey and carrion (Paradiso and Nowak 1982; Samuel and Nelson 1982; Voigt 1987). Modern Ontario wolves do consume a terrestrial meat-based diet but it is from a lower trophic level, i.e., up to 80% white-tailed deer (Pimlott et al. 1967:71), and foxes are more flexible consumers who eat small prey and foods like berries and insects (Samuel and Nelson 1982; Voigt 1987).

The $\delta^{13}C_{sc}$ values support the interpretation of significant maize consumption by some Late Woodland dogs. Comparing the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values also enables the separation of dogs into two groups (Figure 2.6). Most of one group (Ai.) pre-date A.D. 1450 (hereafter referred to as Middle Ontario Iroquoian stage) and have significantly higher $\delta^{13}C_{sc}$ (–6 to –3‰) and $\delta^{13}C_{col}$ values (> –12‰). Most of the second group (Aii.) post-date A.D. 1450 (hereafter referred to as Neutral) and have significantly lower $\delta^{13}C_{sc}$ (–9 to –5‰) and $\delta^{13}C_{col}$ values (–16 to –12‰) (Tukey HSD, p>0.000). The isotopic compositions of the Middle Ontario Iroquoian dogs correspond to those of their contemporary humans, who have been interpreted as heavy maize-consumers (Harrison and Katzenberg 2003; Katzenberg et al. 1985). The predominately Neutral group of canids, however, has slightly lower $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values than humans, which suggests less maize (C_4) consumption. (A more detailed exploration of the anthropological meaning of the dog data is provided below).

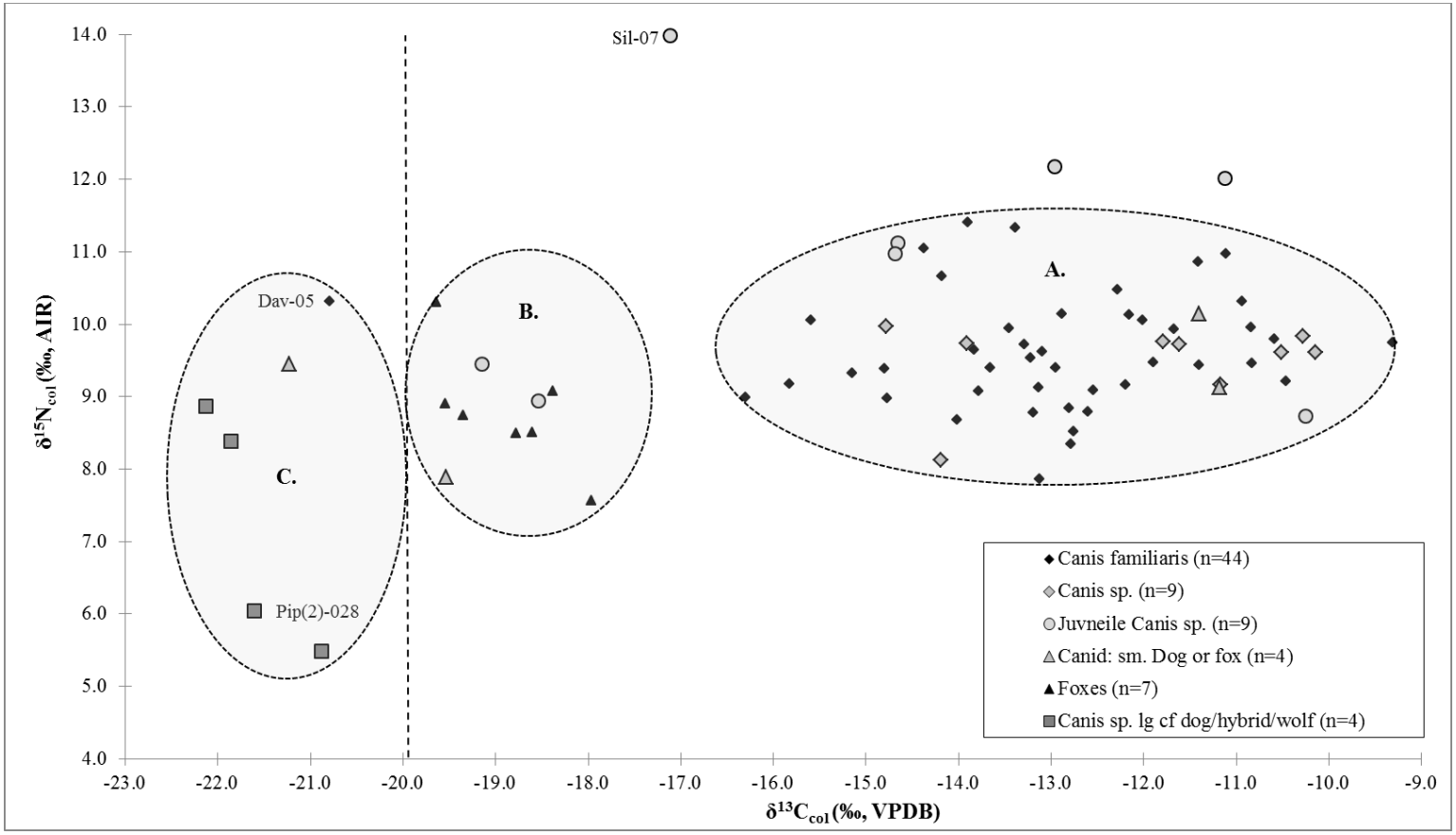


Figure 2.5: $\delta^{15}N_{col}$ versus $\delta^{13}C_{col}$ values for all canids. Distinct canid ecological/dietary categories are circled. Category A = dogs/kept canids, B =foxes living near human settlement/horticultural zones, and Category C= canids living in a C_3-only food web. The latter includes pre–horticulture dogs, a fox, and four probable wolves/large dog hybrids. The dashed line at $\delta^{13}C_{col}$ –20‰ demarcates specimens believed to have a C_4 component in their diet versus those in a C_3-only food web.

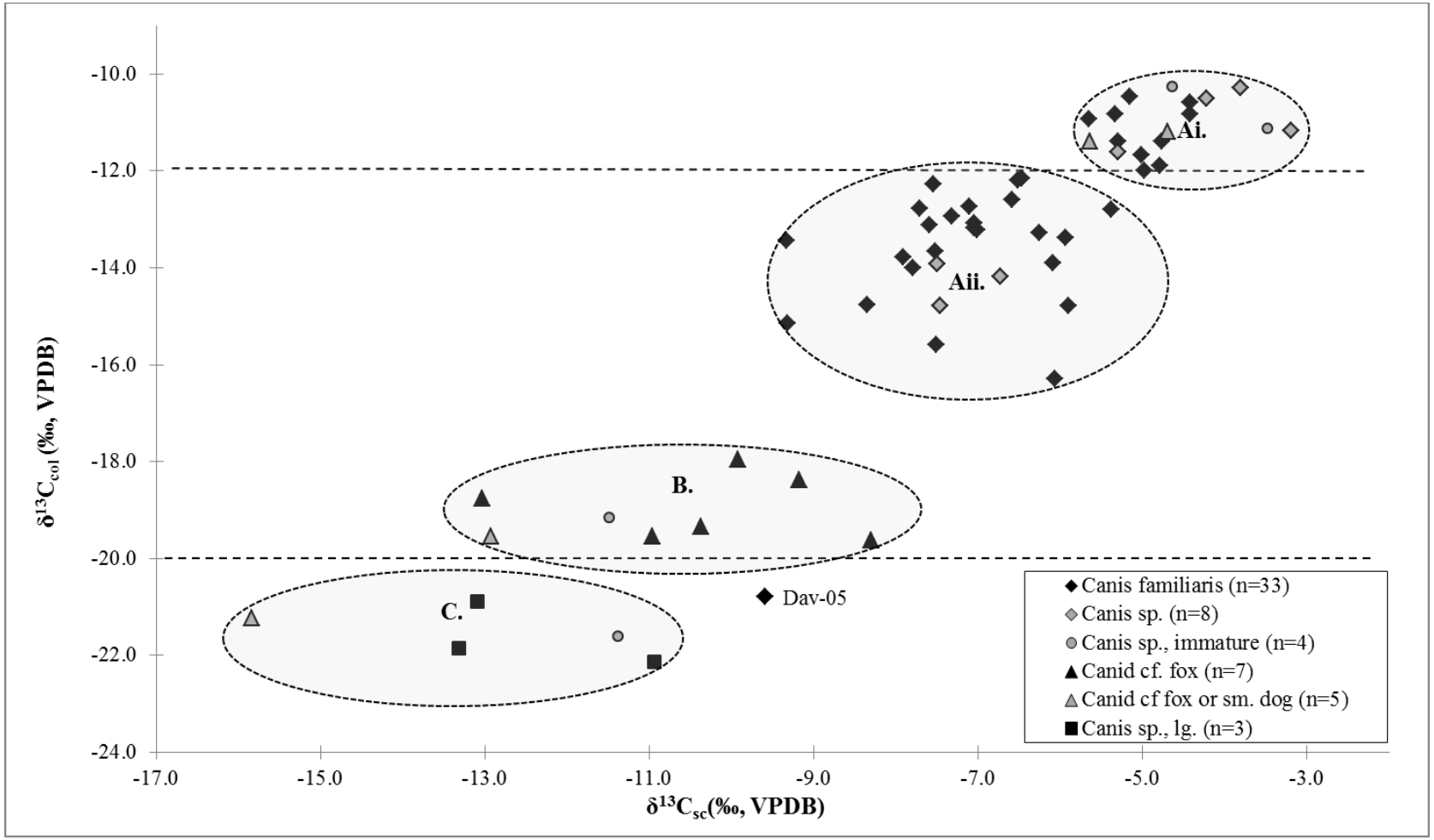


Figure 2.6: $\delta^{13}C_{col}$ versus $\delta^{13}C_{sc}$ values for all canids. Category B and C are still distinct. Category A is further subdivided into dogs with more (Ai) and less (Aii) consistent access to maize products following Harrison and Katzenberg 2003:238, Figure 8.

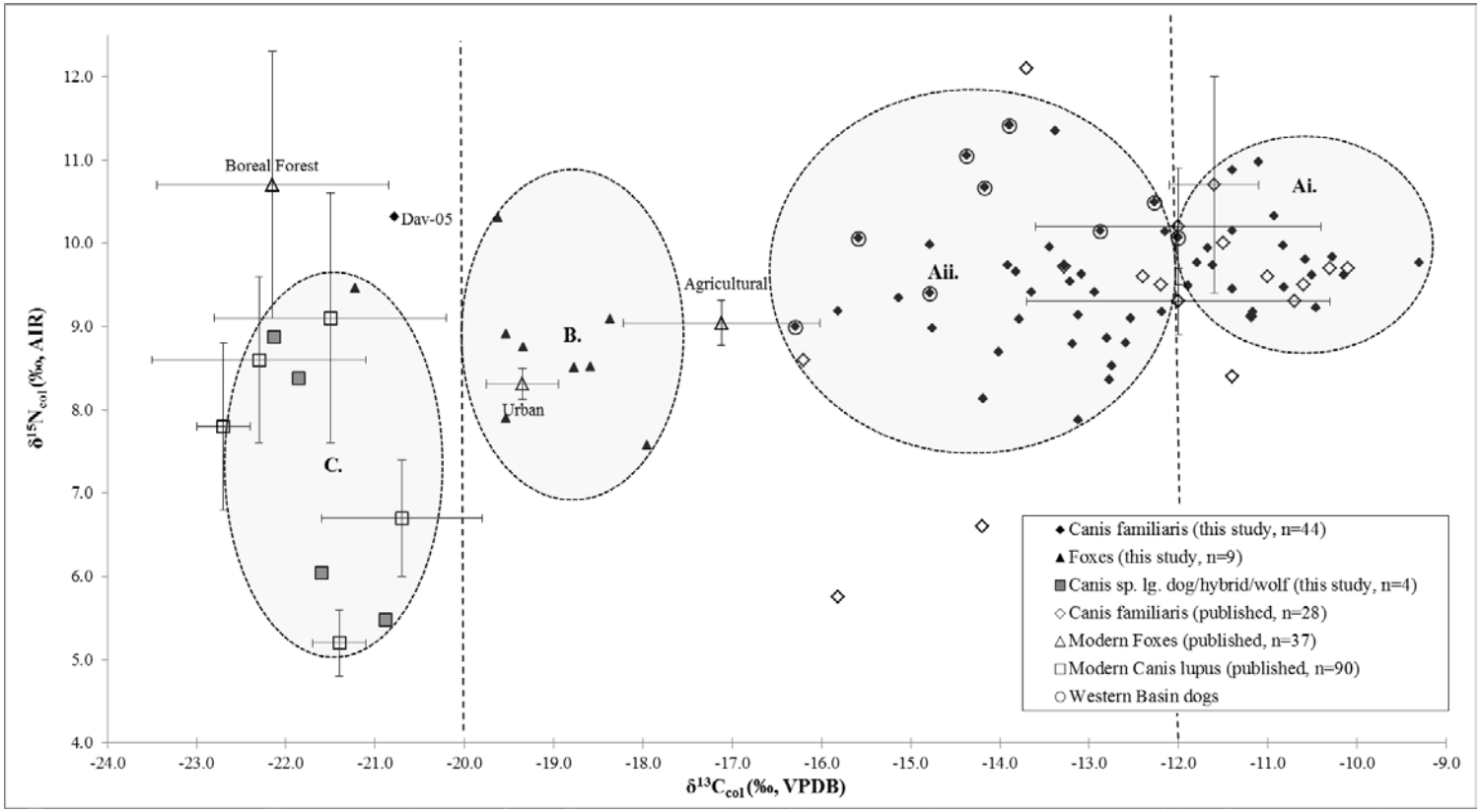


Figure 2.7: $\delta^{15}N_{col}$ versus $\delta^{13}C_{col}$ values for all canids, plotted with published archaeological (dogs) and modern (foxes and wolves) data.[10] Circled black diamonds = Western Basin dogs. Plain black diamonds = Ontario Iroquoian dogs. Ai and Aii categories based on $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values (Figure 2.6) are also shown.

[10] Archaeological dogs: Katzenberg 1989; 2006. Modern canids: Fox-Dobbs et al. 2007; Schwarcz et al. 1991; Urton and Hobson 2007

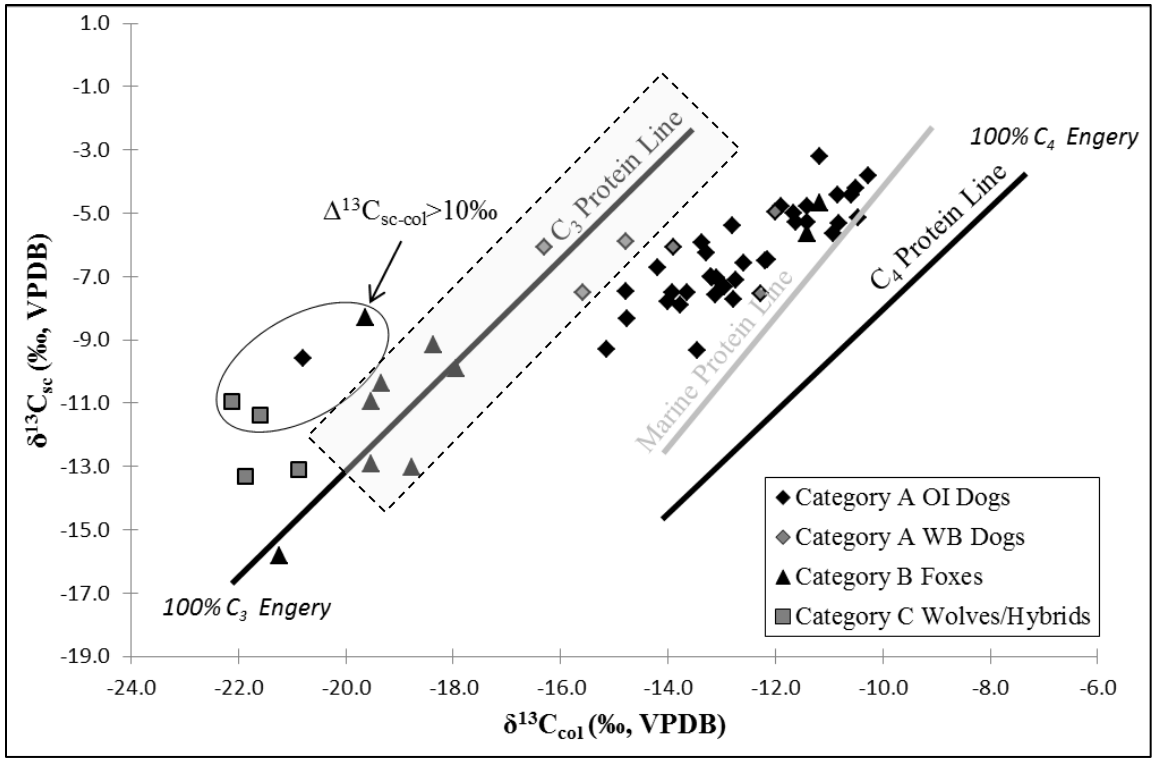


Figure 2.8: The relationship between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values for Category A, B, and C canids.

The data are plotted according to the protein-line[11] model developed by Kellner and Schoeninger (2007, Figure 2B). A diet comprised primarly of C_3 protein with some C_4 energy resources is enclosed in the gray square. $\Delta^{13}C_{sc-col}$ values > +10‰ are circled.

[11] The protein-lines used in this study were developed by Kellner and Schoeninger (2007) as models for the relationship between protein and energy (i.e., carbohydrate and lipid) dietary sources based on experimental dietary data. Animals which fall on or near the C_3 protein line have a diet primarily consisting of C_3 protein but may have some energy sources that vary in C_3 and/or C_4 compositions depending on where they plot on or near the C_3 protein line.

2.4.1.2 Category B – foxes

Category B canid remains were identified as either foxes (n=7) or probable foxes (n=1) because of the considerable uniformity in size, morphology and isotopic compositions. Although they could have been either red or gray foxes (*V. vulpes* or *U. cineroargenteus*), they occupied an ecological niche near human settlement. Their $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values do not suggest the same access of C_4 resources as the domestic dogs, but they are still enriched in ^{13}C. As flexible consumers foxes eat a range of prey, scavenged food and plants (Voigt 1987). Modern fox diets mainly consist of meadow voles and other small rodents, along with rabbits, woodchucks, ducks, fruit, insects, carrion and human garbage (Samuel and Nelson 1982; Voigt 1987). The prey of archaeological foxes may reflect C_4 consumption, including human waste as well as maize-consuming prey, e.g., gray/black squirrels (*Sciurus carolinensis*) and wild turkeys (*Meleagris gallopavo silvestris*) (Katzenberg 1989; 2006; Morris *unpublished data this study*), which could explain the isotopic composition of the archaeological fox collagen. For example, predators consuming large quantities of Late Woodland Ontario squirrel or turkey (Katzenberg 1989; 2006; Morris *unpublished data this study*) would have a predicted $\delta^{13}C_{col}$ values of ~–19 to –17‰ and $\delta^{15}N_{col}$ values of ~7 to 9‰, which correspond well with the results for the foxes in this study (Figure 1.1 and Figure 2.5).

Published stable isotopic data from two modern dietary behavioural studies, which include foxes, are plotted with the archaeological data in Figure 2.7. The modern fox studies provide stable isotope profiles for three ecological niches: (1) a fox population from the Boreal forest (Urton and Hobson 2006), (2) a rural environment with agricultural access, and (3) an agricultural (maize and soybeans) farm (Lavin et al. 2003). The isotope data from this study closely correspond to Lavin et al.'s (2003) $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for foxes that exploited agricultural and rural environments, and ate obligate herbivores (i.e., rabbits, groundhogs) and higher trophic herbivores/omnivores (i.e., squirrels, birds) (Lavin et al. 2003: 1077: Figure 8). The $\delta^{15}N_{col}$ values of the foxes are significantly lower than those of domestic dogs. The difference suggests that the foxes are consuming different animal resources. Plotting the canid data onto previously established protein-source lines (after Kellner and Schoeninger 2007: Figure 2.8), certain

patterns emerge. All the wild canids (Category B, as well category C discussed in the proceeding section) fall on or above the C_3 protein line, which suggests heavy consumption of C_3–protein. There is a continuum of maize field niche exploitation by Late Woodland foxes that trends along the lower half of the C_3 protein line and is distinct from all other wild and domestic canids. The $\delta^{13}C_{sc}$ values of foxes ranging between –12 and –9‰ are consistent with those of swine experimentally fed 13–20% (by weight) protein comprised of 20% C_4, and a non-protein portion between 23% and 50% C_4 (Warinner and Tuross 2009). A diet that consisted of wild foods with some C_4–consuming game (i.e. squirrel) and/or occasional maize would adequately explain the majority of fox diets. Three additional foxes had diets with $\delta^{13}C_{sc}$ values lower than –13‰, which are more consistent with a diet comprised of ~100% C_3 protein and 75 to 100% C_3 non–protein (i.e. diets that were almost exclusively C_3–based); two of these foxes may have occasionally consumed maize or maize–consuming prey, while the third falls in Category C and is assumed to have consumed no C_4 resources.

Late Woodland Category B canids (i.e., foxes) likely preyed on C_4-consuming herbivores (e.g., squirrels) and occasionally ate maize waste (from middens or caches). Maize fields offered a hunting ground for the foxes, placing them in close proximity to humans and making them convenient meat and/or fur source. Alternatively, foxes may have been viewed as crop pests because of their frequent appearance in fields. The behaviour inferred from these isotopic data suggests that the Late Woodland peoples hunted foxes living near their settlements. Foxes are, however, markedly underrepresented in Western Basin faunal assemblages (Foreman 2011). In fact, less than 25% of Western Basin sites had fox remains, compared to 51% of Ontario Iroquoian sites (Foreman 2011; Lennox 1977; Stewart 2000). Only one Western Basin fox (Dobleaar site, Wolf phase [A.D. 1400 to 1550]) could be obtained for isotopic analysis. This difference may be the result of preferential hunting of foxes by Ontario Iroquoian people, differences in the disposal of the remains, or differences in land-use. In the latter case, it may have been that Western Basin maize fields were less extensive, at least prior to A.D. 1400, and/or that the ecological niche exploited opportunistically by Ontario Iroquoian foxes was unavailable in the Western Basin region. The seasonal mobility of Western Basin people may also have had an influence on hunting practices. Western Basin peoples might have lived near

planted maize in the summer but only hunted/trapped foxes in the late fall or early winter (as in modern contexts, Samuel and Nelson 1982), at which time groups may have disbanded and moved to winter camps (Foreman 2011; Murphy and Ferris 1990). These smaller sites are less frequently identified by archaeologists and often have very few preserved animal bones, which may account for the underrepresentation of foxes at Western Basin sites. These behaviours would suggest that Western Basin peoples had a different relationship with their landscape than their eastern neighbours, the Ontario Iroquoian peoples.

2.4.1.3 Category C – large *Canis sp*.

Morphologically, this category is represented by an Archaic (pre-maize) dog, four large *Canis sp.* (large dogs, dog–wolf hybrids or small/female wolves) and one small canid. The small canid (Van–075) likely represents a fox or small, feral dog and dates to the Early Ontario Iroquoian period (A.D. 900 to 1200), but its diet is consistent with that of the other large canids in Category C as well as the forest environment of modern foxes (Urton and Hobson 2006).

According to descriptions of the “Common Indian” or “North American” dog (Allen 1920; Richardson 1929), the Category C husky-sized canids are most likely small wolves or dog-wolf hybrids. Dog-wolf hybridization is possible wherever dog and wolf populations overlap (Crockford 2000) and is discussed in some ethnohistoric accounts (Barton 1805; Richardson 1829) e.g.:

“*In Captain Parry's and Captain Franklin's narratives, instances are recorded of the female Wolves associating with the domestic dog... The resemblance between the northern wolves and the domestic dog of the Indians is so great, that the size and strength of the Wolf seems to be the only difference.*” (Richardson 1829:64)

Although other researchers have maintained that stories of hybridization are exaggerated in pre-contact North America (Allen 1920; Ryder 2000; Vilá and Wayne 1999), there is also zooarchaeological evidence of dog-wolf hybrids, primarily from the Plains region, where indigenous dogs were much larger (Ryder 2000; Schwartz 1997). The remains in

Category C are substantially larger than the majority of the dog remains collected for this study or the terrier-sized dogs described by Prevec and Nobel (1983) from Neutral sites. Even if dog-wolf hybrids are present in this sample, it is assumed that they would normally pursue a wild existence (Crockford 2000; Coppinger and Coppinger 2001). This assumption appears to be upheld as all Category C canids are also isotopically distinct from all other *C. familiaris* and *Canis sp.* samples. They have the lowest $\delta^{13}C_{col}$ values (indicative of pure C_3-food consumption), highly variable $\delta^{15}N_{col}$ and $\delta^{13}C_{sc}$ values, and the largest $\Delta^{13}C_{sc-col}$ difference (Table 2.6). Their consumption of low trophic level prey in an exclusively C_3 food web suggests an ecological niche that is generally isolated from human-altered (i.e. agricultural or urban) landscapes i.e., comparable to that of modern wolves from Ontario, Saskatchewan and Minnesota (Fox-Dobbs et al. 2007; Schwarcz et al. 1991; Urton and Hobson 2007) (Figure 2.6, Table 2.7).

Regardless of the taxonomic classification of the large canid remains, the important question is whether Late Woodland people would have identified these four large canids as dogs or as wolves. Their isotopic distinctiveness makes them a behaviourally discrete group, and their large size would suggest that they were not only real wolves but also perceived as such. Henceforward, they will be referred to as wolves. Wolves are not common in the faunal assemblages of Ontario Iroquoian sites (present at 24% of sites) (Foreman 2011; Lennox 1977; Stewart 1991), and are not even reported at any Western Basin sites (Foreman 2011). Their limited appearance in faunal assemblages suggests that they had minimal interaction with humans. It is even possible that wolves were not actively hunted. Great Lakes mythology suggests they were sacred and that their loss was serious enough to "*bring death unto the world*" (Brehm 2011:28). Therefore, they may have been killed only in specific circumstances, e.g., if they were considered a threat to human life or competing for prey, such as white-tailed deer. Ellis (2002) noted a shift from the Archaic period emphasis on wolves in ritual, such as the inclusion of wolf remains in human burials (Donaldson and Wortner 1995) and the presence of wolf masks (Baby 1961; Parmalee and Stephens 1972) to an emphasis on the use of dogs in sacrifice and feasting in the Woodland period. The shift from wolves to other canids in ceremonial activities could explain the minimal presence of wolves in faunal assemblages. There is, however, continuity in cosmological role of wolves, and *Wolf* remained a central clan

and/or national symbol of both the Iroquoian and Alongkian-speaking people throughout the Late Woodland and Historic time periods (Ellis 2002). If wolves were given a special status, it is plausible that any purposefully killed wolves might have been given distinctive post-mortem treatment because of their sacred status, resulting in scarce inclusion in middens or refuse pits. Further evidence of this differential post-mortem treatment is the high $\Delta^{13}C_{sc-col}$ values of the wolves, discussed in detail in Chapter 4.

The pre-agricultural Davidson Site dog (Dav-05) also represents pure C_3 food web exploitation (–20.78), which is expected for a site pre-dating the entry of maize into the region by over 3000 years. While the $\delta^{13}C_{col}$ values of this dog are lower than –20‰, they are not as low as the values of the wolves and one fox believed to be exploiting the C_3 environment. Two potentially complementary explanations are: (1) the Archaic dog consumed freshwater fish (discussed below), and (2) the wolves exploited prey in deeper forest canopy areas, away from Late Woodland human-altered landscapes (Bonafini et al. 2013; Cerling and Harris 1999; Druker and Bocherens 2009; Vogel 1978). For a discussion of deer who may have also exploited deeper forests, resulting in low $\delta^{13}C_{col}$ values, see Chapter 4.

The pre-agricultural dog had a $\delta^{15}N_{col}$ value (10.31‰) that was high relative to the wolves but similar to the Category A domestic dogs, which suggests a different trophic feeding level and a domesticated relationship with humans. The Archaic dog probably consumed a lot of freshwater fish, an interpretation that is also consistent with their $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values (Figure 2.6). Such fish could include salmon, lake trout or burbot (Van der Merwe et al. 2003: 255). Furthermore the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values of the Davidson dogs distinguish them from the other wild canids (Figure 2.5 and Figure 2.8). Although a high degree of herbivory could explain the dog's large $\Delta^{13}C_{sc-col}$ spacing (+11.19‰), its high $\delta^{15}N_{col}$ value make this interpretation unlikely. Alternatively, its $\delta^{13}C_{sc}$ value may have been altered by post-mortem processing (i.e., boiling, see Chapter 4), which might suggest that the Archaic dogs were eaten.

2.4.2 Juvenile Canids

Juvenile canids were not morphologically identified beyond *Canis sp.* because of interpretive difficulties but their isotopic compositions suggest association with the same ecological niches identified for the adult canid remains (Figure 2.4). Five of the specimens fall within the expected range of isotopic compositions for dogs and two of the samples fall within the range for foxes. Sil–07 appears to be an outlier based on its high $\delta^{15}N_{col}$ value. As previously discussed, Pip (2)–028, an older immature (incompletely fused long bone) large *Canis sp*. shares its isotopic composition with that of wolves.

As expected, there is a breastfeeding, trophic level enrichment evident in the $\delta^{15}N_{col}$ values for most of the juvenile canids (Williams et al. 2005; Wright and Schwarcz 1998). The mean $\delta^{15}N_{col}$ value of the juvenile canids is significantly higher relative to that of the adult canid remains (Tukey HSD, p=0.020). There are distinct patterns of C_4 consumption among the juvenile canids that suggest the same variation in maize consumption as that found in the adult canids, and most likely reflect species differences (i.e. domestic versus wild canids). The mean $\delta^{15}N_{col}$ value of juvenile domesticated dogs (i.e., those with $\delta^{13}C_{col} > -15‰$) is significantly higher than that of adults (Tukey HSD, p=0.005). There is also a significant relationship between $\delta^{18}O_{sc}$ and $\delta^{15}N_{col}$ values of dogs ($r^2 = -0.105$, p=0.018), which probably also reflects infant breastfeeding (see Williams et al. 2005). Because the juveniles have statistically higher $\delta^{15}N_{col}$ values due to breastfeeding, they are not used in the further comparisons of dog-human diets. There is no significant difference between the $\delta^{15}N_{col}$ values of juvenile and adult foxes. This may be because foxes wean quickly, i.e., within four to five weeks of birth (Larivière, S., Pasitschniak-Arts 1996).

2.4.3 Dogs as proxies for human diet

In order to determine whether dogs can be used to reconstruct human subsistence practices, the isotopic compositions of the Category A dogs, as well as those of previously reported Late Woodland domesticated dogs (Booth et al. 2011; Katzenberg 1989, 2006), have been compared to those published for adult humans from the Great Lakes region (Figure 2.9). The isotopic data for Western Basin dogs are compared with

those published for Western Lake Erie humans (Allegretto 2007; Dewar et al. 2010; Schurr and Redmond 1991; Stothers and Bechtel 1987; Spence et al. 2010; Watts et al. 2011). The isotopic data for Ontario Iroquoian dogs are compared to those published for humans from southwestern and central Ontario (Harrison and Katzenberg 2003; Katzenberg 1995; Schwarcz et al. 1985; van der Merwe et al. 2003) (summary of human published data Table 2.8). For statistical purposes, dogs and humans were categorized into temporal phases that roughly correspond to recognized cultural periods/phases (Table 2.9).

Table 2.7: Summary of published modern canid (A.) and archaeological dog (B.) isotope data and references.

A. Modern canids

Species (*TISSUE*)	Location	N	original $\delta^{13}C$ (‰,VPDB)	Corrected $\delta^{13}C$ (‰,VPDB)	±SD	Original $\delta^{15}N$ (‰,AIR)	Corrected $\delta^{15}N$ (‰,AIR)	±SD	Reference
Canis lupus (COLLAGEN)	Isle Royale	25	–23.2	–21.7	0.3	5.2	5.2	0.4	Fox–Dobbs et al 2007
	Central Ontario					5.9	5.9	0.5	Schwarcz 1991
	Northern Minnesota	18	–22.5	–21.0	0.9	6.7	6.7	0.7	Fox–Dobbs et al 2007
Canis lupus (FUR*)	PANP, Saskatchewan	16	–22.9	–22.7	0.3	6.6	7.8	1.0	Urton and Hobson 2006
	Outside PANP, SK	14	–22.5	–22.3	1.2	7.4	8.6	1.0	Urton and Hobson 2006
	La Ronge SK	17	–21.7	–21.5	1.3	7.9	9.1	1.5	Urton and Hobson 2006
Vulpus vulpes (FUR*)	Saskatchewan	9	–22.4	–22.2	1.3	9.5	10.7	1.6	Urton and Hobson 2006
Vulpes vulpes (BLOOD**)	Illinois: urban	21	–22.2	–19.4	0.4	7.9	8.3	0.2	Lavin et al 2003
	Illinois farm	7	–20.0	–17.1	1.1	8.6	9.0	0.3	Lavin et al 2003
	Illinois: rural	53	–17.2	–14.4	0.5	9.1	9.5	0.2	Lavin et al 2003
Canis latrans (BLOOD**)	Coyote	6	–17.4	–14.5	0.6	9.1	9.5	0.1	Lavin et al 2003

*Fur $\delta^{13}C$ data corrected +1.3‰ and $\delta^{15}N$ data +1.2‰ to make them comparable to collagen data (Dairmont and Reimchen 2002).

**Blood $\delta^{13}C$ data corrected +0.8‰ and $\delta^{15}N$ data +0.4‰ to make them comparable to collagen data (Roth and Hobson 2000).

B. Archaeological domestic dogs.

Sample Name	Site Name	Date	$\delta^{13}C_{col}$ (‰,VPDB)	±SD	δ^{15N}_{col} (‰,AIR)	±SD	$\delta^{13}C_{sc}$ (‰,VPDB)	References
CLV-01.1	Cleveland	A.D. 1540	-	-	-	-	-6.28	Booth et al. 2011
CLV-02.1	Cleveland	A.D. 1540	-	-	-	-	-7.85	Booth et al. 2011
CLV-03.1	Cleveland	A.D. 1540	-	-	-	-	-6.18	Booth et al. 2011
IR-HOL20.1	Holly	A.D. 1280-1330	-13.28	-	9.72	-	-6.25	Booth et al. 2011
55Ez13	Kelley-Campbell	A.D. 1636	-11.5	-	10.0	-	-	Katzenberg 1989: Table 3
5OEh16	Kelley-Campbell	A.D. 1636	-11.0	-	9.6	-	-	Katzenberg 1989: Table 3
6OEm4	Kelley-Campbell	A.D. 1636	-10.6	-	9.5	-	-	Katzenberg 1989: Table 3
50Ee54	Kelley-Campbell	A.D. 1636	-12.4	-	9.6	-	-	Katzenberg 1989: Table 3
50Eg13	Kelley-Campbell	A.D. 1636	-10.7	-	9.3	-	-	Katzenberg 1989: Table 3
Em8	Kelley-Campbell	A.D. 1636	-10.1	-	9.7	-	-	Katzenberg 1989: Table 3
S5E2	Kelley-Campbell	A.D. 1636	-12.2	-	9.5	-	-	Katzenberg 1989: Table 3
Ed69	Kelley-Campbell	A.D. 1636	-10.3	-	9.7	-	-	Katzenberg 1989: Table 3
n=5	Ball	A.D. 1636	-11.6	0.5	10.7	1.3	-	Katzenberg 1989: Table 3
n=4	Seed	A.D. 1600	-12.0	1.7	9.3	0.4	-	Katzenberg 2006: Table 19.1
n=5	Wallace	A.D. 1600	-12.0	1.6	10.2	0.7	-	Katzenberg 2006: Table 19.1
n=-1	Draper	A.D. 1210-1490	-11.4	-	8.4	-	-	Katzenberg 2006: Table 19.1
n=4	Jacob's Island	2912-2889 B.P.	-21.5	0.6	10.8	1.1	-15.9	Conolly et al. 2014: Table 3
ACRF 1526	Swaiton, NJ	cal A.D. 1350	-13.7	-	12.1	-	-10.3	Allitt et al. 2008: Table 3
ACRF 1527	Newport, NJ	cal A.D.1193	-16.2	-	8.6	-	-9.4	Allitt et al. 2008: Table 3
ACRF 1528	Mohr Site, PN	cal A.D.1462	-14.2	-	6.6	-	-7.3	Allitt et al. 2008: Table 3

Table 2.8: Summary of published Southern Ontario and Western Lake Erie human isotope data and references.

SOUTHERN ONTARIO

Site Name	δ13Ccol (‰,VPDB)	SD	δ15Ncol (‰,AIR)	SD	N	δ13Csc (‰,VPDB)	SD	N	References
Archaic									
Jacob's Island	-21.5	4.0	12.6	0.3	26	-14.0	1.9	22	Conolly et al. 2014: Table 3 and 4
Morrison's Island	-20.8	1.4	12.3	0.4	3	-13.6		1	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Donaldson 1*	-19.2	0.3	13.3	0.7	3	-9.5		1	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Middle Woodland (A.D. 50 to 300)									
Jacob's Island	-19.8	1.6	12.9	0.7	4				Conolly et al. 2014: Table 4
Donaldson 2	-18.9	0.9	12.4	1.2	3	-12.1	0.3	2	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
LeVesconte	-21.4	0.7	13.3	0.9	9	-15.1	0.2	5	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Serpent Mounds E	-18.2	5.0	12.6	0.6	3				Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Transitional Woodland (A.D. 500 to 800/900)									
Serpent Mounds G and I	-20.2	1.8	12.5	1.1	8	-14.6	0.3	5	
Serpent Mounds E**	-16.1	0.7	11.1	0.8	2	-9.2	0.1	2	Harrison and Katzenberg 2003
Monarch Knoll	-20.5		11.2		1				Katzenberg et al. 1995
Surma	-17.7	1.4	12.8	0.7	4	-12.0	0.6	3	Katzenberg et al. 1995, Harrison and Katzenberg 2003: Table 2
Early Ontario Iroquoian(A.D. 800/900 to 1200/1300)									
Varden***	-19.3	0.2	11.2	0.4	15	-12.0	1.6	5	Katzenberg et al. 1995: Table 4, Harrison and Katzenberg 2003: Table 2
Miller	-13.9	0.9	13.5	0.9	5	-6.6		1	Katzenberg et al. 1995: Table 4, Harrison and Katzenberg 2003: Table 2
Serpment Mounds/ Pit 2	-15.3	0.8	12.4	0.2	3				Schwarcz et al. 1985: Table 2
Serpment Mounds/ Pit 3	-15.8	3.0	12.6	0.1	2				Schwarcz et al. 1985: Table 2
Middle Ontario Iroquoian(A.D. 1200/1300 to 1450)									
Bennett	-11.5		12.1		1	-			Katzenberg et al. 1995: Table 4
Force	-12.4	0.6	11.6	0.4	4	-5.2	0.8	4	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Moatfield	-12.3	1.4	12.2	0.5	11				van der Merwe 2003: Table 2
Fairty Ossuary	-11.3	1.1	11.8	0.4	4	-4.3	0.6	2	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Neutral (A.D. 1450 to 1650)									
Uxbridge	-10.8	0.5	11.1	0.7	9	-4.9	0.5	9	Harrison and Katzenberg 2003: Table 2
Woodbridge	-11.6	1.1	10.8	0.7	3				Katzenberg et al. 1995: Table 4
Kleinberg Ossuary	-12.2	0.4	12.2	0.2	4	-5.4	0.1	3	Schwarcz et al. 1985: Table 2, Harrison and Katzenberg 2003: Table 2
Ossossane Ossuary	-11.8	0.8	12.6	1.1	9	-5.1	0.7	5	Harrison and Katzenberg 2003: Table 2
Ball	-12.6	1.0	11.6	0.7	5				Schwarcz et al. 1985: Table 2
Cooper Ossuary	-13.6	1.4	11.2	0.6	3				Schwarcz et al. 1985: Table 2

Table 2.8 continued.

WESTERN LAKE ERIE

Site Name	δ13Ccol (‰,VPDB)	SD	δ15Ncol (‰,AIR)	SD	N	δ13Csc (‰,VPDB)	SD	N	References
Archaic									
Danbury, OH	-19.3		8.2		1	-13.4		1	Allegretto 2007: Table 4.3
Williams, OH	-21.6	1.4			1				Stothers and Bechtel 1987: Table 1
Marblehead, OH	-27.5	0.0			1				Stothers and Bechtel 1987: Table 1
Riviere au Vase (A.D. 500 to 800)									
Missionary Island, OH	-18.9				1	0.0			Stothers and Bechtel 1987: Table 1
Patyi-Dowling, OH	-16.5				1	0.0			Stothers and Bechtel 1987: Table 1
Danbury, OH	-12.1	1.8	10.9	1.1	12	-8.2	1.0	9	Allegretto 2007: Table 4.3
Gard Island No 2, MI	-14.0	1.4	12.7	0.6	10				Schurr and Redmond 1991: Table 1
Riviere au Vase, MI	-12.7	1.6	12.4	0.9	34	-11.6	2.3	29	Allegretto 2007: Table 4.3
Younge Phase (A.D. 800 to 1200)									
Waterworks Mound, OH	-12.4				1				Stothers and Bechtel 1987: Table 1
Danbury, OH	-12.5	1.6	11.1	0.8	4	-8.1	0.5	4	Allegretto 2007: Table 4.3
Great Western Park, ON	-11.7	1.7	11.7	0.1	2				Dewar et al. 2010: Table 1
Inland West Pit, Loc 9, ON	-12.5		11.9		1				Spence et al. 2010
Krieger, ON	-11.1	0.8	13.1	0.5	9	-3.7	1.2	9	Watts et al. 2011: Table1
Missionary Island, OH	-15.5				1				Stothers and Bechtel 1987: Table 1
North Bass Island, OH	-13.2				1				Stothers and Bechtel 1987: Table 1
Springwells Phase (A.D. 1200 to 1400)									
Patyi-Dowling, OH	-13.4				1				Stothers and Bechtel 1987: Table 1
Williams Floodplain, OH	-13.2				1				Stothers and Bechtel 1987: Table 1
Black's Knoll, OH	-11.7				1				Stothers and Bechtel 1987: Table 1
Dodge, OH	-15.6	0.1			2				Stothers and Bechtel 1987: Table 1
LaSalle, OH	-11.4				1				Stothers and Bechtel 1987: Table 1
Great Western Park, ON	-11.7	0.8	12.3	0.4	3				Dewar et al. 2010: Table 1
Indian Hills, OH	-10.7	1.1			2				Stothers and Bechtel 1987: Table 1

Site dates are based on C^{14} dates reported in citations referenced.

*Donaldson I, possible Transitional Woodland (Dr. Michael Spence, personal communication)

** Serpent Mound E, possibly only Middle Woodland (Dr. Michael Spence, personal communication)

***Varden, newest date could shift site to the Transitional Woodland (Foreman and Molto 2008)

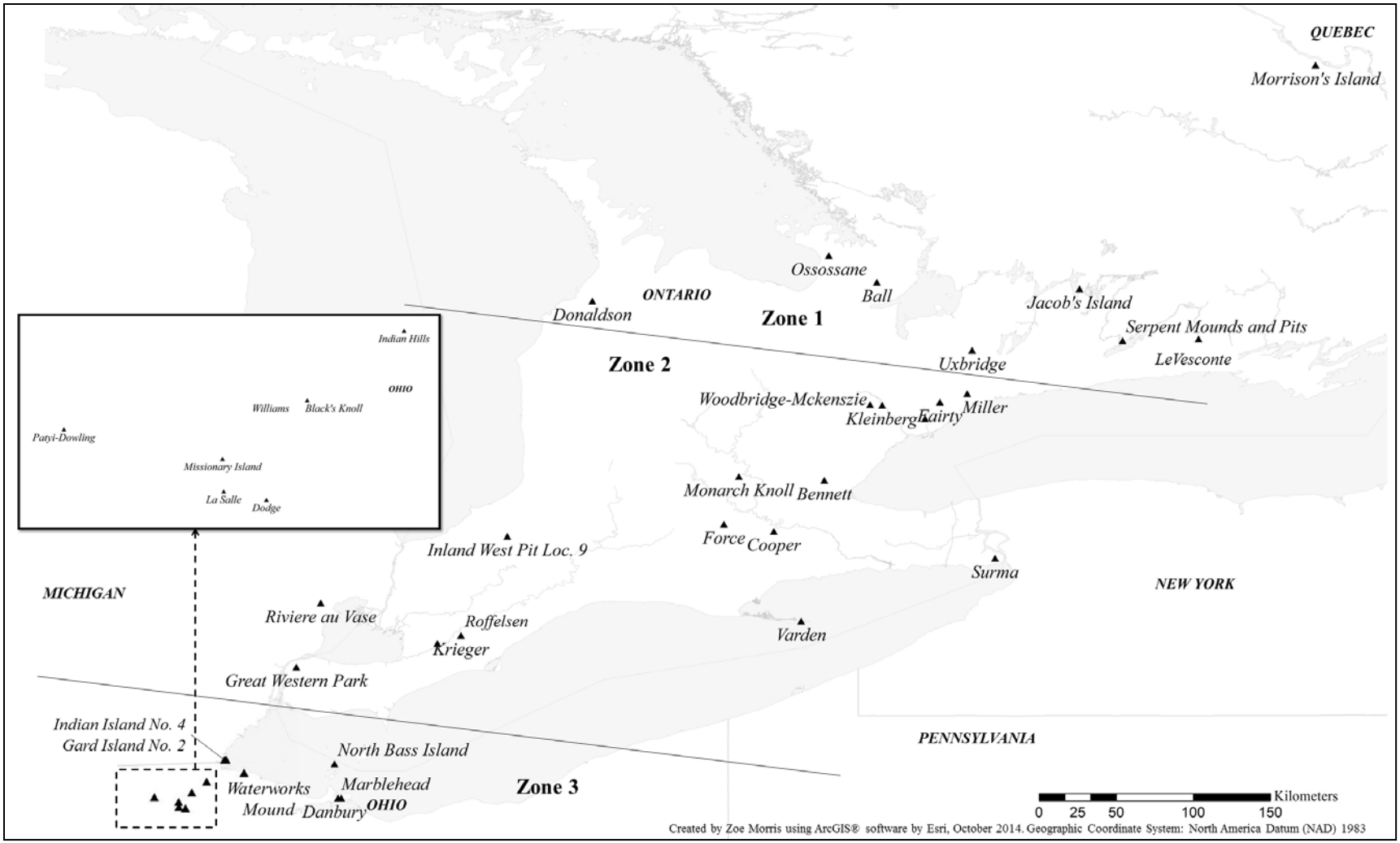


Figure 2.9: Archaeological sites with published isotopic data for humans.

Solid lines separate three zones: (1) sites north of the Carolinian Zone, (2) Ontario sites within the Carolinian zone, and (3) sites along western Lake Erie.

Table 2.9: Distribution of dog and human samples (this study and published samples listed in Tables 2.7 [dogs] and 2.8 [humans] by time, cultural period and location.

Approximate Dates	Cultural Phase/Period	Ontario Iroquoian Dogs	Ontario Western Basin Dogs	SW/Central Ontario Humans	Western Lake Erie Humans
Archaic	Archaic–Early Woodland No evidence of maize	n_{col}=2 n_{sc}=3	n=0	n_{col}=7 n_{sc}=3	n_{col}=13 n_{sc}=1
A.D. 50 to 500	Middle Woodland* Introduction of maize into Ontario	n=0	n=0	n_{col}=19 n_{sc}=7	n=0
A.D. 500 to 800/900	Princess Point/Riviere au Vase Transitional Phase	n=1	n=0	n_{col}=15 n_{sc}=10	n_{col}=56 n_{sc}=37
A.D. 800/900 to 1200/1300	~Early Ontario Iroquoian/Younge	n_{col}=2 n_{sc}=1	n_{col}=7 n_{sc}=4	n_{col}=25 n_{sc}=6	n_{col}=19 n_{sc}=13
A.D. 1200/1300 to 1450	~Middle Ontario Iroquoian/Springwells	n_{col}=23 n_{sc}=18	n= 0	n_{col}=20 n_{sc}=6	n_{col}=11 n_{sc}=0
A.D. 1450 to 1650	~Late and Historic Neutral/Wolf	n_{col}=28 n_{sc}=21	n= 1	n_{col}=33 n_{sc}=17	n= 0

* No canid samples available from this period.

Table 2.10: Statistical summary (one–way ANOVA with post–hoc Dunnett T3) of dog and human $\delta^{13}C_{col}$ comparison.

Approximate Dates	Ontario Iroquoian Dogs *vs* SW/Central Ontario Humans	Ontario Western Basin Dogs *vs* Western Lake Erie Humans	Ontario Iroquoian Dogs *vs* Ontario Western Basin Dogs	SW/Central Ontario Humans *vs* Western Lake Erie Humans
Archaic	Dunnett T3, p=1.000	N/A	N/A	Dunnett T3, p=0.771
A.D. 50 to 500	N/A	N/A	N/A	N/A
A.D. 500 to 800/900	N/A	N/A	N/A	Dunnett T3, p=0.066
A.D. 800/900 to 1200/1300	Dunnett T3, p=1.000	Dunnett T3, p=1.000	Dunnett T3, p=1.000	**Dunnett T3, p=0.002**
A.D. 1200/1300 to 1450	Dunnett T3, p=0.669	N/A	N/A	Dunnett T3, p=1.000
A.D. 1450 to 1650	Dunnett T3, p=0.252	N/A	N/A	N/A

N/A = No statistical comparison possible due to sample size.

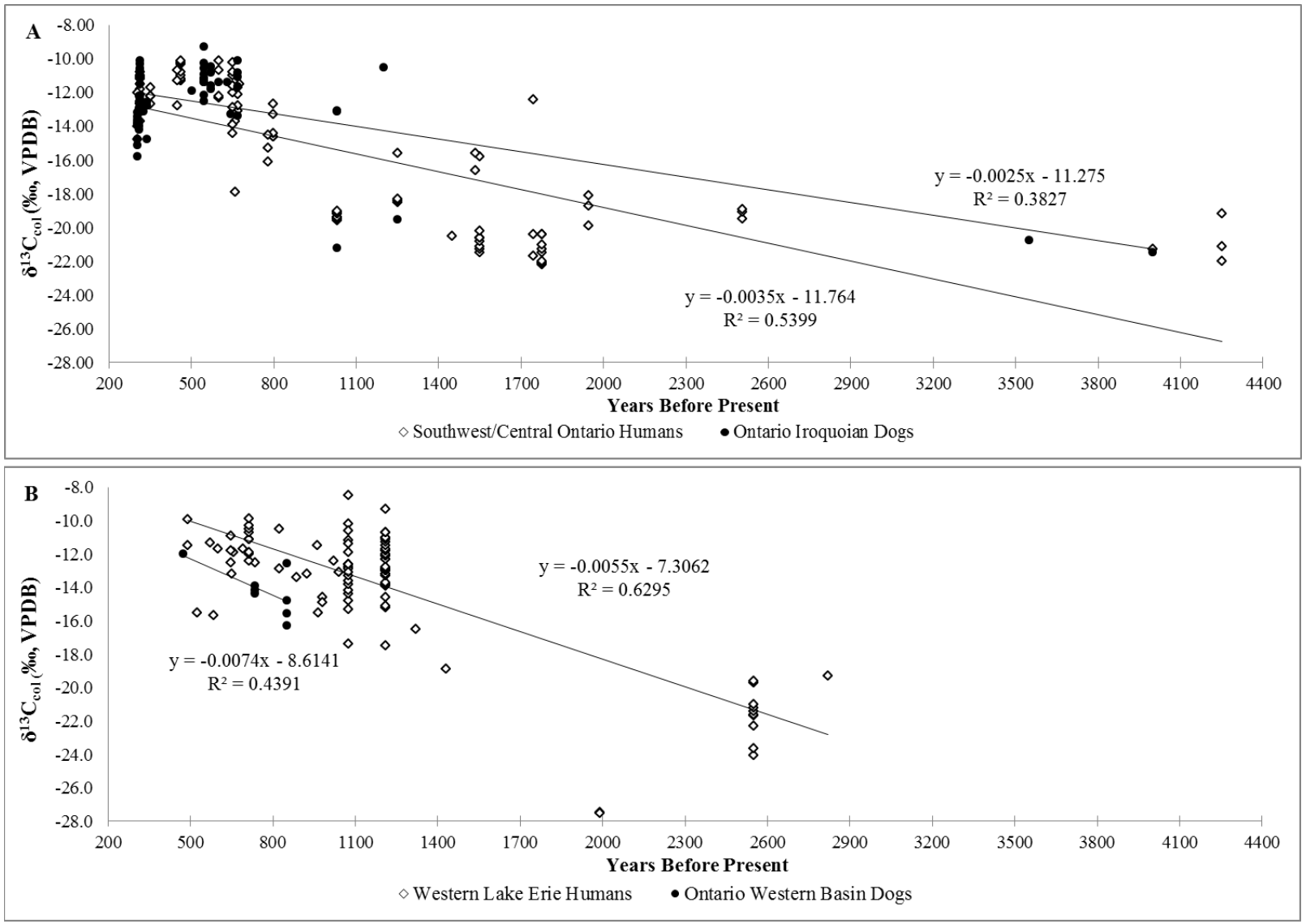


Figure 2.10: $\delta^{13}C_{col}$ values for dogs and humans through time; (A) compares Ontario Iroquoian dogs and southwest/central Ontario humans; (B) compares Ontario Western Basin dogs and Western Lake Erie Humans.

2.4.4 ^{3}C values of humans versus dogs

The $\delta^{13}C_{col}$ values of humans and dogs from southwestern/central Ontario and Western Lake Erie regions correspond well through time suggesting that dogs can serve as proxies for human maize consumption for the Great Lakes region (Table 2.10, Figures 2.10A and B).

2.4.4.1 No evidence of maize: Archaic

No dogs were analysed from the Western Lake Erie region earlier than the Younge Phase (A.D. 900 to 1200). Only two Archaic dogs were analysed and collagen was preserved in only one of those. The δ-value ($\delta^{13}C_{col}$ = -20.785‰), for the well–preserved sample from the Davidson site reflects the pre-maize values of humans (Table 2.9). The Davidson dog collagen value is similar to that of four other Archaic dogs from Jacob's Island, Ontario, that had a mean $\delta^{13}C_{col}$ value of -21.5±0.6‰ (Conolly et al. 2014, Table 3). Transitional Woodland: A.D. 500–800/900

Archaeological evidence suggests that maize was introduced to Ontario as early as A.D. 200 (Allegreto 2007; Capella 2005; Crawford et al. 2006). The Princess Point phase marks an important shift to the use of cultigens (Capella 2005) in Ontario. Only one dog is definitively dated to this period (Old Lilac Garden site [OLG–14], Coote's Paradise, Smith 1997; Smith and Crawford 2002). The $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values for OLG-14 are unexpectedly high (–10.5 and –4.2‰, respectively), which suggests that the Old Lilac Garden site may actually date to the latter end of the Princess Point period as maize is found infrequently at sites early in the phase. Conversely, these data may suggest that maize was adopted earlier as a staple crop than previously thought.

2.4.4.2 Western Basin Younge/Early Ontario Iroquoian: A.D. 900/1000 to A.D. 1200

All isotopic measures suggest that post A.D. 900/1000 both groups of dogs and humans consumed significant quantities of maize. There is no significant difference between $\delta^{13}C_{col}$ values of the Ontario Iroquoian dogs and the humans dated to the Early Ontario Iroquoian Phase. Similarly the eight Western Basin Younge Phase dogs and humans are

not significantly different (Table 2.10). With the shift to the Late Woodland period, both Western Basin and Ontario Iroquoian dogs consumed significant amounts of maize, as did their human counterparts. In fact, Western Lake Erie humans have significantly higher $\delta^{13}C_{col}$ values than their Ontario Iroquoian neighbours, which could have resulted from consumption of either more maize or possibly more freshwater fish (another ^{13}C-enriched resource, see $\delta^{15}N_{col}$ discussion below).

2.4.4.3 Western Basin Springwells/ Middle Ontario Iroquoian Phase: A.D. 1200 to 1400/1450

No Western Basin dogs were available from the Springwells Phase (A.D. 1200 to 1400). Archaeological evidence supports heavy maize reliance among the Ontario Iroquoian peoples between A.D. 1280 and 1450, with evidence of increasing sedentism and population growth. Because of the well–established chronology of maize horticulturalism at Crawford Lake site (Finlayson and Bryne 1975), the traditional chronology of the Middle Ontario Iroquoian phase, A.D. 1300 to 1400 (Dodd et al. 1990), was extended to A.D. 1450 (Finlayson 1998). The $\delta^{13}C_{col}$ data support the assumption that both Ontario Iroquoian dogs (–11.33±0.94‰, n=23) and humans (–12.40±1.70‰, n=22) consumed maize year round and there was no significant difference between dogs and humans (Table 2.10). The isotopic composition of dogs is much less variable than that of the humans, which may simply reflect sampling differences i.e., the isotopic data for humans come from a much larger region. When separated by region, i.e. within and north of the Carolinian zone (Figure 2.9), the isotopic results for dog and human become more consistent (Table 2.11, Figure 2.11). The Eastern Carolinian, or Eastern Deciduous, forest range is a unique biotic niche that extends into the southwestern tip of Ontario. Not surprisingly, dogs and humans north of the Carolinian zone, where the growing season is shorter and average annual temperatures are lower, have slightly lower $\delta^{13}C_{col}$ values relative to the dogs and humans from sites with the Carolinian zone (Table 2.11, Figure 2.11).

Table 2.11: Average $\delta^{13}C_{col}$ values for Middle Ontario Iroquoian and Neutral dogs and humans recovered from sites: (1) North of the Carolinian Forest Extent, and (2) within the Carolinian Forest (see Figure 8).

	Zone 1: North of Carolinian Zone		Zone 2: within the Carolinian zone	
1200–1450 A.D.	dogs (n=2)	humans (n=2)	dogs (n=21)	humans(n=20)
	–12.34±1.33‰	–15.80±2.97‰	–11.24±1.33‰	–12.07±1.18‰
1450–1650 A.D.	dogs (n=11)	humans (n=23)	dogs (n=21)	humans(n=10)
	–11.31±0.8‰	–11.60±0.98‰	–13.64±0.94‰	–12.44±1.22‰

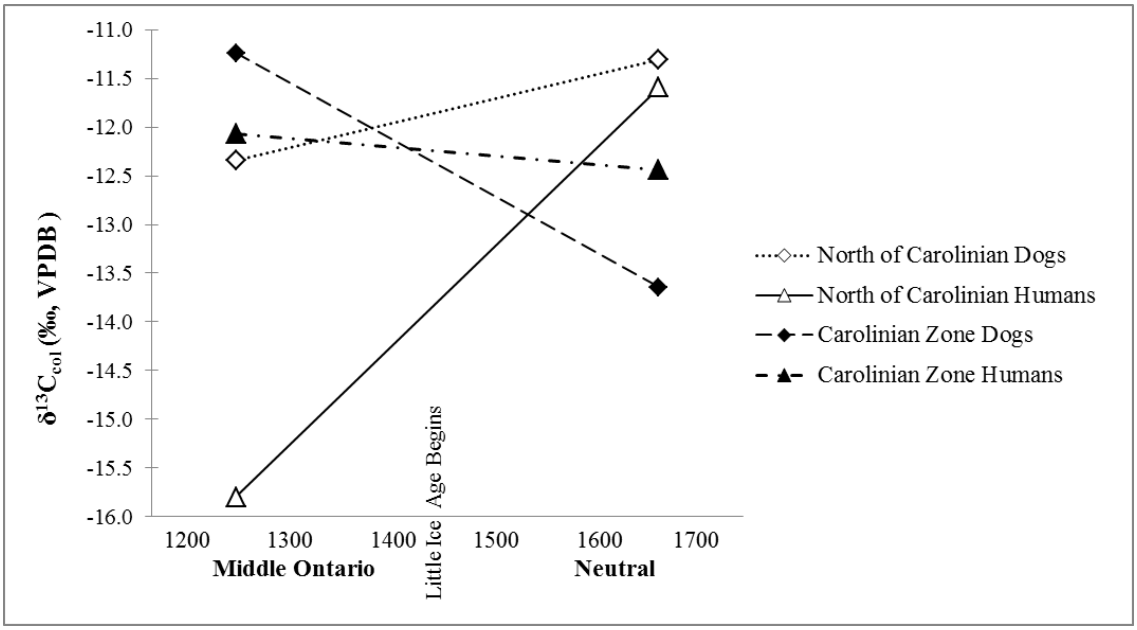


Figure 2.11: Average $\delta^{13}C_{col}$ values of Middle Ontario Phase and Neutral dogs and humans recovered from sites (1) North of the Carolinian Forest Extent, and (2) within the Carolinian Forest (see Figure 2.9).

2.4.4.4 Western Basin Wolf phase/Ontario Iroquoian Neutral: A.D. 1450–1550/1650

Only one Western Basin dog (Dob-1) was analysed from the Wolf phase (A.D. 1450 to 1550), and its $\delta^{13}C_{col}$ value (–12.00‰) is very consistent with the Wolf Phase Western Lake Erie mean human value of –11.86±1.52‰. It is evident that Western Basin peoples in Ontario successfully combined seasonal movement with the demands of maize cultivation, which challenges the long held belief that sedentism is necessary for

extensive horticulturalism. The Western Basin context supports Cappella's (2005) theoretical argument that maintenance of a mobile settlement system and the cultivation of maize are not mutually exclusive because minimal time planting and harvesting is required at a site.

Overall, Ontario Iroquoian dog and human $\delta^{13}C_{col}$ values demonstrate increasing C_4 consumption over time (Spearman's ρ=–0.338, p=0.010, Figure 2.11A). However, the Ontario Iroquoian Neutral phase is marked by increasing C_4 food consumption by humans (–11.85±1.52‰) and decreasing C_4 food consumption by dogs (–12.92±1.48‰), (Figure 2.10). Dogs and humans north of the Carolinian zone appear to have consumed more maize during the Neutral phase and the amount of variability between dogs and humans is virtually the same, unlike that for the Middle Ontario Iroquoian dogs and humans. The beginning of the Little Ice Age coincides with the beginning of the Neutral phase. Therefore, the increase in maize consumption is unlikely the result of increased length of growing season. Greater horticultural sophistication, larger fields and/or increased storage are more likely to account for the significant increase in $\delta^{13}C_{col}$ values at the northern sites. Conversely, maize consumption decreased for dogs and humans from sites within the Ontario Carolinian zone though only significantly for dogs (Tukey HSD, p>0.000), which suggests that for this region, human maize consumption was relatively consistent from A.D. 1200. The disparity in the isotopic data obtained for dogs is discussed in greater detail below.

It is evident that both Late Woodland Western Basin and Ontario Iroquoian dogs had access to maize or C_4 products year round in spite of inter–regional differences in settlement flexibility and seasonal site occupation. Overall, dogs serve as good proxies for maize consumption by contemporary humans for both cultural regions.

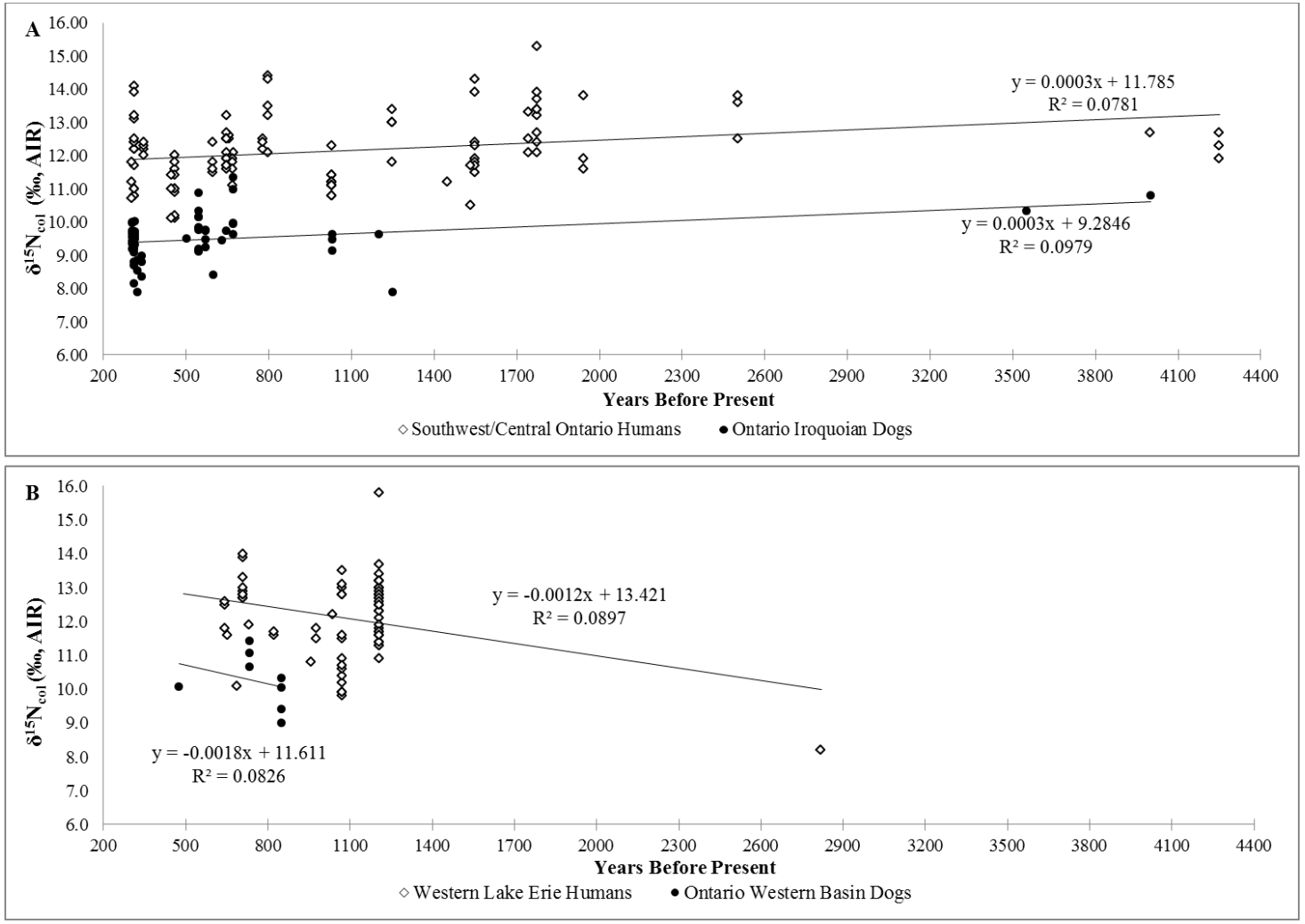


Figure 2.12: $\delta^{15}N_{col}$ values for dogs and humans through time; (A) compares Ontario Iroquoian dogs and southwest/central Ontario humans; (B) compares Ontario Western Basin dogs and Western Lake Erie Humans.

2.4.5 $\delta^{15}N_{col}$ values of humans versus dogs

The $\delta^{15}N_{col}$ values of dogs are consistently lower relative to humans across all time periods for both regions (Figure 2.12A and B) (Tukey HSD, $p<0.005$ for all time periods). There is also a strong correlation between human and dog $\delta^{15}N_{col}$ values for both cultural groups (Western Basin, Pearson's $r=0.794$ and $p=0.019$ Ontario Iroquoian, Pearson's $r=0.897$, $p<0.0005$), which suggests that dogs had access to protein resources supplied by humans.

In the Western Basin Lake Erie region, $\delta^{15}N_{col}$ values of both dogs and humans increase with time (Figure 2.12 B), which suggests increasing amounts of higher trophic level foods. By contrast, in the Ontario Iroquoian region, $\delta^{15}N_{col}$ values of both dogs and humans decrease slightly over time (Figure 2.12A), which suggests consumption of lower trophic level foods or decreased carnivory. The contrast in protein sources between the two traditions likely indicates that, while Western Basin Lake Erie people were increasing their dietary emphasis on fish, Ontario Iroquoian peoples were moving away from fish consumption.

Dogs from combined Western Lake Erie and Central/Southwestern Ontario (i.e., Great Lakes) sites were on average 2–3‰ lower than their contemporaneous humans, i.e., slightly less than one trophic level (Table 2.12). The difference in $\delta^{15}N_{col}$ values between Great Lakes dogs and humans is the same and is consistent with previously reported human-dog $\delta^{15}N_{col}$ differences (see summary Guiry 2012), specifically in the Eastern Woodland region (Allitt 2007; Katzenberg 1989; Schwarcz and Schoeninger 1991), and elsewhere (Allitt 2007; Katzenberg 1989, 2006). Proposed explanations for the previously noted offsets include diet differences, trophic enrichment of humans from consumption of dogs, coprophagy by dogs, and/or metabolic differences between dogs and humans (Allitt 2007; Allitt et al. 2008; Cannon 1999; Guiry 2012; Katzenberg 1989; 2006; Schwarcz and Schoeninger 1991; White et al. 1991).

Table 2.12: Average $\delta^{15}N_{col}$ values for dogs and humans by region

	Western Lake Erie	Central/Western Ontario
Humans	~11.5 to 13‰	10.5 and 13‰
Dogs	~9 to 11‰.	8.5 to 10.5‰
Average $\Delta^{15}N_{human-dog}$	~+2 to 2.5‰	~+2 to 2.5‰

Diet differences do not provide an adequate explanation as the human-dog difference in $\delta^{15}N_{col}$ values is consistent across time periods and between different cultural traditions. In terms of trophic enrichment from dog consumption, the Jesuit Relations do describe dog consumption but only in ritual contexts (Thwaites 1896–1901 1; 23; 43; 60; Wrong 1939). Ritual consumption of dogs, however, is unlikely to account for a significant portion of Late Woodland diet. It is more likely that humans consumed more, higher trophic protein sources, including a variety of carnivorous mammals (e.g. raccoons and minks, which are found in faunal assemblages) and freshwater fish (Chapter 1).

The consumption of human faeces by dogs likely contributes to their lower $\delta^{15}N_{col}$ values (Katzenberg 1989) but this explanation is not well supported because dogs would also have had access to small, low–trophic level animals, such as rabbits and squirrels (Kleinman 1967) found in and around villages and campsites. Their access to hunted game (such as deer, beavers and bear) may have been restricted for any number of reasons, including a cultural taboo against dogs eating the bones (and by extension, the meat) of hunted animals (Harrington 1921; Schwartz 1997; Thwaites 1896–1901 1; 20). One such account of this taboo is described in the Jesuit relations:

"When they [bones from a feast] have been well sucked and gnawed, they are not thrown to the dogs, as in France; that would be very unwise, because, they say, the animals would become much harder to catch, being informed by their brothers and kindred that their [page 301] bones are given to the dogs. Therefore, they throw them into the fire, or into the river, or else bury the bones of beavers, from fear lest the dogs may find them." (Thwaites 1896–1901:44:301–3).

The lower $\delta^{15}N_{col}$ values of dogs are probably due to the compounding effects of coprophagy, the restricted access of dogs to hunted game (including higher trophic

species), the consumption of low-trophic small prey by dogs, and the consumption of dogs by humans as an important ritual food source. Regardless of the reason for the $\Delta^{15}N_{human\text{-}dog}$ offset of 2–2.5‰, its consistency in all time periods and for both traditions (Tukey HSD, p= 0.992) supports the premise that dogs can serve as proxies for human subsistence practices in this region.

2.4.6 Models used for reconstructing dog diets

Because the Late Woodland period was a time of shifting subsistence, settlement and cultural practices and because dogs appear to be good proxies for human subsistence related activities, their data are now used to shed more light on the nature of the Western Basin and Ontario Iroquoian traditions, in particular, the *in vivo* behaviour and treatment of dogs as related to subsistence, and their post-mortem treatment. The $\delta^{13}C_{col}$, $\delta^{15}N_{col}$ and $\delta^{13}C_{sc}$ values are used to elucidate protein sources, i.e., C_3 vs. C_4/marine using a multivariate cluster model (after Froehle et al. 2012, Figure 2.13). This model was developed using archaeological human data from areas with well-established subsistence patterns, including data from the Great Lakes region.

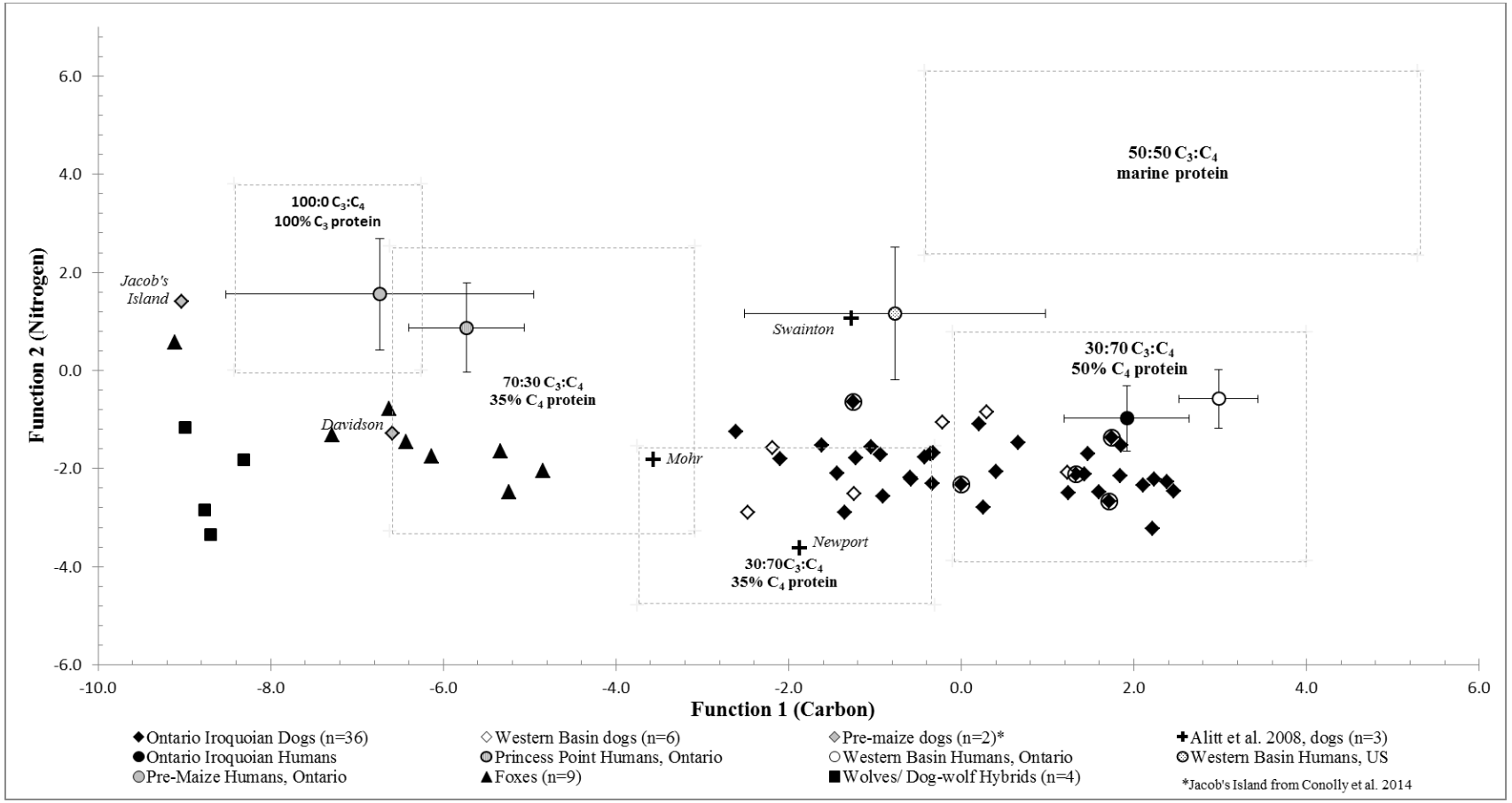


Figure 2.13: Comparison of Late Woodland dog diets using a modified version of Froehle et al's (2012) multivariant model. Ontario Iroquoian dogs are differentiated by time period. Dogs with post-mortem alteration (burning and/or cut marks) are circled. Allitt et al.'s (2008) dog diets are plotted as examples of dogs with marine diets.

2.4.7 Western Basin dogs

Published isotopic data for Western Basin humans are currently available for only three Ontario sites: Krieger (Watts et al. 2011), Great Western Park (Dewar et al. 2012) and Inland West Pit, Location 9 (Spence et al. 2010). The isotopic data for dogs in the current study significantly expand the number of Ontario Western Basin sites from which paleodietary information can be inferred (Figure 2.1, Dobleaar, Roffelsen and Inland West Pit, Location 12). The dogs associated with these sites not only consumed quantities of maize comparable to larger, contemporary Western Basin villages to the west in Michigan and Ohio, but also to Iroquoian villages to the east.

Late Woodland Western Basin dogs from this study are not only significantly enriched in ^{15}N relative to Ontario Iroquoian dogs (Mann-Whitney, Z=–2.789, p=0.005) but also have significantly lower $\delta^{13}C_{col}$ values (Mann-Whitney, Z=–2.986, p=0.003). Although there is no difference in their $\delta^{13}C_{sc}$ values, Western Basin dogs have a significantly larger $\Delta^{13}C_{sc-col}$ values (Mann-Whiteny U, Z=–2.348, p=0.019). Increased herbivory could explain a larger $\Delta^{13}C_{sc-col}$ value, but it is also possible that a greater portion of the Ontario Iroquoian dog diet came from C_4 resources. The most probable explanation for the difference in $\delta^{15}N_{col}$ values is that dogs from Western Basin sites consumed more higher trophic-level protein, such as freshwater fish, though perhaps less meat over-all, and similar amounts of maize relative to Ontario Iroquoian dogs. Although there is inter-site variability among the Western Basin dogs in terms of freshwater fish access, their diets are consistent with archaeological evidence of subsistence and settlement patterns for their human counterparts, in particular the location of summer camp sites near lacustrine and riverine resources (Foreman 2011; Murphy and Ferris 1990). Of the structural carbonate isotopic compositions of six Western Basin dogs that were analysed, over half (all from Arkona) fall along the C_3 protein line (Figure 2.8) and have diets corresponding with animals experimentally fed a diet that was 20% protein (100% C_3) and 80% non–protein (70 to 100% C_4) (Tieszen and Fagre 1993; Ambrose and Norr 1993). The four Arkona dogs plot within the 30:70/C_3:C_4 and 35% C_4 protein box shown on Figure 2.13 (the fourth plots just outside). Although there is some protein in maize (e.g. 3.2±0.04% in modern fresh maize and 8.6±1.1% in dried maize, USDA 2012), it is

negligible compared to that of game meat or fish, which is approximately 20% (raw) and 30% (cooked) protein by weight (USDA 2012). However, a diet in which meat protein is supplemented with cooked maize could account for the isotopic results and still be consistent with the archaeological interpretation that Western Basin dogs consumed more ^{13}C-rich freshwater fish. Dogs from the Younge Phase, Arkona site cluster have the lowest $\delta^{15}N_{col}$ and $\delta^{13}C_{col}$ values, which suggests a regionally or temporally specific pattern in dog provisioning, i.e., unlimited maize access but limited access to freshwater fish or any game that may have consumed maize, including crop or village pests such as mice or squirrels. Interestingly, the Arkona sites represent more settled communities that have greater contact with their Iroquoian neighbours.

The other two Western Basin dogs are from very different contexts and plot closer to the upper C_4 protein line (Figure 2.8) and to the 50% C_4 protein consumption box (Figure 2.13). The Roffelsen dog is one of two from a special context mortuary site that was used for a single family group and dates to approximately A.D. 900–1000 (Grant 2012; Spence et al. 2014). The dog buried at the site was given ritual treatment; i.e., located at the base of a wall (Grant 2012; Spence et al. 2014). Because of itsspecial treatment after death, this dog may also have received distinctive treatment in life. By contrast, the Dobleaar site is later in time (Wolf phase A.D. 1450–1550), and its assignation as a component of the Western Basin cultural continuum is contentious (Stothers and Pratt 1981). The high δ^{13}C value of Dobleaar dog (–12.00‰) relative to all other Western Basin dogs, as well as the presence of the fox (discussed previously) at this site, distinguish it from other Western Basin sites, but without further data the reason for the differences cannot be explained.

2.4.8 Ontario Iroquoian dogs

An ethnohistoric account of Iroquoian dog diets comes from Sagard (1632) who describes the diet of dogs whose "*most usual fare is nothing but the refuse they find in the streets and on the roads*" (Wrong 1939:226). According to Eastern Woodland mythology, dogs were transitional creatures moving between domestic and wild spaces. Their ideologically transitional state would enable them to scavenge within villages as well as maize fields and caches. The lower $\delta^{15}N_{col}$ values of the Late Woodland Ontario

Iroquoian dogs would suggest they did not access as much fish as Western Basin dogs but may have een consumed scraps of fish and meat as well as scavenged maize/maize products, perhaps supplemented with small game hunting. Assuming they were mainly scavengers, the type of refuse they found appears to have changed over time and indicates two dietary patterns, which correlate roughly with the transition from the Middle Ontario Iroquoian phase (A.D. 1200 to 1450) to Neutral phase (A.D. 1450–1650), i.e., A-1 and A-2 groups of domestic dogs noted above.

The primary dietary difference between the two clusters is the C_4 protein contribution. The Middle Ontario Iroquoian dogs cluster in the 50% C_4 protein box, whereas the Neutral phase dogs consumed only 35% C_4 protein (Figure 2.13). The shift in protein source between the two time periods may represent human fishing strategies if lower $\delta^{13}C_{col}$ values indicate increased procurement of fish such as pike, bowfin and perciformes during later periods (see for example, van der Merwe et al 2003: Fig. 4, page 255). Although this interpretation would be consistent with the composition of faunal assemblages (Foreman 2011), a similar shift is not noted in the isotopic data for humans. Alternatively, the shift may be related to variable scavenging ability caused by variable defensibility (presence or absence of palisades) of Middle Ontario Iroquoian sites. For example, the Crawford site was not palisaded, which would provide dogs with greater access to corn–pests in fields and refuse in middens found outside village fortifications, but Neutral sites were predominately and more heavily palisaded (Dodd et al. 1990), which potentially isolated dogs from the world outside the walls.

The function of dogs and their changing role in the community through time could also account for the variation, and reflect a Middle Ontario Iroquoian emphasis on specialized treatment for particular types of dogs (e.g. the use of certain dogs for ritual consumption) compared to a more generalized role of dogs during the Neutral. Wright (2004:1373) remarked on the number of butchered dogs found at Middle Ontario Iroquoian sites, postulating that this time period may have been one "*of heightened ceremonial-political activity.*" Campbell and Campbell (1989) noted increased numbers of dogs in middens at Neutral sites and suggested a shift to a more utilitarian role during the Neutral period. Burning [Fon-117, Ham-25, Rif-020] and cut marks [Pip(1)-180, Pip(2)-103 and Rif-020]

(see examples, Figure 2.15) were noted on five of the canids examined for this study suggesting the animals were butchered and probably consumed (Davis 1987; Prevec and Nobel 1983; Morey 2010; Tarcan et al. 2000; Wright 2004). The isotopic composition of the structural carbonate and collagen of butchered dogs indicates that these dogs consumed substantial quantities of maize year-round, which could imply human intervention in their diet (Figure 2.13, circled black diamonds). The purposeful feeding, post-mortem butchering, burning and probable consumption indicates planned ritual and different or favourable treatment of certain dogs during life. Such ideologically based interaction between humans and dogs has been found elsewhere, e.g., among the Maya, where dogs placed in special contexts had consumed pure C_4 diets (White et al. 2001). These Middle Ontario Iroquoian dogs, however, did not exclusively consume a C_4 food, which begs the question of whether they were purposefully cared for or simply successful scavengers.

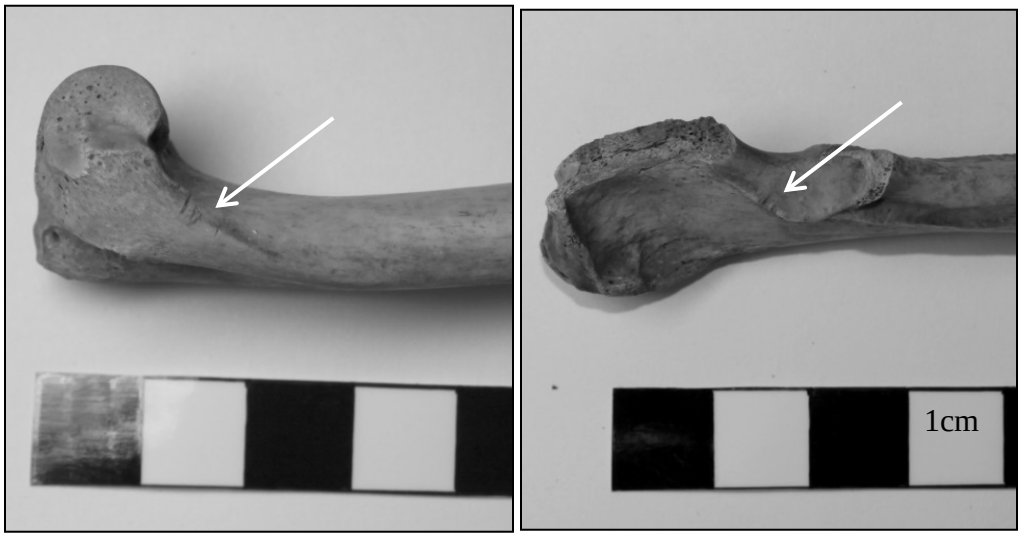


Figure 2.14: Examples of butcher marks on Pip(2)-103 (left) and Pip(1)-180 (right)

Another plausible explanation for the shift from higher to slightly lower C_4 diets from the Middle Ontario stage to the Neutral may be related to individual human-dog relationships. For example, associations between particular dogs and humans are remarked upon in many Eastern Woodland mythologies, including the naming of dogs, sleeping with them and grieving at their death. Isotopic variation may also be accounted

for by individual human preference in the treatment of "their" dog or simply be a function of the sample size. Many of these explanations are not mutually exclusive as their multiple roles and ideological nature enables dogs simultaneously to occupy many positions within a single community.

2.4.9 $\delta^{18}O_{sc}$ of canids: geographic associations

The $\delta^{18}O_{sc}$ values of the canid bones have the potential to reveal information related to *in vivo* geographic locations, e.g., whether wild canids were hunted near human settlements. There are several assumptions that need to be made: (1) the $\delta^{18}O$ values of structural carbonate are well preserved and will reflect locally ingested waters; (2) locally ingested waters will be associated with local precipitation, and (3) local precipitation can be extrapolated from modern water station data. Local $\delta^{18}O_{precipitation}$ values were interpolated with a Kriging analysis using precipitation isotopic data from across the Great Lakes region (IAEA/WMO 2013; Longstaffe, *unpublished data*, Figures 1.2 and 2.16). Structural carbonate isotopic data were transformed to phosphate isotopic compositions following Iacumin et al. (1996:4):

$$\boldsymbol{\delta^{18}O_{phosphate} = 0.98(\delta^{18}O_{sc}) - 8.5} \qquad \textbf{[Equation 2.2]}$$

Currently, there is no specific equation for the relationship between $\delta^{18}O_{phosphate}$ and $\delta^{18}O_{precipitation}$ values for canids, as there is for humans (Daux et al. 2008), deer (Luz et al. 1990), and experimental rats and pigs (see for example Longinelli 1984; Luz and Kolodny 1985). For this study, two equations were used to calculate $\delta^{18}O_{precipitation}$ values: Luz et al.'s general equation (1984:1690) and Luz et al.'s deer-specific equation (1990:1724). Neither produced significantly different results, and therefore Luz et al.'s (1990:1724) relationship was selected because it was developed from North American data, including the Great Lakes region, and allowed the addition of average humidity to the calculation.

$$\boldsymbol{\delta^{18}O_{phosphate} = 34.63 + 0.6506(\delta^{18}O_{precipitation}) - 0.171(humidity)}\ ^{12} \qquad \textbf{[Equation 2.3]}$$

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[12] humidity was estimated at 85%, based on an Ontario average.

For the canids whose structural carbonate was analysed (n=56 adults, 4 juveniles), the $\delta^{18}O_{sc}$ values were compared with several geographic variables, including site longitude and latitude, and estimated $\delta^{18}O_{precipitation}$ for the site. The only statistically significant relationship was an association between $\delta^{18}O_{sc}$ values and latitude (Spearman's ρ=0.255, p=0.049). In order to explore these variables further, juveniles were removed from the sample set because of a potential breast-feeding weaning bias, with the exception of Pip (2)-028, the near adult wolf/dog wolf hybrid. Domestic dogs and wild canids were analysed separately because they are expected to have different access to water sources i.e., domestic dogs may have consumed water within villages.

Water sources may vary in their $\delta^{18}O$ values for several reasons. First, the source of the water being consumed by an animal will affect the $\delta^{18}O$ values (i.e., ground water, direct precipitation, surface water). For example, ground water $\delta^{18}O$ values are usually the average $\delta^{18}O$ value of precipitation from the recharge area, which may have a different $\delta^{18}O$ composition than surface water depending on size and retention-time of the surface waters (i.e., large lakes versus streams) or if ground water is fed by multiple recharge areas (Clark and Fritz 1997; Sharp 2007). Variation in the precipitation feeding ground and surface water (as well as evaporation rates related to temperature and humidity) will be compounded by the time of year (i.e., changes in temperature, humidity and air mass sources) (Clark and Fritz 1997; Sharp 2007). Finally, drinking water sources may be altered by human behaviors, for example boiling of the water will result in highly evaporated water, which is expected to be enriched in ^{18}O.

The following analysis works on the assumption that if fauna are consuming largely unaltered precipitation (i.e., minimally evaporated surface water) there will be a relationship between the estimated $\delta^{18}O$ value of local precipitation and the $\delta^{18}O_{sc}$ values of faunal tissues. However, the low geographic variability of the $\delta^{18}O_{precipitation}$ values across the Great Lakes region of interest (~2‰ based on the interpolation from IAEA/WMO 2013 and Longstaffe *unpublished data* water stations), relative to other factors, such as seasonal fluctuations and source water, means all interpretations should be taken with some caution. While a statistical analysis is completed in the following sections, further work is needed to confirm the findings.

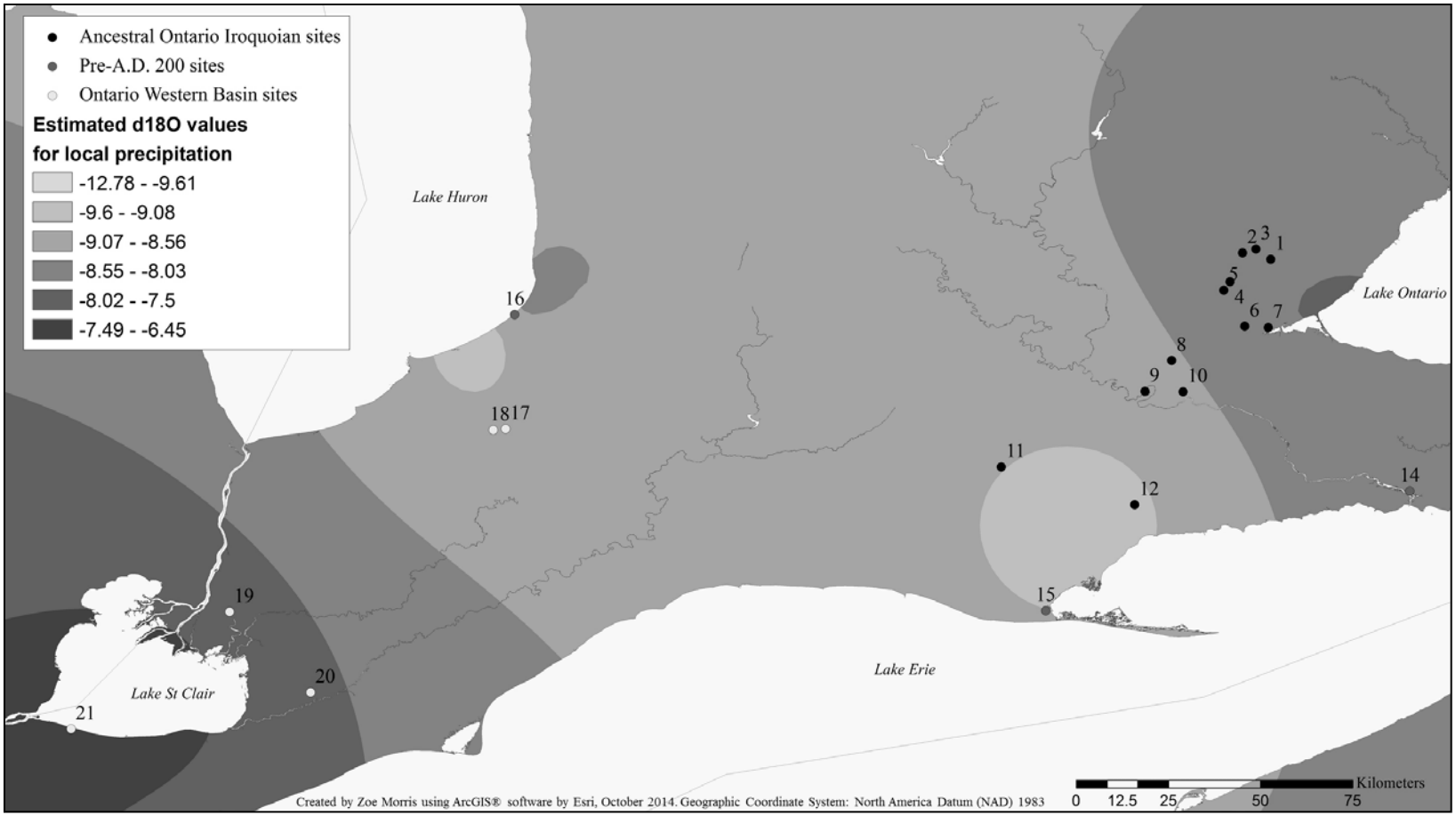

Figure 2.15: Archaeological sites with canid remains overlaid on the interpolated δ^{18}O values for local precipitation from the previously described Kriging model (IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2).

Ancestral Ontario Iroquoian Sites: 1. Pipeline; 2. Rife; 3. Crawford Lake; 4. Bogle II; 5. Hamilton; 6. Winking Bull; 7. Old Lilac Garden; 8. Fonger; 9. Porteous; 10. Walker; 11. Van Besien, 12. Slack-Caswell; 13. Thorold.Pre-maize Sites: 14. Cranberry Creek; 15. Bruce Boyd; 16. Davidson. Ontario Western Basin Sites: 17. Figura; 18; Inland West Pit Sites, Loc. 3, 9 and 12; 19. Dobbelear; 20. Roffelson, 21. Silverman..

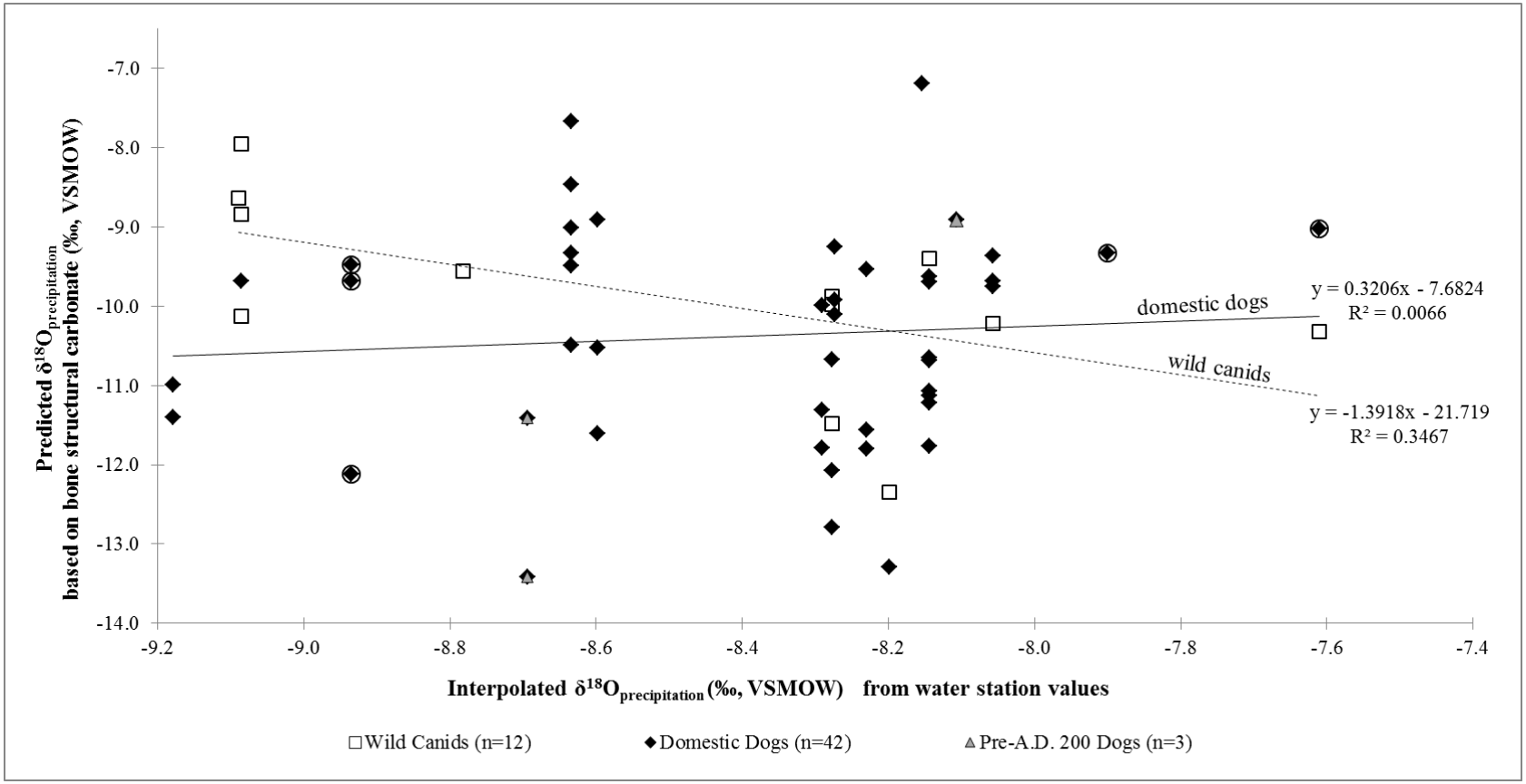

Figure 2.16: Interpolated $\delta^{18}O_{precipitation}$ values[13] compared to calculated $\delta^{18}O_{precipitation}$ values based on the $\delta^{18}O_{sc}$ values[14]. Ontario Iroquoian domestic dogs = black diamonds, Western Basin domestic dogs = circled black diamonds.

[13] Interpolated from water station data from IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2

[14] Calculated from Iacumin et al. (1996:4) and Luz et al.'s (1990:1724).

There was a stronger association between the wild canid $\delta^{18}O_{sc}$ values and the predicted $\delta^{18}O_{precipitation}$ values (Spearman's ρ=–0.631, p=0.028, Figure 2.16), but the correlation is negative making, which makes interpretation difficult.

For domestic dogs, the only geographic variable significantly correlated with $\delta^{18}O_{sc}$ values was latitude (Pearson's R=–0.340, p=0.016), which suggests some geographic relationship between the $\delta^{18}O_{sc}$ values of their bones and site location. However, unlike the wild canids, water consumed by the domestic dogs does not reflect local $\delta^{18}O_{precipitation}$ values (Figure 2.16). One putative explanation is that domestic dogs were restricted geographically (e.g., by palisades or by choosing to stay close to scavenged food) and therefore limited to imbibing evaporated waters found within villages and campsites (e.g., puddles, water collected in pots, or boiled water in *sagamite* and stews). The $\delta^{18}O_{sc}$ values of the domestic dogs, however, are not significantly higher than those of the wild canids, which would be expected if the domestic dogs consumed evaporated waters. An alternative explanation is that dogs ranged between isotopic zones as hunting partners or were traded between isotopic zones. Ethnohistoric documents from the Eastern Woodland report that dogs may have been traded and/or sought across great distances (Thwaites 1896–1901 43; 23). The two possibilities are not mutually exclusive as multiple roles and treatments are evident for the domestic dogs.

2.5 Conclusion

This paper has demonstrated the importance of integrating multiple isotope analysis with zooarchaeological data and of using wild and domestic species to understand cultural preferences regarding hunting strategies and subsistence choices. Wild canids, i.e., foxes and wolves, have been used here to identify hunting locations and an opportunistic approach toward certain hunted species. Domestic dogs proved to be excellent proxies for human diet for both Ontario Iroquoian and Western Basin populations, thereby expanding the number of sites that could yield dietary data and enabling a better understanding of the similarities and differences in diet and subsistence.

Differences in the frequency of wild canid species recovered from Ontario Iroquoian and Western Basin faunal assemblages suggest different hunting strategies or patterns of disposal. The isotopic compositions of bone collagen and structural carbonate of dogs and wild canids demonstrate variable access to maize and protein sources. The four large Canid sp., presumed to be wolves, consumed only from a C_3 food web, which suggests geographic separation from human settlement. However, their presence in Iroquoian faunal assemblages and their $\delta^{18}O_{sc}$ values suggest that overlapping hunting territories could have resulted in occasional interspecies aggression and/or ritual use of wolf remains. The carbon and nitrogen isotopic compositions of foxes from Ontario Iroquoian and post A.D. 1400 Western Basin sites indicate they were consuming 'crop-pests' and, in turn may, have been opportunistically hunted while in maize fields. The higher frequency of fox remains at Iroquoian sites suggests different seasonal land use, hunting strategies or disposal patterns. Ontario Iroquoian peoples may have actively pursued crop pests (explored further in the following Chapter 3) while Western Basin peoples pursued game more often during cold weather and their hunting grounds may have been geographically separated from the location of their maize fields.

Dogs from both Late Woodland Iroquoian and Western Basin sites effectively serve as proxies for human diet, thus facilitating comparison of the well-known Ontario Iroquoian dedicated maize horticultural diet with the diet of the semi-mobile, horticultural Western Basin peoples. The findings suggest that domestic dogs ate protein from a higher trophic level than wild canids, which probably indicates more fish in their diet. Both Western Basin and Ontario Iroquoian dogs ate comparable amounts of maize, which supports recent evidence of heavy maize consumption by Western Basin human populations. These findings support year-round maize consumption at Western Basin sites despite the archaeological evidence of seasonal mobility.

Western Basin dogs appear to have consumed a lot of fish in general, though inter-site variability suggests that site-specific patterns should be further explored. Younge Phase dogs at Arkona have distinct diets, marked by more C_3 protein. A dog from Roffelsen, a unique Younge Phase site, has a diet consistent with purposeful maize feeding, which may be related to its roles before and after death as it was recovered from a special

context burial. The single, late phase Western Basin Dobleaar dog had a diet consistent with year-round maize access and is believed to have consumed large quantities of maize and presumably freshwater fish.

The Late Woodland Ontario Iroquoian dogs varied both geographically (north of the Carolinian versus within the Carolinian forest) and temporally. As might be expected, domestic dogs recovered from within the Carolinian forest, an area marked by longer growing seasons, had greater access to maize. An unexpected finding was the higher $\delta^{13}C$ values from the earlier, Middle Ontario Iroquoian stage (A.D. 1200–1450) relative to the Neutral (A.D. 1450 to 1650). Previous research has suggested that the Middle Iroquoian stage may have been a time of increasing ceremonialism, resulting in more dog sacrifice. Three of the Middle Ontario Iroquoian dogs display cut marks consistent with post-mortem butchery and may have been ritually consumed or sacrificed. By contrast, the later Neutral dogs show no cut marks (although there were two incidences of burning), a reduction of maize access and more variability in $\delta^{15}N_{col}$ values. A shift in the type of freshwater fish consumed by humans (e.g., pike, bowfin and perciformes, which have lower $\delta^{13}C_{col}$ values) may explain some of the change, and is consistent with the species composition of faunal assemblages. In addition, the economic and spiritual role of Iroquoian dogs may have changed with increasing population size and sedentism. Whether or not such shifts were the result of stricter taboos, food scarcity or the development of a different relationship between dogs and people cannot be deciphered from the stable isotopic analysis alone.

An Archaic dog from the Davidson site represents the oldest canid analysed isotopically in southwestern Ontario. The dog appears to have consumed high trophic level prey, probably from both terrestrial and aquatic systems within a C_3–dominated food web. Itsr likely consumption of freshwater fish, not readily available to wild canids, marks its domesticated status. This finding makes this 3500 year old canid the earliest-known, definitively domesticated dogs in southwestern Ontario.

No significant differences in oxygen isotopic composition were found between Ontario Iroquoian and Western Basin domestic dogs. There are, however, differences between

domestic dogs and wild canids, which may be related to water access. The negative correlation between wild canid $\delta^{18}O_{sc}$ values and local precipitation is problematic to interpret. The $\delta^{18}O_{sc}$ values of domestic dogs are not correlated with precipitation isotopic compositions, perhaps because they drank from variable water sources (i.e., puddles) or moved around as hunting partners and/or trade items.

The demonstration that dogs can provide a valid dietary proxy for contemporary humans is a significant step forward in our ability to reconstruct the life-ways of indigenous peoples in this region, especially as access to human remains is tightly restricted. This study also provided insight into other aspects of human-canid relationships. The analysis of both wild and domestic canids from Ontario Iroquoian and Western Basin sites successfully demonstrated: (1) differences in cultural relationships to land use; (2) dietary shifts that might reflect changing economic and spiritual roles of dogs during the Late Woodland period, and (3) differences in hunting patterns.

2.6 Future Work

Future research should focus on the selection of: (1) a wider temporal and geographic sample of canids in order to fill gaps, particularly from the Middle to Late Woodland transition, as well as the entire Western Basin temporal span in Ontario, and (2) specimens where multiple tissues (e.g. enamel, dentine and bone) are available. The latter would enable expansion of seasonal studies regarding canid access to maize, and geographic studies of the movement of dogs as proxies for trade. Future work should also expand on the structural carbonate isotopic analysis of all canids to create more detailed dietary profiles.

In an exploratory study, isotopic analyses were performed on serial samples of the first and second permanent mandibular molar (the third permanent molar was not available) from an archaeological dog (Van 124) from Van Besien site, an Early Ontario Iroquoian village. The test was successful in capturing a clear weaning signal (Figure 2.17). Based on modern domestic dog eruption sequences (Hillson 2005:258, Mulligan et al. 1998:72) and radiographs (n=8) of juvenile dogs (Morris, *unpublished*), the two molars are estimated to form over approximately three months, the first molar completing formation

just prior to the second molar. The third permanent molar, estimated to form over the fourth and sixth month of life (Morris, *unpublished*) will be included in future serial section studies. This multiple tissue research can be used to reconstruct the geographic movement of dogs and patterns of seasonal maize consumption, which could be particularly informative of how the maize subsistence of Western Basin peoples was integrated with hunting and fishing activities.

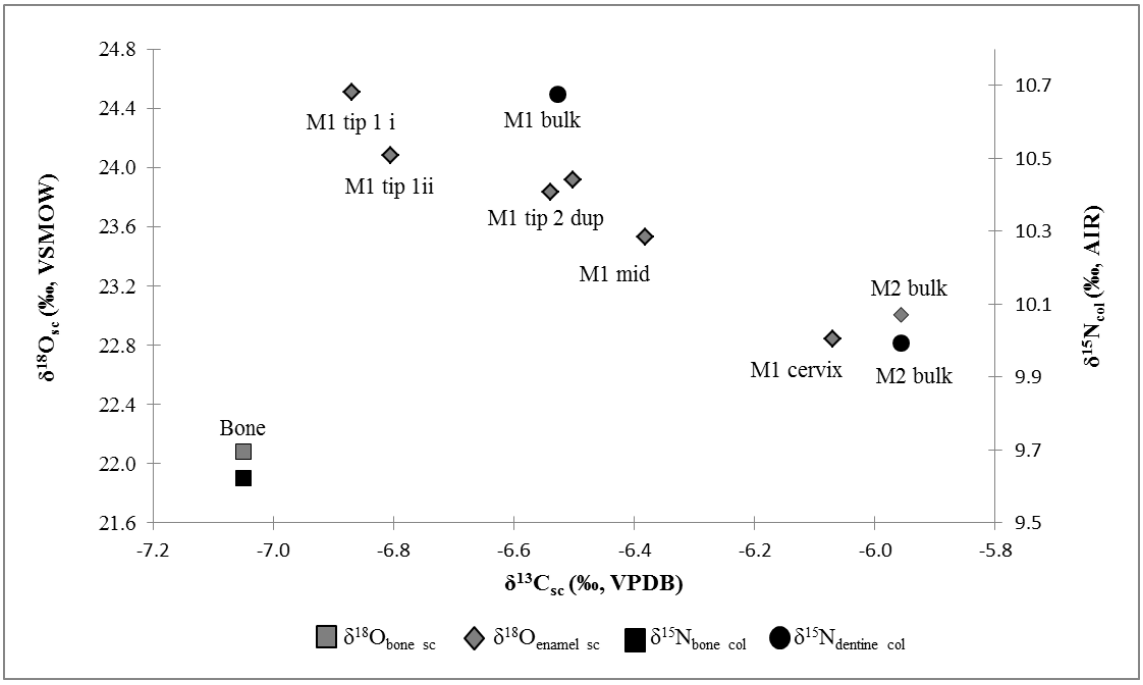

Figure 2.17: $\delta^{18}O_{enamel}$ and $\delta^{15}N_{dentine}$ values versus $\delta^{13}C_{enamel}$ for serial sections of first and second permanent mandibular molar of Van Besien site dog specimen Van–124.

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Chapter 3

3 Wild Turkey

3.1 Introduction

"In some districts… there are turkeys, which they call Ondettontaque*, not tame but migrating wild birds. The son–in–law of the great' chief of our town chased one for a long time near our hut but was unable to catch it. For though these turkeys are heavy and clumsy they can fly, and in spite of their weight make their escape from tree to tree, and in this way avoid the arrows. If the savages were willing to give themselves the trouble of feeding young ones they would domesticate them as well as we do here."* (Wrong 1939:220)

Gabriel Sagard's quote, describing the relationship of turkey to the Iroquoian-speaking nations, highlights a commonly held belief that animals are limited to either wild or domestic spheres. This paper attempts to dispel the myth that human-animal relations are a dichotomy of the wild versus domestic, and instead, examines the nuanced and varied relationships of the ancestral Neutral Ontario Iroquoian people with the eastern "wild" turkey. Employing the concept of spectrum (Russell 2012:251) to explain a range of human-animal interactions, the stable isotopic and faunal data provide evidence of "protection" of wild turkeys in the form of purposeful discard of maize waste in fields, a behaviour that attracted the birds and provided increased food assurance for the Late Woodland Iroquoian people. As Harris (1996) notes, the range of relations between wild and domestic is neither inevitable nor unidirectional (i.e. it is reversible). Therefore no assumptions are made regarding wild turkey domestication in southwestern Ontario.

As the largest terrestrial avian species indigenous to North and Central America, wild turkeys were an important hunted species, even in regions where domesticated turkeys are present (see for example use of Merriam's turkey in the southwest, Speller 2009). The wild turkey was exploited by indigenous peoples for food, ritual, medicine, tools, and clothing (Dickson 1992; Laubin and Laubin 1977; McNeese 1998; Ritzenthaler and Ritzenthaler 1970; Schorger 1966). Numerous ethnohistoric accounts from the northern

Eastern Woodland region describe the hunting and consumption of wild turkeys (Thwaites 1896–1901 vols. 34; 47; 54; 58; 59; 60; 65; 66; 67; 69; 70; 71; Wrong 1939), the hunting of turkeys in colder months (Thwaites 1896–1901 vols. 21; 32; 34; 59; 60), the use of turkeys to construct cloaks and hair pieces (Leland 1886; Thwaites 1896–1901 vol. 65), and the use of turkeys in ritual and medicine (Thwaites 1896–1901 vol. 13).

Zooarchaeological data provide evidence of the ubiquity of wild turkeys in Late Woodland faunal assemblages, though their relative importance varies by site and time compared to other birds (such as the passenger pigeon), mammals and fish (Foreman 2011; Prevec and Nobel 1983; Stewart 2000). Further, there was a decrease in wild turkey procurement over the course of the Late Woodland (A.D. 900 to 1600), which is attributed to a shift to spring planting and fall harvesting of domestic crops (Foreman 2011). It is speculated that the diversion of labour necessitated by these activities would have caused a reduction of hunting opportunities for cold weather–hunted species including white-tailed deer and wild turkey. As long-term settlement use and domestic crop dependency increased over the 700-year period, faunal procurement became less specialized and more informal (Foreman 2011).

Although there are ample archaeological and ethnohistoric data to indicate that turkeys of the Eastern Woodland were hunted wild for food, feathers and bones, there are no data to indicate they were domesticated by either Late Woodland groups of the northeast or Mississippian peoples of the southeast. They might, however, have been managed and/or loosely protected by food baiting, i.e., creating a winter feeding-ground by leaving maize in fields after harvest. This practice has not been described elsewhere in North American archaeology but is sometimes used today not only by individual hunters and farmers but also by jurisdictions attempting to aid re-introduction and survival of wild turkeys (see for example the New Hampshire Fish and Games and Department of Environmental Conservation [2014, updated May 2015) advisory for feeding wild turkey).

The importance of maize horticulturalism increased significantly around A.D. 1000 becoming a dietary staple for Ontario Iroquoian and Western Basin peoples, two neighbouring Great Lakes cultural groups. Despite a mutual growing dependence on

maize, the two groups maintained different subsistence-settlement strategies (Murphy and Ferris 1990). Sedentism and population growth increased exponentially after A.D. 1000 among the Iroquois while Western Basin peoples pursued more varied settlement patterns, often moving in order to exploit seasonal resources. Examination of the animals exploited by archaeological peoples provides insight into ancient subsistence and hunting strategies. In this case, the isotopic compositions of wild turkeys from faunal assemblages were compared with those from modern Ontario wild turkeys and archaeological turkeys from Eastern Woodland, American Southwestern, and Mexican sites (Figure 3.1) in order to better understand the faunal record and determine whether Late Woodland Ontario peoples managed wild turkeys by using maize. Because maize was the only horticultural C_4 plant in southwestern Ontario during the study period, stable isotopes can provide evidence of human provisioning of wild turkeys with maize. Furthermore, the fact that turkeys are non–migratory, terrestrial birds that opportunistically forage on available resources (Eaton 1992; Lippold 1974; Schorger 1966) makes them an ideal proxy for examining human landscape change in the past.

3.2 Background

3.2.1 The eastern wild turkey: habitat and behaviour

Prior to European contact, the turkey (*Meleagris gallopavo*) was represented by six subspecies in Northern and Central America (Figure 3.1). The eastern wild turkey (*Meleagris gallopavo silvestris*, or *M.g. silvestris*) was native to the eastern United States and southwestern Ontario (Eaton 1992; Godfrey 1966; Shorger 1966). Because severe winters can devastate wild turkey populations (McIlwraith 1886), the mild climate of southwestern Ontario is the only Canadian location for these birds and represents their northern limit (Dean 1994; Prevec and Noble 1983). *M.g. ocseola* was found in Florida, and integrated with *M.g. silvestris* in the southeastern Atlantic and Gulf States. *M.g. intermedia* was found from eastern Texas along the northeastern coast of Mexico, while *M.g. mexicana* was originally dispersed along the west coast of Mexico. *M.g. gallopavo* was originally dispersed throughout central Mexico. Finally, *M.g. merriami* was found in the southwest, north of the Mexican border (Eaton 1992; Leopold 1944; Schorger 1966; Speller et al. 2010).

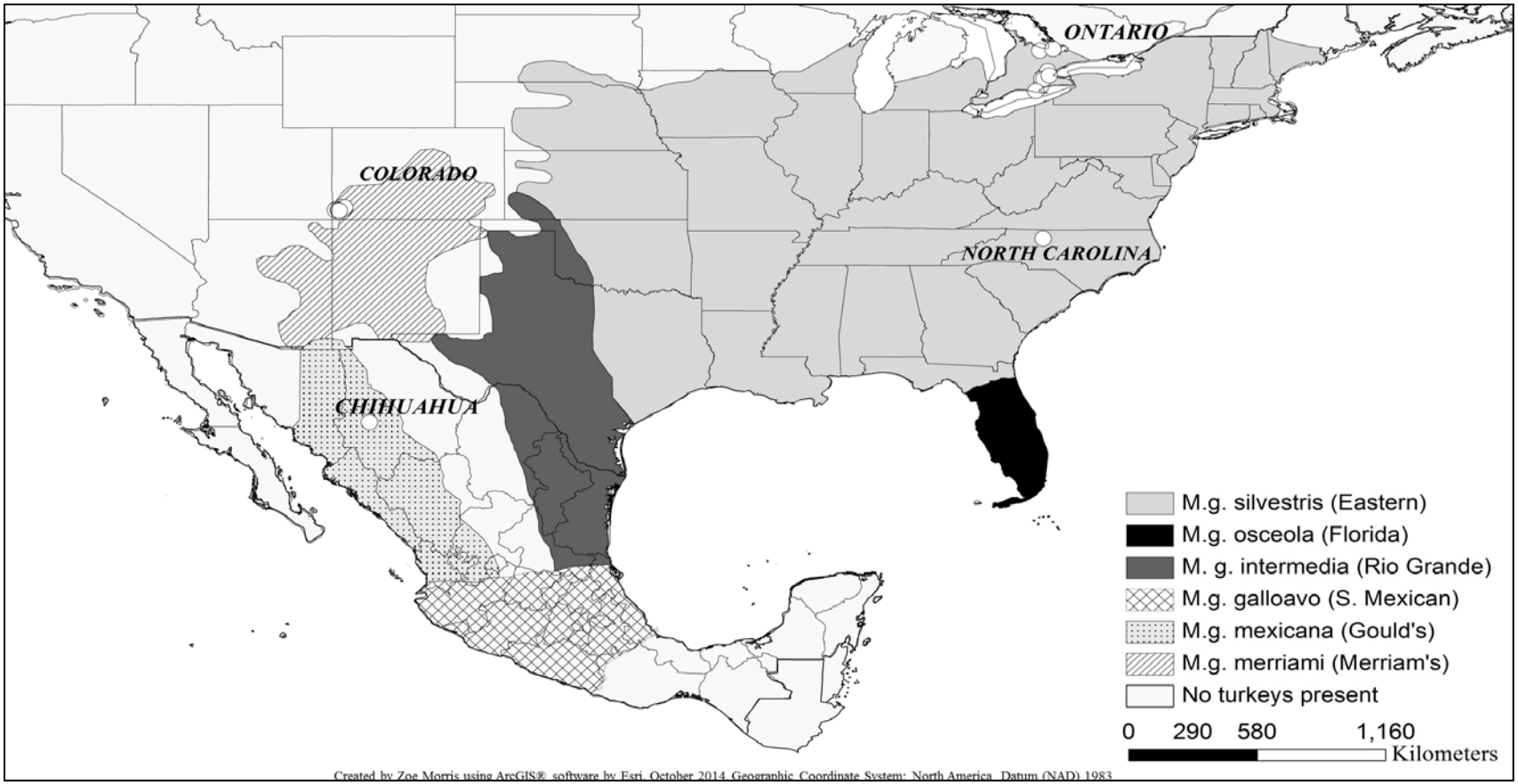

Figure 3.1: Distribution of wild turkey prior to European contact.[15]

[15] Adapted from Speller et al. (2010:Figure 4) (United States and Central America), Eaton (1992) (Ontario) and Schorger (1966:43, 49) (United States and Canada). Areas mentioned in text marked by white circles: (1) Southwestern Ontario (Katzenberg 1989, 2006; This Study), (2) Southeastern United States (Price et al. 2010; Price unpublished data), (3) Southwestern United States (Rawling and Driver 2010), and (4) north–central Mexico (Webster and Katzenberg 2008).

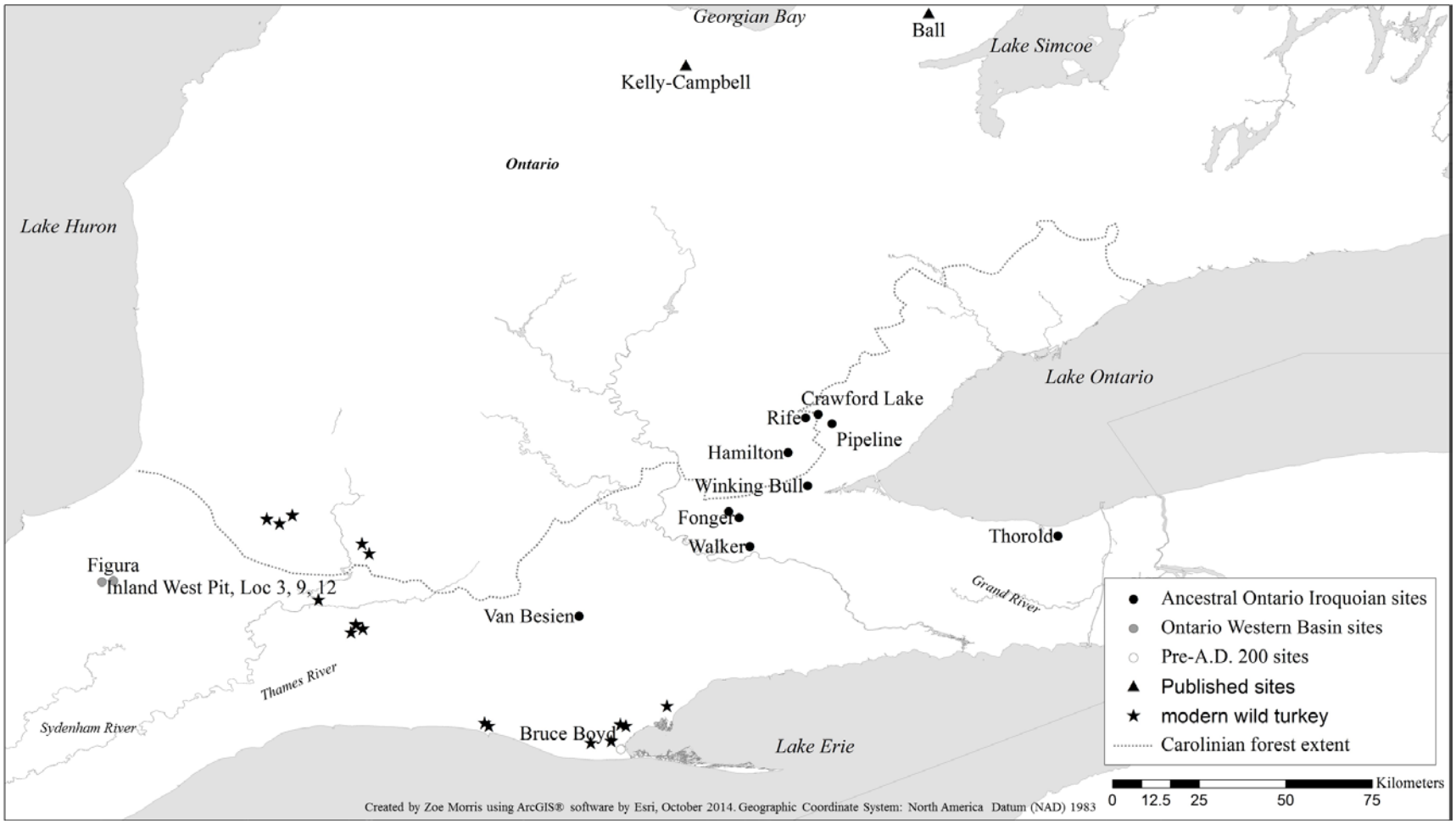

Figure 3.2: Archaeological sites with wild turkey remains analysed in this study and published isotope data (Katzenberg 2006). Approximate hunting and/or recovery locations of modern turkey samples analysed in this study are shown as black stars.

Wild turkeys (*M.g. silvestris*) were extirpated from Ontario due to a disease contracted from introduced domestic species, over hunting, and land clearing activities, but were re-introduced to the region in the 1980s (Heckleau 1982; McIlwraith 1886; Weaver 1989). Weaver (1989:1) analysed the movement of a re–settled population of wild turkeys in southwestern Ontario describing them as "*ecological generalists, adapted to variable and unpredictable environments*." The modern range of re-introduced wild turkeys is greater than their post-contact, historic range and considerably more diverse because they are broadly adaptable (Weaver 1989). Modern ecological studies of wild turkeys suggest that they can tolerate human population densities up to fifteen persons per km^2, exploit a wide range of food resources and inhabit areas of mature forest that are interspersed with open meadow or agricultural fields (Hecklau et al. 1982), but they must be near water sources (Eaton 1992; Schorger 1966; Weaver 1989). Although the diet of the turkey is widely variable and best described as opportunistic, regionally and seasonally adaptable, it is dominated by hard and soft mast (i.e., nuts and fruits from trees and shrubs), as well as insects and small vertebrates (Eaton 1992; Schorger 1966; Weaver 1989). In areas with available agricultural sources more than half of the diet will include cultigens, with waste maize comprising up to 77% of the agricultural component or approximately 35% of the total diet (Groepper et al. 2013; Tefft et al. 2005).

The adaptability of wild turkeys is also reflected in their flexible patterns of movement and use of home ranges. Researchers have argued that food location and abundance controls turkey movement, particularly in the winter (Ellis and Lewis 1967). Wild turkeys in southwestern Ontario do not significantly re-locate during winter (Weaver 1989), which suggests that they are able to meet nutritional requirements without increasing daily distance travelled. In fact, the average annual range of southwestern Ontario turkeys is approximately 1000 acres (Weaver 1989), which is lower than that for the northeastern United States (see for example Schroger 1960). However, their use of agricultural land, particularly maize fields, increases during winter months and is often a primary factor in selection of wintering areas (Ellis and Lewis 1967; Leopold 1944), contributing to higher survival rates (Hayden 1980; Porter 1977; Porter et al. 1980; Vander–Haegan et al. 1989; Weaver 1989). Although the feeding range of wild turkeys changes with season, once a

food source is found, it is often accessed using the same routes, which makes them vulnerable to predators, including human hunters (Schorger 1960). Their daily pilgrimage routes are predictable as are their times of arrival and departure.

The presence of wild turkeys in maize fields has led to their characterization as crop–pests but, in fact, they rarely cause crop damage. Extensive research in the mid–west and Ontario has demonstrated that they eat only maize damaged by wind or water, or knocked down by other animals or left in the fields after harvest (Greene et al. 2010; Groepper et al. 2013; Tefft et al. 2005; Wright et al. 1989). Turkeys can remove kernels from cobs that have fallen to the ground but cannot reach or pull down the cobs from standing stalks. Damage to crops is usually the result of depredation by other species, such as deer and raccoons (Ontario Ministry of Natural Resources 2007; Tefft et al. 2005). The presence of wild turkeys in fields may, in fact, benefit farmers because insects (including known crop-pests such as grasshoppers) are an important summer food for turkeys (Groepper et al. 2013; MacGown et al. 2006; Wright et al. 1989). Young poults born in the early summer consume far more insects than mature turkeys, and then convert to a primarily plant-based diet within four to five weeks after hatching (Dickson 1992; Eaton 1992; Wright 1989). The fact that wild turkeys can only eat maize ears and other remnants left on the ground has profound implications for archaeological interpretation of human harvesting patterns and the possible management of wild turkey populations to create a stable cold weather food source for ancient peoples .

Wild turkey hunting in the northeast, both today and in the past, appears to be restricted to colder months (October through March), likely because summer turkeys are low weight and tick-infested (Boone 1851; Foreman 2011; Lippold 1974; Schorger 1966).

3.2.2 Wild versus domesticated: dichotomies versus continuums

In reference to domestication of animals, including wild turkeys in the southwest United States;. "*It has already been shown that agriculture was, in its beginning, an art of the desert; it may now be affirmed that the sister art, zooculture, is also a child of sun and sand*," (White 1945:230).

An important economic and ritual resource in many indigenous regions (Davis 2001; Dickson 1992; McKusick 1986; Rawlings and Driver 2010), the turkey was the only animal domesticated in North America prior to European contact. Even the dog arrived to the Americas already domesticated. After contact, turkeys quickly became a globally important food source as Europeans brought domesticated turkeys back to Europe and other colonies (Crawford 1992; McIlhenny 1914; Russell 2012; Schorger 1966).

Currently, the widely accepted definition of domestication is the selective modification of a plant or animal in captivity (or isolation from wild counterparts) for the benefit of humans, resulting in genetic and morphological differences in that organism relative to their wild progenitors (Bökönyi 1969; Branford Oltenacu 2004; Clutton-Brock 1994; Harris 1996; Ingold 1994). Russell (2012) has argued that most definitions such as this, however, are either so broad as to become meaningless, or too exclusionary. Russell does note that having a definition of domestication is important for defining criteria to identify human-animal relationships in the past (i.e., morphological changes, shifts to animals as property, etc.). The concept of domestication defined above does provide a general understanding of how (isolated, selective breeding) and why (human benefit) domestication may occur. Therefore, it is possible to examine wild and domestic species morphologically and consider the various ways humans used those animals for their benefit. However, the definition does not leave room for other human-animal interactions. For example, management of certain species to maintain “wild” populations would not be recognized as domestication, but may alter natural distributions of a species. Even the population size and age profiles of “wild animals” may be changed for human benefit so may not be a clear example of an unaltered relationship (i.e., aquaculture, Webster et al. 2004). Nor does the above definition address why certain organisms may or may not be candidates for domestication. In fact, there are certain criteria that have been recognized as important for successful domestication for both plants and animals (see for example Chapter 2, domestication of the wolf). Wild turkeys exhibit behavioural patterns critical for animal domestication, which include their social nature (flocking behaviour), promiscuous mating system, strong parent-young bonding, high fertility, short flight response (non-migratory behaviour), low reactivity to humans and environmental change and their omnivorous diet and innate adaptability (Breitburg

1993:163, after Hale 1969). Their ease of domestication has been demonstrated in the American southwest and Mexico, where they became an important economic and ritual resource (Beachum and Durand 2007; Davis 2001; Dickson 1992; McKusick 1986; Rawlings and Driver 2010).

While some organisms may be prone to domestication, the range of interactions between humans and animals, which are neither "domestication" nor "not-domestication" cannot be ignored, as they may be part of the process towards the domestication of species. For example, there may be different behaviours exhibited by humans interacting with animals, such as taming, protective herding and free-range management, including adaptation to human landscape changes and consumption of human waste products, which alters the nature of their relationship and may begin the process of modification in the organism, with or without intent for domestication (Harris 1996; Ingold 1994; Russell 2012).

The limiting dichotomy of wild versus domestic, therefore, has justifiably been challenged by many researchers who advocate a more fluid conceptualization or a continuum of this human-animal relationship (Harris 1996; Ingold 1994; Russell 2012; Zeuner 1963). For example, Russell (2012) remarks on the difficulty of defining domestication because it is only one of a myriad of human-animal relationships, and argues that the complicated nature of human-animal interactions should be viewed as a spectrum rather than a continuum, which implies a smooth and/or directional process (2012). Zeuner (1963:63) described stages of "intensity" where the relationship between animals and humans may pass from loose contact to the extermination of the wild ancestors, which is the most extreme result of domestication. The process of domestication is neither inevitable nor irreversible, but includes a stage of "protection," which according to Harris (1996:447-8) falls between predation and domestication. Protection may include taming of wild animals or free-range management. The spectrum approach is particularly useful when considering the case of the wild turkey in southwestern Ontario.

Humans benefit from the food security conferred by domestication, as a domesticated organism is a more controllable, available, and predictable food source than a wild gathered plant or hunted animal. Increased access to secondary food products such as eggs, dairy, and by-products (e.g., honey) are also associated with domestication. Other reasons for domestication include companionship, hunting partners, and beasts of burden (Clutton–Brock 1994; Harris 1996; Russell 2012).

Nearly simultaneous, but independent, domestication of turkeys in the Americas has been confirmed genetically, and occurred approximately 2000 years B.P. (Mock et al. 2002; Speller 2009; Speller et. al. 2010; Thornton et. al. 2012). *M.g. gallopavos* was domesticated in south-central Mexico (Schorger 1966) and an as-of-yet unknown progenitor, most likely *M.g. silvestris* or *M.g. intermedia*, was domesticated in the southwestern United States (Breitburg 1993). The motivation for turkey domestication is unclear. Some ethnohistoric accounts suggest turkey were domesticated as a food source for meat and eggs while others argued their feathers were valued more than meat because of their ritual significance (Breigburg 1993). The activity of feasting, which may involve the ritual and practical use of animals, has also been suggested as a major motivation for turkey domestication (Hayden 2009). The separation of ritual and food uses of turkey may, therefore, be artificial (see for example Zimmerman-Holt 1996) when trying to understand their domestication.

3.2.3 Previous stable isotope bird studies

The majority of bioarchaeological, paleodietary and paleoenvironmental isotopic studies focus on the analysis of mammals (human or other). There are fewer studies of ancient birds, though modern research has been conducted for several species (e.g., Kelly 2000 for summary). Modern bird research has focused on metabolic factors (Hobson and Clark 1992a; 1992b), migration (Hobson 1999; Rubenstein and Hobson 2004), starvation and fasting (Hatch 2012; Hobson 1993; Kempster et al. 2007), diet reconstruction (Mizutani et al. 1992) and seasonality (Stearns 2010). The latter study used δ^{13}C values of wild turkey feathers collected during winter months in Utah to demonstrate the inclusion of agricultural fields in the winter feeding-range of wild turkeys. Generally, the principles of

stable isotopic analysis of bone apply to both birds and mammals, though some key differences are addressed below.

Bone is a dynamic tissue that continuously remodels throughout life and generally represents a long-term average of what an organism eats and drinks, but the isotopic turnover rate of any tissue is correlated with metabolic rate (Hobson and Clark 1992a; Tieszen et al. 1983). Differences in metabolic rates have been noted between mammals and birds, and are influenced by habitat, dietary niche and body size (Nagy 1987, 2005). Birds, in general, have higher metabolic rates than land mammals (e.g., Hobson and Clark [1992a] calculated the half-life of carbon in Japanese quail collagen to be 173.3 days) but captivity slows down metabolism (Hobson and Clark 1992a; Nagy 1987). Nonetheless, the family to which turkeys belong (Galliformes) has a low metabolic rate compared to other birds regardless of wild or captive state (Nagy 2005). As large terrestrial birds, turkeys most likely have a metabolic rate comparable to equivalent-sized mammals (Lasiewski et al. 1967). Young birds, however, have much faster bone turnover rates than adult birds. Consequently, the collagen of juveniles (i.e., < 1 yr old) is assumed to represent their growth phase, and that of adults, a life-time, post-growth phase average (Hobson and Clark 1992a). The results of adult and juvenile wild turkeys were therefore initially considered separately to ensure that there were no statistically significant differences between the adult and juvenile populations.

Differences in tissue isotope fractionation between birds and mammals could also be caused by the fact that that birds produce uric acid instead of urea, but to date, no such differences have been found for collagen (Hobson and Clark 1992b). There are also no data to suggest that the structural carbonate contained in bone bioapatite behaves differently in birds and mammals.

3.3 Materials and methods

3.3.1 Materials

Archaeological turkey samples were selected from previously excavated faunal collections housed at various institutes across southwestern Ontario (Department of Anthropology, McMaster University; Department of Anthropology, The University of

Western Ontario; Ontario Museum of Archaeology) Site descriptions may be found in Appendix A). Modern wild turkey samples were donated by the Comparative Faunal Laboratory, Department of Anthropology and Department of Biology, The University of Western Ontario, as well as by several individuals (Brad Tweddle, Jim Keron, Dr. Ryan Hladyniuk, Dr. Wendy Russell, and Ted Barney). Figure 3.2 shows the approximate locations for the modern turkeys and the locations of archaeological sites in Ontario discussed in the text. Due to variable preservation quality, archaeological wild turkey samples were selected based on their availability, but where multiple turkeys of the same age/size were found within a single feature, the same element and side were selected to avoid duplicate sampling of the same individual. The ulna was preferentially selected because the wings were the most common portion of the bird donated by hunters.

De-fleshing of the modern turkey samples was completed by the author in the Zooarchaeology Laboratory, Department of Anthropology, The University of Western Ontario. Specimen identification was completed by the author, Dr. Lindsay Foreman and Dr. Lisa Hodgetts, all from the Department of Anthropology, The University of Western Ontario. The Western comparative collection includes several adult, eastern wild turkey (*M.g. silvestris*) skeletons, along with many other indigenous birds from Ontario, which were used for morphological comparison. Wild turkeys are the largest terrestrial bird in Ontario and therefore have a morphologically distinct skeleton, which helps to differentiate their fragmentary remains from those of other large bird species, most of which are migratory and/or aquatic.

The collagen of eighty wild turkeys was analysed for this study (summarized in Appendix B). Forty–four Ontario Iroquoian wild turkeys, including 34 adults and 10 juveniles, were selected for collagen analysis from ten sites located in southwestern Ontario. The isotopic analyses of two Late Woodland wild turkeys from previous work by Katzenberg (2006) expand the geographic range of the Ontario Iroquoian samples. An additional fifteen adult wild turkeys were analysed from the neighbouring Western Basin Inland West Pit sites (A.D. 1150–1270), near Arkona, Ontario. To provide an isotopic baseline for turkeys prior to the entry of maize to the region (Crawford et al. 2006), two wild turkeys from the Bruce Boyd site (component dating to ~700 to 400 B.C.) were also

analysed (Spence et al. 1978) (Table 3.1). Published isotopic data for archaeological wild and domestic turkeys from other North American sites were used for comparison including: the Donnaha Site in North Carolina, n=16 (Price et al 2010; Price 2009), several sites in Colorado, n=30 (Rawlings and Driver 2010), and a single sample from the Chihuahua region of Mexico (Webster and Katzenberg 2008) (Figure 3.1). Collagen from nineteen modern turkeys from southwestern Ontario was also analysed (Appendix C). Additionally, the isotopic composition of bone bioapatite structural carbonate from fourteen modern and thirteen archaeological turkey samples was analysed to assess whether the relationship between avian collagen and structural carbonate is comparable to that of mammals (Appendix D and E).

Table 3.1: Summary of wild turkeys analysed for this study

		Pre–horticulture pre A.D. 200 (sites n=1)	Ontario Iroquoian A.D. 900–1600 (sites, n=10)	Western Basin A.D. 900–1600 (sites, n=3)	Modern Wild Turkey (known hunted locations, n=6)
Adult	Collagen	2	34	15	18
	Structural Carbonate	0	8	1	13
Juvenile	Collagen	0	10	0	1
	Structural Carbonate	0	4	0	1
TOTAL	**Collagen**	**2**	**44**	**15**	**19**
	Structural Carbonate	**0**	**12**	**1**	**14**

3.3.2 Sample description

Age and sex determinations are recorded in Appendix B for the archaeological samples and Appendix C for the modern samples. All but two modern wild turkeys were still fleshed when donated. Therefore aging and sexing of the modern birds was possible and either provided by the donator/hunter or assessed by the author prior to the removal of bone for sampling. All fleshed, modern turkeys were adult males, ranging in age from one to five plus years, based on spur and beard presence and length (beard length age was estimated by the hunter/donators) (Dickson 1992; Schroger 1966). Wild turkeys are sexually dimorphic, males being larger than females.

For the archaeological remains definitive sex identification was difficult because of bone fragmentation; sex determination could only be made if the tarsometarsal bone was

present (males have a spur) (Gilbert et al. 1996). In some instances size was used to provide possible sex differences (i.e. distal coracoid breadth).

For the juvenile samples, age was assigned as a relative category based on McKusick's (1986) criteria. The majority of the samples represent older juveniles estimated to be three to five months of age at the time of death. In Ontario, wild turkeys begin nesting in the spring, as early as late April and into May with an incubation period of approximately thirty days. If early nests are destroyed, however, female turkeys may lay a clutch of eggs later in spring/summer (Weaver 1989). Based on the osteological analysis of the juvenile remains and breeding/nesting behaviour, it is estimated that the majority of juvenile turkeys were killed in the fall/winter, between late September and January (also see Lennox 1977).

3.3.3 Burial context

The burial context for many of the samples was not available. Despite this lack of contextual data, some assumptions can be made based on the osteology and available archaeological feature/square information. With the exception of Bruce Boyd, an Early Woodland burial that was part of a multi-component site (Spence et al. 1978), all turkeys were recovered from villages or hamlets of varying sizes that were occupied year round. The majority were recovered from middens, usually as single, fragmentary bones. For example, the vast majority of turkey remains at the Hamilton site were recovered from large middens (A and C) outside the palisades. One turkey bone, Ham–05, however, was buried in a small midden within the village walls (Lennox 1977). At the Walker site, a large, Neutral village, one turkey (Wal–50) was associated with a winter house (House 8) (Wright 1977).

Several features appear to contain special context burials including multiple co-mingled turkeys of varying ages, complete or nearly complete turkeys, and ritual bundles. The burial of multiple individuals within the same feature might indicate consumption or disposal of the turkeys in a single event (i.e., the turkeys were killed and/or eaten at the same time) such as a feast (Hayden 1996). Cold weather feasting might explain the assemblage of one feature type at both Crawford Lake (A.D. 1435–1459) and Hamilton

(A.D. 1638–1651) sites (Lennox 1977). Both include multiple individuals and juveniles with fall/winter ages-at-death. Complete single burials were also found at these sites. The completeness of the Crawford Lake burial and lack of burning or cut marks might suggest the turkey was not butchered or eaten prior to burial. Turkeys were also interred on top of a male human burial in Feature 1 at the Bruce Boyd site (ca. 700–400 B.C.). The fauna in this bundle were likely procured during a spring hunt (Spence et al. 1978).

3.3.4 Post-mortem alteration

Burning was observed only infrequently on turkey remains, none of which were selected for analyses. Other forms of post-mortem alteration were noted, including cut marks consistent with butchery (Davis 1992; Prevec and Nobel 1983; Morey 2010; Wright 2004) as well as carnivore puncture marks, consistent with canine teeth (Haynes 1983; Millner and Smith 1989) (Figure 3.3). One turkey, Ham–16, had distinct cut marks on its proximal tibiotarsus indicative of cultural modification, possibly caused by bone bead manufacture (Parker 1916), and was not analysed in this study.

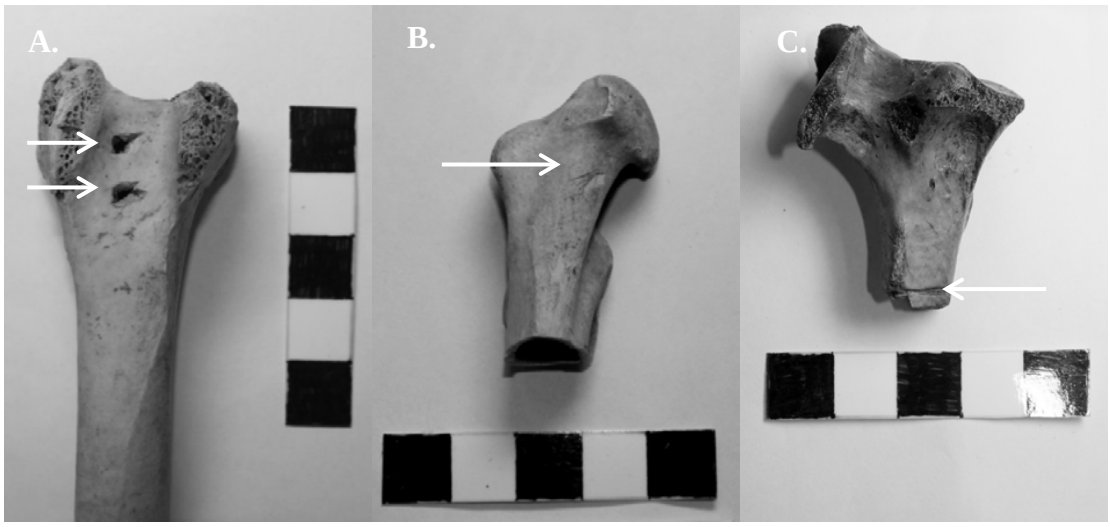

Figure 3.3: Examples of cut marks indicative of (A) canine puncture marks, , (B) cut marks, possibly indicative of butcheryand (C) cut mark,s possibly as a result bone bead manufacture.

3.3.5 Analytical procedures

All isotopic analyses were conducted at the Laboratory for Stable Isotope Science, in the Department of Earth Sciences at The University of Western Ontario. Bone was gently

cleaned with a brush and distilled water, and allowed to dry overnight at room temperature. A small sample of cortical bone (0.2–0.4 g) was removed from complete or large bone fragments. Because bird bone is almost exclusively cortical, it was rarely necessary to remove trabecular bone. The cortical bone was crushed with a porcelain mortar and pestle, sieved, and powder collected at several intervals. The feathers and flesh were cut away manually from the modern wild turkeys, and a piece of the mid–ulna was removed using a handheld Dremel. The bone was rinsed thoroughly in warm water and dried at room temperature. When necessary, additional removal of dried flesh was completed through manual scrubbing and additional rinses.

3.3.5.1 Extraction and analytical protocols

For complete collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$) and carbonate (($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$) extraction protocols see Chapter 2, sections 2.2.3.1 and 2.2.3.2 respectively.

The collagen was analysed to obtain $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values and carbon and nitrogen contents, which were used to calculate a C:N ratio. The $\delta^{13}C_{col}$ values were calibrated to Vienna Pee Dee Belemnite (VPDB) using the standards USGS-40 (accepted value, –26.39‰), and USGS-41 (accepted value = 37.63 ‰). The $\delta^{15}N_{col}$ values were calibrated to AIR also using USGS-40 and USGS-41 (accepted values = –4.52 ‰ and 47.57 ‰, respectively), following Coplen (1994) and Coplen et al. (2006). An internal laboratory standard, Keratin (#90211, MP Biomedicals), was analysed approximately every fifth sample to evaluate the accuracy and precision of the collagen analysis. Accuracy and precision were excellent. The accepted keratin value for $\delta^{13}C_{col}$ is –24.04‰ (compared to the mean sample $\delta^{13}C_{col}$ value of –24.08 ± 0.08‰, n=86), and for $\delta^{15}N_{col}$ it is 6.36‰ (compared to the mean $\delta^{15}N_{col}$ value of 6.31 ± 0.15‰, n=80). Method duplicate pairs (i.e., a different extraction and analysis of collagen on the same sample) were performed for ~10% of the turkey and had a mean reproducibility of ± 0.06‰ for $\delta^{13}C_{col}$ and ± 0.11‰ for $\delta^{15}N_{col}$. The analytical precision for ~10% $\delta^{13}C_{col}$ duplicates (i.e., replicate analysis of the same collagen) was ±0.03‰, and for $\delta^{15}N_{col}$ was ±0.05‰.

The $\delta^{13}C_{sc}$ and $\delta^{18}O$ values were obtained for structural carbonate from thirteen archaeological and thirteen modern turkey samples. The $\delta^{13}C_{sc}$ values were calibrated to

VPDB, following Coplen (1994), using the NBS-19 standard (accepted value of 1.95 ‰) and Suprapur (accepted value of –35.28 ‰). The $\delta^{18}O$ values were calibrated to VSMOW, following Coplen (1996), using NBS-19 and NBS-18 standards (accepted values of 28.60 ‰ and 7.20 ‰, respectively). An internal laboratory calcite standard, World Standard 1 (WS-1), was analysed approximately every fifteenth sample in order to assess the accuracy and precision of the carbonate analysis. The mean $\delta^{13}C_{sc}$ value of 0.76 ± 0.22‰ (n=11) and the mean $\delta^{18}O_{sc}$ value of 26.20 ± 0.19‰ (n=10) compared favourably to the accepted WS-1 values of 0.76‰ and 26.23‰, respectively. Carbonate pre-treatment method duplicates were conducted on three pairs of turkey samples with a mean reproducibility of ±0.04‰ for $\delta^{13}C_{sc}$ and ±0.19‰ for $\delta^{18}O_{sc}$. The analytical precision for duplicate analyses of the same structural carbonate preparation was ± 0.07‰ for $\delta^{13}C_{sc}$ and ±0.07‰ for $\delta^{18}O_{sc.}$

3.3.5.2 Fourier transform infra–red spectroscopy (FTIR)

For complete description of the Fourier transform infra–red spectroscopy (FTIR) procedures, see Chapter 2, Section 2.2.3.3.

3.4 Results

3.4.1 Sample integrity

Collagen yields and carbon:nitrogen (C:N) ratios were used to assess post–mortem alteration of the organic portion of bone (Table 3.2). Samples yielding less than 1% collagen are considered to be too degraded to give reliable results (Van Klinken1999; Ambrose 1993). Yields varied, with slightly lower collagen yields at the oldest site (Bruce Boyd, 5.0±0.7%) relative to Late Woodland (A.D. 1000–1600) sites (Table 3.2). No archaeological turkeys had yields less than 4% yield, suggesting the preservation was acceptable for isotopic analysis. Modern turkey had excellent preservation, as is expected for fresh bone, with a mean collagen yield of 20.4% (Van Klinken 1999). The C:N ratios for all samples fell well within the range of 2.9 to 3.6 recommended by DeNiro (1985). There was no significant correlation (Pearson's Correlation) between $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values and either C:N ratio or percent collagen yield. Therefore, all isotopic collagen data were accepted.

For the structural carbonate, three checks were used to assess the integrity of the samples; FTIR analysis, percentage of bioapatite by weight, and percentage of CO_3 (as CO_2) in bioapatite by weight.

The expected CI for fresh bone lies below 2.8 and 3.0, which is consistent with that measured for the modern turkeys (2.63±0.19, n=19) (Table 3.3). The mean CI of the archaeological turkey samples (2.78±0.23, n=19) was below that limit, and closer to that of the modern samples (Table 3.3). Re-crystallization is, therefore, not indicated and all wild turkey samples were retained for isotopic analysis.

All fresh (i.e., de-fleshed) modern turkey bones had C:P ratios > 0.6 (Table 3.3), higher than is expected for bioapatite (King et al. 2011; Nielsen-Marsh and Hedges 2000; Pucéat et al. 2004), which is most likely related to a methodological error trying to analyse fresh bone that still contained a high percentage of organic matter such as lipids. The C:P ratio for the archaeological turkey bone samples was 0.53±0.33, suggesting a larger amount of structural carbonate than normally expected for some archaeological bone (Nielsen–Marsh and Hedges 2000; Wright and Schwarcz 1996). A comparison of C:P ratios prior to pre-treatment and after pre-treatment of mammalian (n=41) and wild turkey samples (n=12) demonstrated that pre-treatment lowers the C:P ratio in over 70% of cases, shifting the mean C:P for archaeological turkey bone samples to an acceptable ratio of 0.33±0.16 (Table 3.3).

The structural carbonate from turkey samples used in this study for isotopic analysis is considered to represent unaltered material because (1) the CI indices were acceptable, (2) there were peaks in the FTIR profiles that suggest secondary contamination or recrystallization, and (3) pre-treatment lowered sample C:P ratios to within the expected range.

Fresh bone has an expected bioapatite [$Ca_{10}(PO4)_6(OH)_2$]) yield by weight of 70 –75% (Ambrose 1993; Sillen 1989) to 90% (Lee–Thorp 1989). The yields measured here aligned closely with those reported by Ambrose (1993) and Sillen (1989): modern turkey bone = 65.7±7.2%, range = 47.6–72.7%, and archaeological turkey bone = 79.3±3.9, range = 76.0–84.8% (Table 3.2). The higher bioapatite yield of archaeological turkey

bone relative to modern turkeys may be due to the fact the modern bone was fresh when weighed and some organics (i.e. lipids) were still present. The percentage of structural carbonate in bioapatite (CO_3) should range from 2 to 7.9% for pretreated samples (Lee–Thorp 1989; Lee–Thorp and Sponheimer 2003; Wright and Schwarcz 1996). The samples analysed in this study fell within this range for both modern (5.3±0.7%, range = 3.6–6.6%) and archaeological (5.5±0.3%, range = 2.0–8.8%) turkey bone. The one sample with a value > 8% was regarded with caution, but its CI, C:P and FTIR peak profile did not indicate secondary carbonates, and hence it was retained for isotopic analysis. A Pearson's correlation test showed no significant correlation between $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values and yield of bioapatite by weight, structural carbonate content by weight, CI, or C:P ratio. Therefore, the isotopic results for all structural carbonate samples were retained for subsequent interpretation.

Table 3.2: Summary of sample integrity checks for collagen (C:N ratio and collagen yield) and structural carbonate (bioapatite yield by weight and percentage of CO_3 by weight).

	n_{col}	C:N Ratio (Range)	% Collagen by Weight (Range)	n_{sc}	% Bioapatite by Weight (Range)	% CO_3 by Weight (Range)
Pre A.D. 200 (sites, n=1)	2	3.11±0.01 (3.10–3.12)	5.0±0.7 (4.5–5.5)	0	–	–
Ontario Iroquoian A.D. 900–1600 Adult (sites, n=9)	34	3.20±0.15 (3.03–3.44)	14.8±6.1 (5.6–25.2)	8	78.7±3.0 (76.0–84.7)	5.7±2.1 (2.0–8.8)
Ontario Iroquoian A.D. 900–1600 Juvenile (sites, n=6)	10	3.25±0.17 (3.05–3.47)	15.6±2.5 (10.9–19.3)	4	79.3±2.9 (76.6–83.4)	5.0±1.0 (3.8–6.1)
Western Basin A.D. 900–1600 (sites, n=3)	15	3.10±0.11 (2.96–3.31)	12±6.2 (5.0–21.9)	1	84.80 –	5.90 –
Modern (locations, n=9)	19	3.31±0.13 (3.23–3.64)	21.0±4.7 (9.6–31.4)	14	65.7±7.2 (47.6–72.7)	5.3±0.7 (3.6–6.6)

Table 3.3: Summary of FTIR Crystallinity Indices (CI) and Carbonate/Phosphate (C/P) ratios for turkey bone samples before and after pre-treatment

	Modern Turkey (Before n=19, After n=3)		Archaeological Turkey (Before n=27, After n=9)	
CI Before Pre-treatment	2.63	±0.19	2.78	±0.23
CI After Pre-treatment	2.99	±0.36	2.83	±0.17
C:P Before Pre-treatment	0.70	±0.15	0.53	±0.18
C:P After Pre-treatment	0.39	±0.12	0.33	±0.16

3.4.2 Isotope results

Table 3.4 summarizes the isotopic results for all, non-modern adult and juvenile turkeys analysed in this study (see also Figure 3.4). A Mann–Whitney U comparison of adult and juvenile Ontario Iroquoian turkeys showed no significant difference in their $\delta^{13}C_{col,}$ $\delta^{15}N$, $\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$, or $\Delta^{13}C_{sc-col}$ values, despite slightly higher $\delta^{13}C_{col}$ values for juvenile turkeys. While the discussion will examine juvenile wild turkeys separately because of seasonal hunting implications, statistically they are not recognized as an independent sample based on their stable isotope results and were therefore combined with adult wild turkeys when compared with modern turkeys and other archaeological turkey groups. No Western Basin juvenile turkeys were available for comparative analysis.

Table 3.4 shows that modern turkeys had significantly higher $\delta^{13}C_{col}$ (n=19) and $\delta^{13}C_{sc}$ (n=14) values relative to the archaeological (collagen n=61, structural carbonate n=13) turkeys, (Mann–Whitney U, Z=–2.730, p<0.000 and Z=–2.378, p=0.017, respectively). In addition the average $\Delta^{13}C_{sc-col}$ value for modern turkeys was significantly lower relative to the archaeological turkeys (Mann–Whitney U, 0.006). Modern wild turkeys also had significantly lower $\delta^{15}N_{col}$ values (Mann–Whitney U, Z–2.511, p=0.012) (Table 19). For modern turkeys, there was a strong correlation between $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values (Pearson's R=0.767, p=0.001). There was no significant difference between the $\delta^{18}O$ values of modern or archaeological turkeys (Table 3.4).

An ANOVA test indicated that there were significant differences among the $\delta^{13}C_{col}$ values of archaeological turkeys, with Ontario Iroquoian (n=44) turkeys having significantly higher values relative to Western Basin turkeys (n=15), (Tukey HSD,

p=0.002) but not the two Early Woodland turkeys analysed from the Bruce Boyd site (700 – 400 B.C.). There was no significant difference in $\delta^{15}N_{col}$ values among the archaeological turkeys. It was not possible to statistically compare the $\delta^{13}C_{sc}$ results among the archaeological wild turkeys because of sample size. For the archaeological turkeys, the $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values correlated significantly (Pearson's R=0.295, p=0.021) as did the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values (Pearson's R=0.858, p<0.000).

3.5 Discussion

3.5.1 Modern wild turkeys: analogies for maize–waste access

The significant differences in the $\delta^{13}C_{col,}$ $\delta^{15}N_{col}$, $\delta^{13}C_{sc}$, and $\Delta^{13}C_{sc-col}$ values of modern wild turkeys relative to ancient turkeys (Figure 3.4) from the same regions suggest differences in subsistence access or behaviours. Specifically, modern wild turkeys appear to have greater access to C_4 foods, probably agricultural maize. The lower $\delta^{15}N_{col}$ values of the modern turkeys corroborates this hypothesis, as increased fertilization and/or access to agricultural legumes could produce lower $\delta^{15}N_{col}$ values, similar to those recorded for modern versus archaeological deer from the region (Cormie and Schwarcz 1994; Katzenberg 1989; 2006; deer data, this study; see Chapter 4).

A comparison with other modern birds with published collagen values from known habitats and dietary niches (summarized in Kelly 2000) (Figure 3.5) confirms that modern and archaeological turkeys occupy a terrestrial, herbivore trophic position. Even the single modern and ten potentially insectivorous juvenile turkeys more closely align with herbivorous $\delta^{15}N_{col}$ values. These results are somewhat surprising as modern ecology studies suggest that insects comprise the majority of young turkey poult diets during the spring and early summer (Eaton 1992; Wright 1989; Schorger 1966: 203). An analysis of the keratin from 47 modern grasshoppers and crickets collected from a maize field and C_3 dominant meadow over several months offers an explanation for the lack of apparent, trophic enrichment of juvenile turkeys. Grasshoppers were selected for this short study because they are known maize-pests today and in the past (Thwaites 1896–1906 vol 14). Grasshoppers, which are herbivores, were compared to crickets, which are omnivores and are generally found in the same niches.

Table 3.4: Summary of collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$) and structural carbonate ($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$) results.

	n_{col}	$\delta^{13}C_{col}$ (‰, VPDB) (Range)	$\delta^{15}N_{col}$ (‰, AIR) (Range)	n_{sc}	$\delta^{13}C_{sc}$ (‰, VPDB) (Range)	$\delta^{18}O_{sc}$ (‰, VSMOW) (Range)	$\Delta^{13}C_{sc-col}$ (Range)
Pre A.D. 200	2	–20.78±0.15 (–20.89 to –20.68)	5.39±0.16 (5.28 to 5.50)	0	–	–	–
Ontario Iroquoian Adult A.D. 900–1600	34	–20.49±2.17 (–23.02 to –10.00)	6.24±0.84 (4.40 to 8.49)	8	–10.73±2.40 (–13.43 to –5.35)	20.40±1.22 (18.06 to 21.86)	8.48±2.49 (4.64 to 11.93)
Ontario Iroquoian Juvenile A.D. 900–1600	10	–19.72±1.96 (–22.83 to –17.08)	6.24±0.78 (4.88 to 7.29)	4	–10.47±1.51 (–12.10 to –8.92)	21.28±1.00 (20.34 to 22.16)	8.99±0.89 (8.16 to 10.24)
Western Basin A.D. 900–1600	15	–22.35±1.01 (–23.71 to –20.21)	6.45±1.00 (4.72 to 8.49)	1	–12.67	20.23	9.21
Modern Wild Turkey	19	–15.95±1.70 (–19.05 to –12.40)	5.64±0.96 (4.36 to 7.58)	14	–7.72±1.64 (–10.51 to –3.88)	20.18±1.64 (15.12 to 21.40)	7.85±0.81 (5.62 to 8.73)

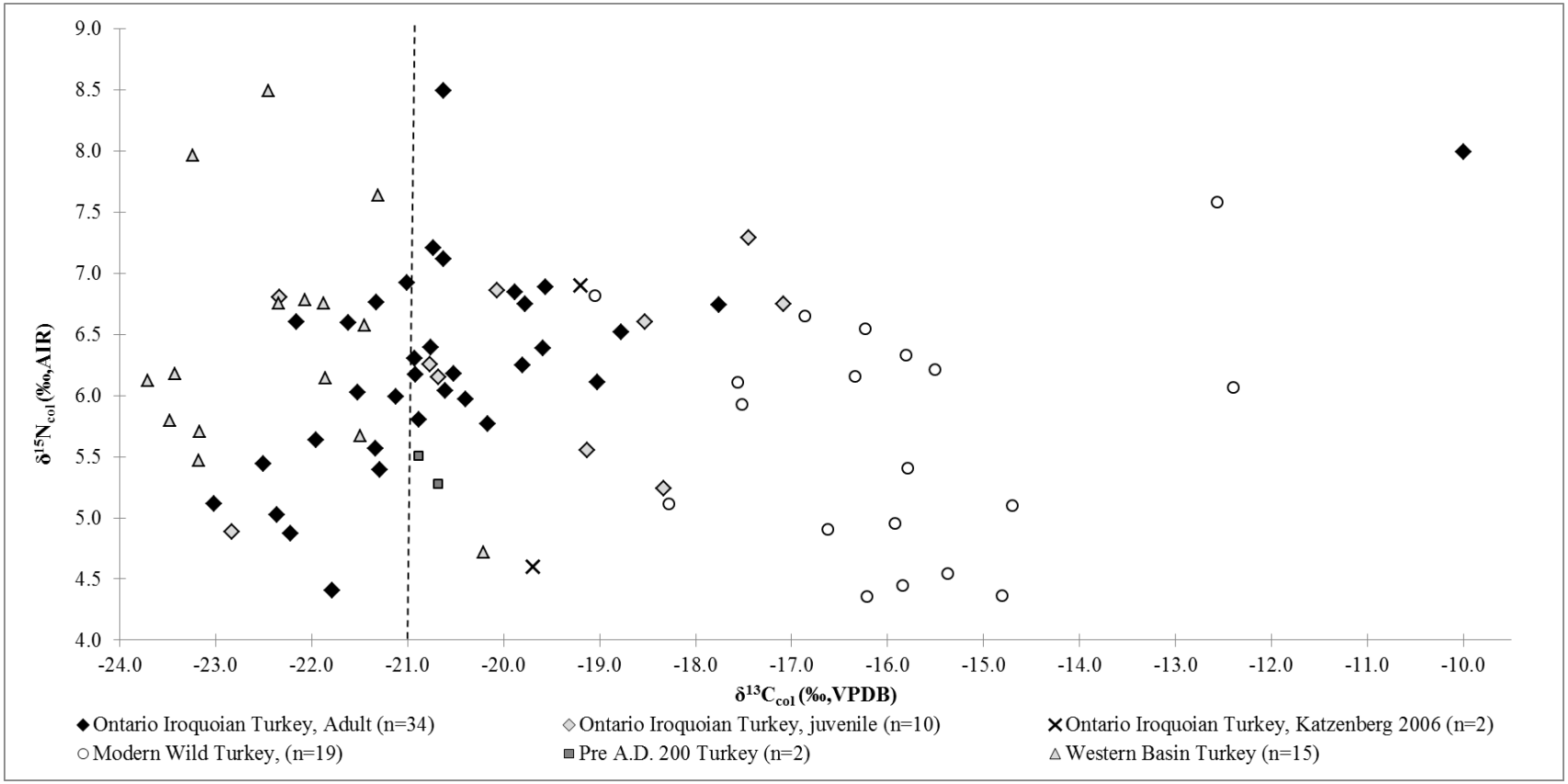

Figure 3.4: $\delta^{15}N_{col}$ versus $\delta^{13}C_{col}$ values for all turkey samples from this study and Katzenberg (2006). Vertical dashed line delineates an entirely C_3-based diet (left) from that which includes a C_4-component (right).

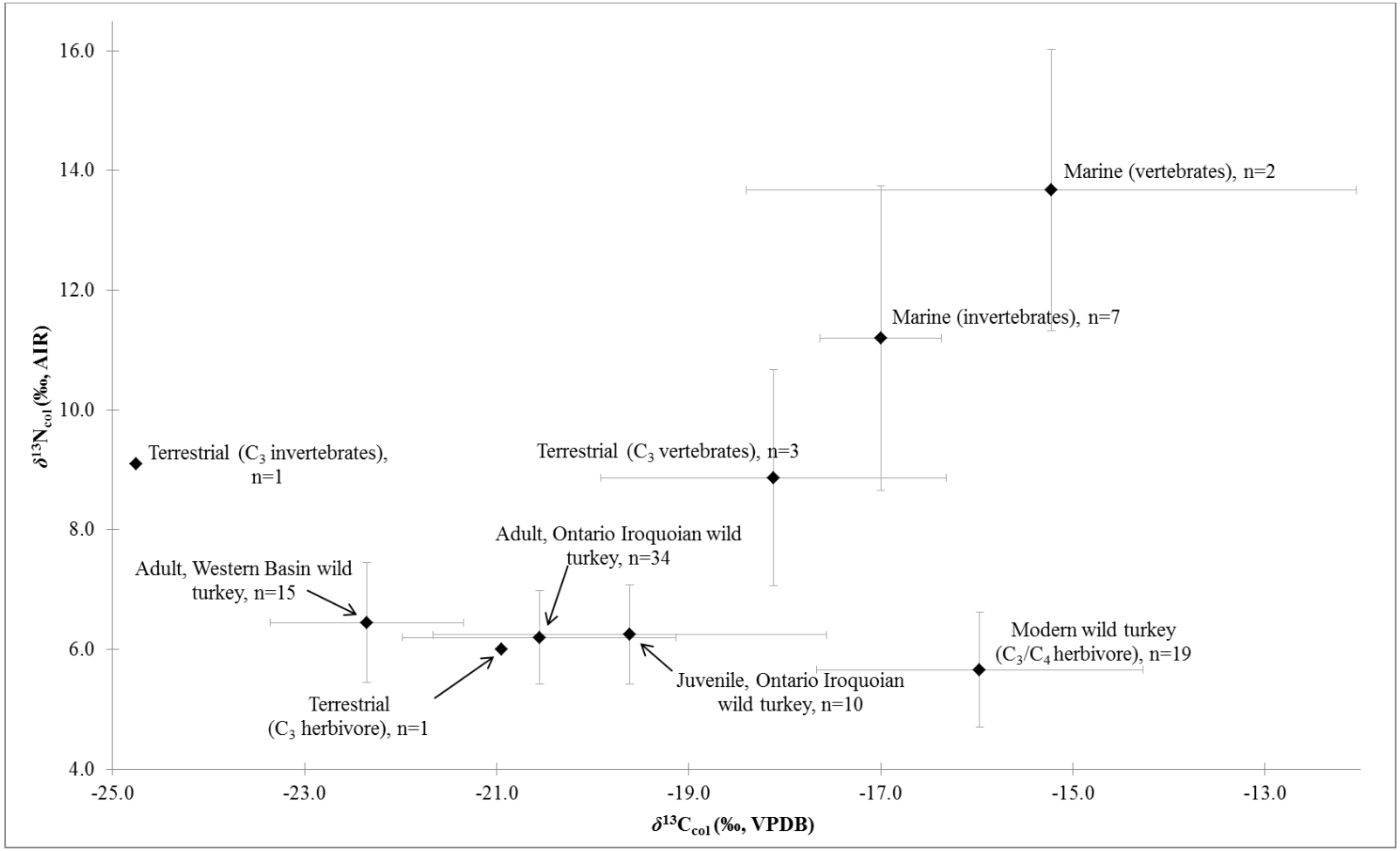

Figure 3.5: $\delta^{15}N_{col}$ versus $\delta^{13}C_{col}$ values for avian species within known dietary niches. All modern, collagen data for non-wild turkey species are from Kelly (2000, summary).

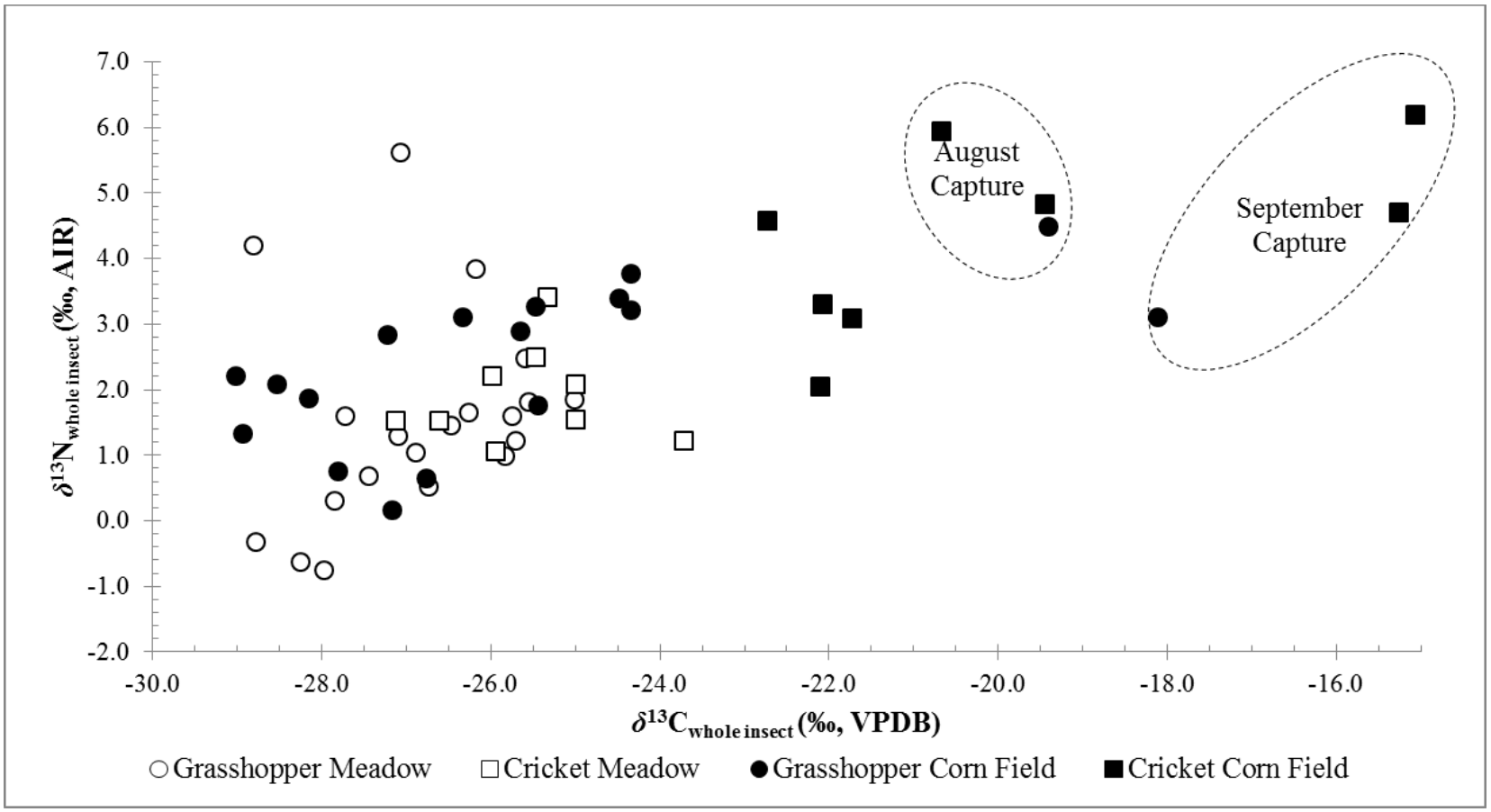

Figure 3.6: δ^{15}N versus δ^{13}C values for whole, modern grasshoppers and crickets.

Samples are from two niches: a C_3-dominated environment (meadow in a wooded area) and a C_4-dominated environment (agricultural maize field). The insects were collected once a month from May through October, 2012. Suess corrected +1.65‰.

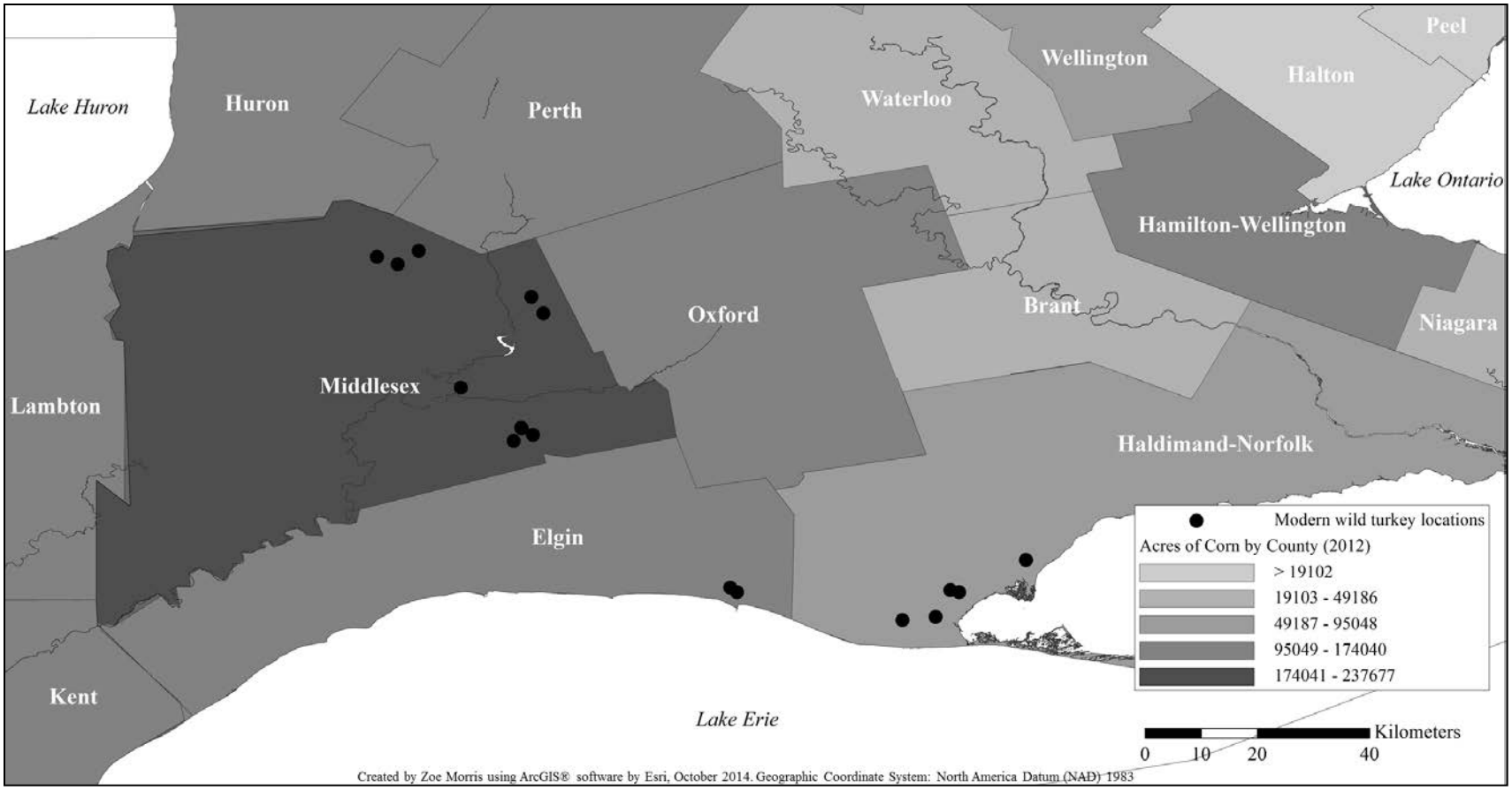

Figure 3.7: Approximate locations of modern turkeys from this study in relation to percentage of land seeded with corn in 2012[16].

[16]Percentage based on total seeded land with fodder, grain and sweet corn (maize) from the Ontario Ministry of Agriculture, Food and Rural Affairs 2012.

The mean $\delta^{13}C_{col}$ value for grasshoppers (n=30) was –26.29±2.09‰ and for crickets (n=16) was –23.01±3.64‰. The results suggested that all of the insects collected in the meadow were eating in a C_3-only environment and, interestingly, many of the insects collected in the maize field did not consume maize, especially in the early spring growing stages. There was evidence that the crickets collected in the late summer/fall from maize fields had consumed some C_4 resources (Figure 3.6). The mean $\delta^{15}N_{col}$ value for the grasshoppers was 1.84±1.41‰ and for the crickets was 2.93±1.64‰. Although, as omnivores, crickets have expectedly higher $\delta^{15}N_{col}$ values, both species are within the range expected for plants in the region (i.e., they are not a trophic level higher than the plants) (Longstaffe unpublished results; Cormie and Schwarcz 1994, 1996). The lack of a clear C_4 signal in the spring/early summer-collected insects and the low $\delta^{15}N_{col}$ values means that, as a food item, grasshoppers and crickets would more closely resemble C_3 plants during the time period that insects play a role in the turkey's diet.

If, therefore, insects were an important part of juvenile turkey diets, they may not have caused the trophic enrichment expected based on published data (Kelly 2006; Rawlings and Driver 2010; Webster and Katzenberg 2008). The modern juvenile turkey and many of the archaeological juvenile turkeys analysed in this study, had, however, clearly consumed C_4 resources. Grasshoppers and crickets, however, were unlikely to be the major C_4 resource responsible for causing the measured enrichment in ^{13}C.

The data also suggest that modern wild turkeys occupy a dietary niche with significantly more maize relative to other birds for which isotopic data for collagen are available. These results are important for understanding maize availability and turkey behaviour because they demonstrate that (1) if available, modern turkeys in Ontario will eat maize, and (2) they are able access maize in quantities sufficient to alter their collagen isotopic composition significantly, despite the fact that turkeys can only eat maize waste (i.e., cobs and/or kernels already on the ground). As would be expected for the low waste production rates of ancient maize fields, many of the adult archaeological wild turkeys, plot close to the expected range for herbivorous birds from C_3-dominated environments (Figure 3.5). Nonetheless, some archaeological turkeys have isotopic signatures

consistent with significant consumption of C_4 foods (i.e., $\delta^{13}C_{col} > -21‰$), so it is clear that some pre–contact turkeys lived in environments with access to relatively large and/or stable maize sources.

Southwestern Ontario agricultural data can provide a useful analog for understanding the relationship between maize waste in fields and agricultural intensity. The mean annual home range for wild turkeys in southwestern Ontario is 1000 acres, but is variable by season and sex of the bird (Weaver 1989:60). Approximately 50% of the range of modern turkeys is comprised of agricultural areas and water sources (Schorger 1960:224). The hunters who donated the birds for this study reported hunting in forested or open areas all of which were located near agricultural fields in Elgin, Middlesex, and Norfolk counties during spring 2012. Examination of the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) 2012 data indicates that in that same year, 30% of Middlesex and Elgin county land was seeded with maize (Figure 3.7).

According to OMAFRA (2012), modern southern Ontario maize fields produce approximately 150 bushels per acre, where one bushel is equivalent to ~15 kilograms of maize (Murphy 2008). The $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values for the modern wild turkeys suggest that all of the birds analysed in this study consumed some maize, though in highly variable quantities. Because turkeys can only consume maize already on the ground, they probably consumed maize lost from combine machines during harvest, which ranges between 2 and 10% of the crop (Sumner and Williams 2012). Using estimates of maize loss from combine waste as well as wind and water damage, as much as 77 to 282 kilograms of maize per acre (calculated from OMFARA 2012; William 2008) can be left in Ontario fields, an amount that creates a rich, post-harvest food source for modern wild turkeys and could provide an overwintering food source for a large number of turkeys, even in competition with other species dependent on agricultural waste, such as white-tailed deer. These interpretations are consistent with a previous study by Groepper et al. (2013), which found that modern wild turkeys with access to maize fields had diets comprising up to 37% maize.

By comparison, the amount of waste maize in today's fields is greater than the total production of ancient Ontario Neutral (A.D. 1450 to 1650) fields, which would rarely have "*exceeded 14.5 bushels of shelled maize per acre*" (Sykes (1981:30, adapted from Heidenreich 1971:191). Although the amount of maize needed to sustain a healthy wild turkey has not been accurately determined, only one tenth of a modern turkey's 1000 acre home range would provide up to 7000 kilograms of maize waste (i.e., 100 acres x 77 to 282kgs/acre of maize waste). These calculations suggest that even if ancient humans left a large amount maize behind after harvesting (which is unlikely, as hand-harvesting would leave less waste) it would not come close to the amount left in fields today.

Although the collagen isotopic data alone provide evidence of maize consumption in all of the modern turkeys, this study also offers a unique opportunity to determine if the relationship between collagen and structural carbonate carbon isotopic composition is the same for birds as mammals.

Harrison and Katzenberg (2003) suggested that in Ontario, $\delta^{13}C_{sc}$ values > –14‰ in humans may indicate some C_4 resource consumption. This study, however, will use a more conservative value of –12‰ to indicate C_4 resource consumption, as it would be more consistent with the deer and dog isotopic compositions obtained in this study. All of the modern wild turkeys had $\delta^{13}C_{sc}$ values > –11‰, which, like the carbon isotopic results for collagen, suggests that all modern turkeys consumed C_4 resources, probably maize. Further, there is a strong positive correlation between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values. The majority of the modern turkey values plot close to Kellner and Schoeninger's (2007) C_3 protein line, while the two turkeys with highest $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values are shifted towards the C_4 protein line (Figure 3.8). An annual mixed diet of C_3 grasses, forbs, nuts and other plants, some insects and small vertebrates, and a significant portion of maize would correspond well with the measured isotopic data. Overall, the relationship between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values appears to follow similar trends for the wild turkey data as that of mammalian tissue.

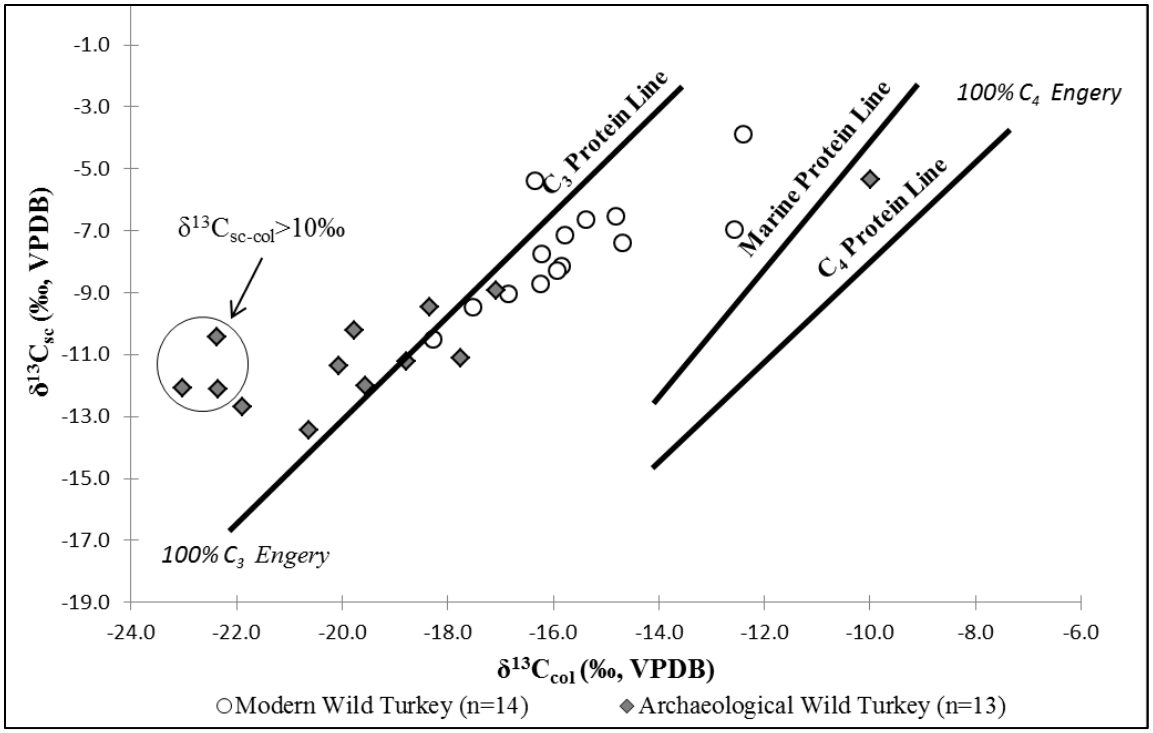

Figure 3.8: $\delta^{13}C_{sc}$ versus $\delta^{13}C_{col}$ values for archaeological and modern wild turkeys according to the model adapted from Kellner and Schoeninger (2007, Figure 2B).

3.5.2 Ontario Iroquoian wild turkeys

"The food and the clothing of this Nation [the Neutral] do not greatly differ from those of our Huron: they have Indian corn, beans, and squashes in equal plenty; the fishing likewise seems equal, as regards the abundance of fish, of which some species are found in one region, that are not in the other. The people of the Neutral Nation greatly excel in hunting [Page 195] Stags, Cows, wild Cats, wolves, black beasts, Beaver, and other animals of which the skin and the flesh are valuable... ***They have also multitudes of wild turkeys, which go in flocks through the fields and woods****."* (Lalement 1642 in Thwaites 1896–1901 21:193–5).

Although the diet of Ontario Iroquoian wild turkeys was primarily comprised of C_3 foods, some had $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values that indicated consumption of C_4 foods, consistent with evidence for other C_4 resource-consuming species during the Late Woodland in southwestern Ontario, including Sandhill cranes, raccoons, squirrels and foxes (Katzenberg 1989, 2006; this study). By the Middle Ontario Iroquoian period (A.D. 1200

to 1450) several sites, including Crawford Lake, Pipeline, Rife and Winking bull have some juvenile and adult birds with $\delta^{13}C_{col}$ values > –21‰ and this trend continues at Neutral (A.D. 1450 to 1650) sites such as Hamilton and Walker, as well as Ball and Kelley–Campbell (Katzenberg 1989; 2006). Even an earlier Princess Point site (~A.D. 500–1000) juvenile wild turkey, Pri–07 had a $\delta^{13}C_{col}$ value of –18.33‰. Despite evidence that some turkeys were eating maize, this trend is not universal and at some later Neutral sites wild turkey carbon isotopic data for collagen and structural carbonate did not reflect maize consumption. For example, none of the birds from the sites of Cleveland, Thorold, or Fonger had values *definitively* associated with maize consumption, nor did the Early Ontario Iroquoian (~A.D. 900) site of Van Besien.

As with the modern turkey, there was a strong, positive correlation between the $^{13}C_{sc}$ and $\delta^{13}C_{col}$ values, which suggests that the former can be used to identify maize consumption among this set of archaeological birds. Overall, Ontario Iroquoian wild turkeys more closely correspond to Kellner and Schoeninger's (2007:1122) "C_3 protein line" (i.e. the dietary protein source is primarily from C_3 resources, whether vegetation or invertebrates), while the energy source (i.e., lipids and carbohydrates) is variably from C_3 and C_4 resources, as the turkeys fall along the C_3 protein line. The exception is the Ham–05 turkey, which falls closer to the C_4 protein line, suggesting a complete diet (i.e., proteins, carbohydrates and lipids) composed of C_4 resources, most likely maize (Figure 3.8). Three turkeys fall some distance from the C_3 protein line and all had larger than expected $\Delta^{13}C_{sc–col}$ values (i.e., > +10‰). Figure 3.8 shows clear overlap between the modern and archaeological turkeys, which is striking when considering the large amount of maize waste available to modern agricultural fields, and not expected to be available in ancient maize fields. The isotopic evidence, however, is strong that there was sporadic, or perhaps seasonal, maize consumption by adult and juvenile wild turkeys at many of the Middle Ontario Iroquoian and Neutral sites analysed in this study.

The spacing between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values ($\Delta^{13}C_{sc–col}$) varies by trophic niche (i.e., herbivore versus carnivore), digestive physiology (i.e., ruminants versus non–ruminants), and macronutrient composition of the food (i.e., high or low protein) (Ambrose and Norr 1993; Cerling and Harris 1999; Howland et al. 2003; Kellner and Schoeninger 2007;

Krueger and Sullivan 1984; Tieszen and Fagre 1993). These studies, however, are based entirely on various mammals with resulting $\Delta^{13}C_{sc-col}$ values between +2 and 12‰. Based on the modern turkey samples analysed in this study, the expected $\Delta^{13}C_{sc-col}$ value is +7.85±0.81‰, which is significantly smaller than the archaeological mean (+8.55±1.92‰, range =4.64 to 11.93‰, Table 3.4). Removing archaeological samples with larger than expected $\Delta^{13}C_{sc-col}$ values based on the adult, fresh modern wild turkeys (Figure 3.8), results in greater consistency in the spacing, which may suggest that the three birds with larger spacings have undergone post-mortem alteration. For example, Tho–35 has the largest $\Delta^{13}C_{sc-col}$ value (+11.93‰) and was also the only sample with a structural carbonate content > 8%. Based on this combined evidence, the $\delta^{13}C_{sc}$ value of Tho–35, despite its acceptable CI and C:P values, is considered to be unreliable.

3.5.2.1 Adult and juvenile Ontario Iroquoian wild turkeys

There is no significant difference among any of the mean isotopic compositions of the Ontario Iroquoian adult and juvenile turkeys (Figure 3.9). This suggests that either there is no difference in the diet of adult and juvenile wild turkeys, or consumption of large quantities of insects, expected for juvenile turkeys, does not significantly alter the carbon isotopic compositions of collagen or structural carbonate.

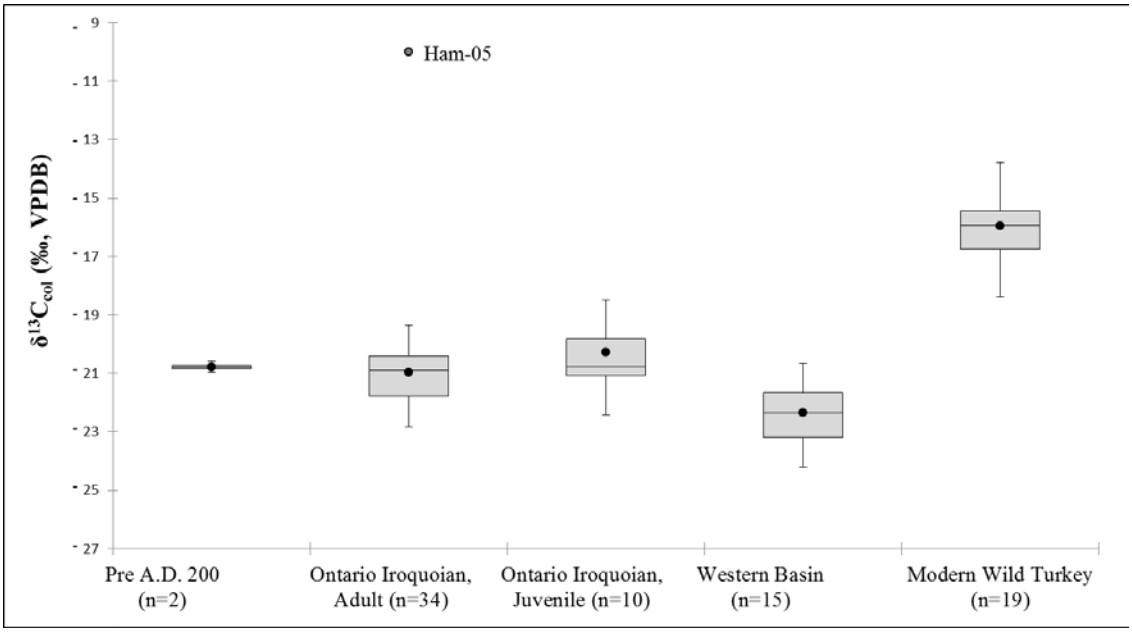

Figure 3.9: Box plot of $\delta^{13}C_{col}$ values for all samples in this study.

The analysis of modern grasshoppers and crickets (above) has already shown that they had relatively low $\delta^{15}N_{col}$ and $\delta^{13}C$ values, many closely mimicking C_3 plants in the region, despite the fact some of the insects were collected in maize fields. The juvenile and adult turkeys that have carbon isotopic compositions reflecting C_4 resource consumption are, therefore, believed to have consumed maize, as opposed to maize–consuming insects. This is significant because insects are consumed earlier in the summer, while maize is consumed by turkeys in the fall or winter, after the crop harvest. It may also be possible that the predominately insectivorous diet, which only lasts the first four to five weeks of a poult's life (Eaton 1992), contributes only a minor portion to the lifetime carbon isotopic average of the bone. The average age-at-death for poults in this study is between three to five months, based on a May/June hatching. The high bone turnover rate for young, growing birds (Hobson and Clark 1992a) may be obscuring any effect of insect consumption. As all the juvenile turkeys are less than one year of age at death, their carbon isotopic composition is the result of a single maize-harvest season. For young turkeys in particular, it may be possible to link the season during which they were killed to access to maize fields.

The presence of three to five month-old juvenile turkeys in faunal assemblages supports the interpretation of a late fall/winter turkey hunt proposed by zooarchaeologists (e.g., Foreman 2010; Prevec and Noble 1983). The seasonality of the turkey hunt is also supported by ethnohistoric descriptions of tracking turkeys through snow and their winter consumption (Denke 1804; Thwaites 1896–1901 32; 59; 60). Juvenile birds were found from sites dating from the Princess Point through Middle Ontario Iroquoian and Neutral stages, which suggests continuity in cold weather turkey hunting throughout the Late Woodland period at Ontario Iroquoian sites. Except in rare cases (for example, Wal–50 from a winter house at Walker village), it has not been possible to provide a season-of-death for the adult turkey remains, so the ability to correlate cold weather turkey hunting with higher $\delta^{13}C$ values (i.e., maize consumption) in juveniles of less than one year of age is an exciting find. In order to determine the archaeological significance of these results, Ontario Iroquoian turkeys are compared next to turkeys from other archaeological contexts across North America with maize horticulture.

3.5.3 Comparative collagen study

The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of Late Woodland Ontario Iroquoian wild turkeys were compared with those of modern wild turkeys and several data sets for archaeological wild and domestic turkeys (Table 3.17, Figure 3.10). At least three different dietary niches are identifiable: (1) a C_3-only environment, with possible canopy effect, (2) a C_3– environment with occasional or seasonal C_4 (i.e., maize) access and (3) consistent maize access (i.e., purposeful feeding of captive and/or free–ranging birds) (Figure 3.10). These dietary niches are statistically distinct based on a one–way ANOVA for both $\delta^{13}C_{col}$ ($F=419.3$, $p<0.000$) and $\delta^{15}N_{col}$ values ($F32.7$, $p<0.000$).

Table 3.5: Summary of the published $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for wild and domestic archaeological turkey data from across North America.

Site Name and Location	$\delta^{13}C_{col}$ ‰ (VPDB)	Std Dev	$\delta^{15}N_{col}$ ‰ (AIR)	Std Dev	n	Reference
Western Basin, Ontario*	–22.28	±0.96	6.40	±0.92	15	this study
Donnaha Site, North Carolinian	–21.51	±0.49	4.57	±0.46	16	Price 2009**; Price et al. 2010
Various sites, Colorado	–9.00	±1.07	7.73	±1.10	30	Rawlings and Driver 2010
Ch–254, Chihuahua, Mexico	–7.00	–	10.40	–	1	Webster and Katzenberg 2008

* All Western Basin samples are from the Arkona region Inland West Pit Sites (A.D. 1160–1270).
**Price's summary data were provided by personal communication; individual data are not available (see Price et al. 2010).

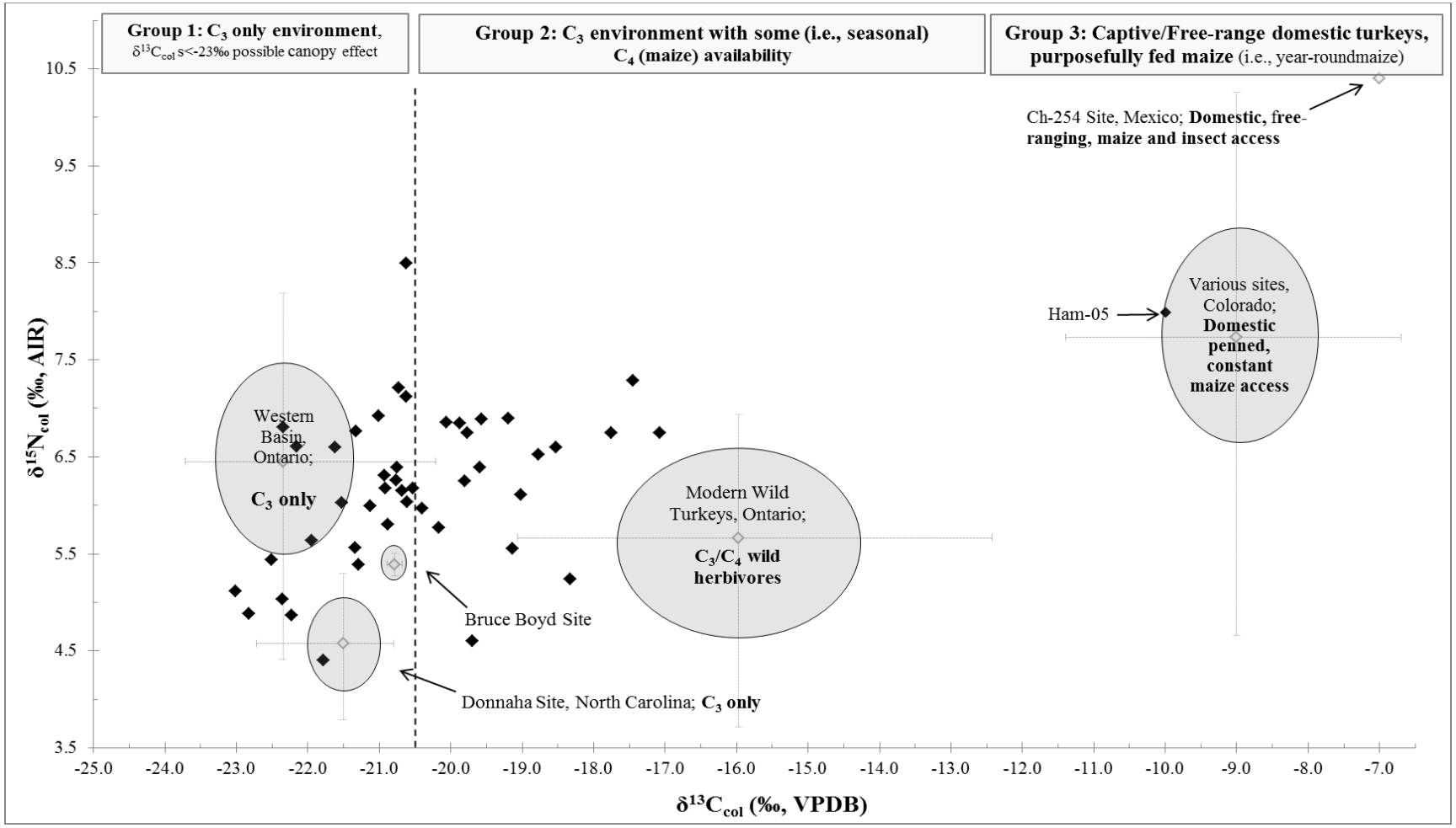

Figure 3.10: Comparative $\delta^{15}N_{col}$ and $\delta^{13}C_{col}$ values for archaeological turkeys from several regions of North America.

Inland West Pit sites (SW Ontario); Donnaha Site, North Carolina (Price et al. 2010; Price unpublished data); various sites, Colorado (Rawlings and Driver 2010); Mexico (Webster and Katzenberg 2008). Gray circle is the mean±StD, error bars are the range.

Based on the $\delta^{13}C_{col}$ values, Western Basin and Donnaha site wild turkeys are not significantly different from each other (post-hoc Dunnett T3 analysis of turkeys by each region) and were grouped together. Post-hoc Dunnett T3 ($\delta^{13}C_{col}$) and Tukey HSD ($\delta^{15}N$) identified the three significantly different dietary niches (Table 3.6). Turkeys that ate from a C_3–only environment (1) had significantly lower $\delta^{13}C_{col}$ values. Modern Ontario wild turkeys form a distinct group (2) that reflects a C_3 environment with occasional maize access. The domestic turkeys from Colorado and Mexico formed the third isotopically distinct group (3), with significantly higher $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values compared to the other turkeys. Ontario Iroquoian turkeys span the range of turkeys from C_3 environment only to C_3 environment with occasional maize access.

Table 3.6: Summary of statistical significance (p-values) among the dietary niche groups identified by one–way ANOVA.

$\delta^{13}C_{col}$ values (Dunnett T3)	**A. C_3–only environment***	**B. C_3 environment, maize access**	**C. Domestic turkeys****	**Ontario Iroquoian turkeys**
1. C_3–only environment*	–	>0.000	>0.000	>0.000
2. C_3–environment, seasonal maize access		–	>0.000	>0.000
3. Domestic turkeys**			–	>0.000
Ontario Iroquoian turkeys				–

***δ15Ncol*values** (Tukey HSD)	**A. C_3–only environment***	**B. C_3 environment, maize access**	**C. Domestic turkeys****	**Ontario Iroquoian turkeys**
1. C_3–only environment*	–	0.901	>0.000	0.017
2. C_3 environment, seasonal maize access		–	>0.000	0.274
3. Domestic turkeys**			–	>0.000
Ontario Iroquoian turkeys				–

*Group A includes pooled data from Western Basin and Donnaha sites.
**Group C includes pooled data from Colorado and Mexico.

3.5.3.1 C_3-only environment

An entirely C_3-based diet (i.e., all $\delta^{13}C_{col}$ values < –21.6‰, 95% confidence interval) is evident for wild turkeys from the southeast United States and western Ontario. Wild turkeys at the Donnaha site (A.D. 1000 to 1450), a village in North Carolina that was occupied year-round, do not appear to have had access to maize or any other C_4 dietary sources (Price 2009; Price et al. 2010) despite the villagers' mixed subsistence economy anchored variably to maize throughout its occupation (Lambert 2000; Woodall 1984). The $\delta^{15}N_{col}$ values of the Donnaha turkeys are also significantly lower than those of the Ontario turkeys (Dunnett T3, p>0.000), possibly indicating different soil conditions or plant access.

The Arkona Inland West Pit sites, located to the west of the Late Woodland Iroquoian sites, include a group of consecutively occupied villages and camps and were the only Western Basin tradition sites with wild turkeys available for isotopic analysis. The sites date to the late Younge Phase (A.D. 1050 to 1270) and have $\delta^{13}C_{col}$ values indicative of a C_3–only diet. In fact, the Inland West Pit turkeys have values lower than those of the pre–maize Bruce Boyd site and the Princess Point site (~A.D. 500 –1000) and Early Ontario Iroquoian site of Van Besien (A.D. 920). These results are remarkable as there is ample evidence of maize storage and consumption at the Inland West Pit sites Locations 1 (Figura), 3, and 9, including numerous pit features with charred maize remains (Golder and Associates 2012), and isotopic data for a human (–12.5‰, n=1, Spence 2010), dogs (–14.85±1.82‰, n=16, this study) and raccoons (–20.68±0.52‰, n=12, this study) showing maize availability similar to that at contemporary Ontario Iroquoian sites. Potential explanations to account for this significant variation are: (1) maize fields were not as extensive at these Younge Phase sites (A.D. 1050–1270) compared to the Ontario Iroquoian sites (ranging from A.D. 1250 and 1650), and/or (2) Western Basin and Ontario Iroquoian peoples were engaged in different turkey hunting strategies.

While the Inland West Pit sites do date to slightly earlier than many of the Ontario Iroquoian sites analysed for this study, the evidence of maize production at these sites is extensive. Further, unlike some other Western Basin sites, the Inland West Pit, Figura and Location 9 sites appear to have been occupied year-round with somewhat larger

populations, particularly at Location 9. If maize dependency was increasing at the sites by this time, as seems probable based on the extensive maize storage pit system (Golder and Associates 2012), maize fields could have been quite large. Differences in human behavioural patterns at Western Basin versus Ontario Iroquoian sites related to turkey hunting practices may be the best explanation for the data. For example, maize production and turkey hunting may have been geographically separate activities at Western Basin sites. Western Basin peoples may have hunted turkeys away from maize fields and/or their harvesting techniques may have left minimal maize waste in fields leaving no cold weather food resource for turkeys. These ideas are explored in more detail below.

3.5.3.2 C_3 environment with seasonal maize access

Although all of the modern turkeys consumed a mixed C_3/C_4 diet and were generally more enriched in ^{13}C, their isotopic compositions overlap with archaeological turkeys from sites within the Grand River basin in central southwestern Ontario as well as the two sites to the north analysed by Katzenberg (1989; 2006). This dietary specialization indicates an interaction between humans and animals whereby: (1) the landscape is altered by domestic crops, (2) humans accidently or purposefully leave behind some of their domestic (maize) produce, creating a niche that will attract turkeys, and (3) humans then use this niche for hunting them. In the case of modern turkeys, maize waste may be accidental; however, modern hunters know that agricultural fields attract turkeys and will often hunt turkeys near the edge of fields. As discussed previously, there is osteological (i.e., juvenile skeletal remains with age-at-death estimates), contextual (i.e., winter house middens), zooarchaeological (Foreman 2011; Noble and Prevec 1983), and ethnohistoric (Thwaites 1896–1901) evidence of cold-weather hunting of turkeys, the time of year turkeys would be expected to be in maize fields. The turkeys analysed at the Ontario Iroquoian sites had eaten some maize suggesting that they may have been hunted in or near maize fields. The question is whether or not Late Woodland Ontario Iroquoian peoples purposefully or accidentally created this C_3/C_4 niche, which is discussed in detail below.

3.5.3.3 Domestic turkeys

Not surprisingly, domestic turkeys have significantly higher mean $\delta^{13}C_{col}$ values, which indicate year-round access to maize, and are the compositions expected for domesticated birds. Almost all of the Ontario Iroquoian turkeys analysed in this study do not appear to have been domesticated turkeys provisioned year-round with maize. However, a single Neutral sample, Ham–05, from the Hamilton site, has a $\delta^{13}C_{col}$ value comparable to the domestic turkeys of the American southwest (Figure 3.10). This turkey was recovered from a small midden found within the palisades, as opposed to the majority of turkeys, which were recovered from middens outside the village walls (Lennox 1977). The location within the walls and the $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values suggest that this turkey was specially treated as discussed below. The domestic turkeys from the American southwest and Mexico also had significantly higher $\delta^{15}N_{col}$ values, which has been attributed to increased regional aridity causing higher $\delta^{15}N_{col}$ values of plants (Ambrose 1991).

3.5.4 Wild turkey food security and garden hunting

In the fall, turkeys will gorge on acorns, maize waste, and other readily available foods to fatten for the winter. During the winter, turkeys in Ontario, at the northern extremes of their natural range, actively seek out winter food resources or face starvation. The Jesuit Relations includes descriptions of turkeys venturing near human settlement to find food during winter scarcity (Thwaites 1896–1901 59:171). This behaviour creates hunting opportunities for humans because maize waste in fields provides a sustainable food resource for the turkeys during these months. Although it has been argued that the attraction of turkeys to food available in human settlements led to self-domestication in the southwest (Dickson 1992), based on the isotopic and zooarchaeological data, this did not happen in Ontario.

Faunal assemblages indicate that starting in the Middle Ontario Iroquoian phase (A.D. 1240 to 1450) there is a marked decrease in the number of cold-weather hunted species such as turkeys and white-tailed deer (Foreman 2011; Prevec and Noble 1983; Stewart 2000). Foreman (2011) attributes the decrease in wild turkeys to a scheduling conflict between crop harvesting/nut collecting and the start of fall hunting season (deer, raccoon

and turkey). With heavier reliance on crops, there was an increasing emphasis on near-settlement, opportunistic procurement of animals (Foreman 2011). A number of the turkeys at Middle Ontario Iroquoian and Neutral (A.D. 1450 to 1540) sites have high $\delta^{13}C_{col}$ values, which support the hypothesis that Ontario Iroquoian peoples hunted crop-eating birds in their fields opportunistically.

The number of archaeological turkeys exhibiting these high $\delta^{13}C$ values, some of which overlap with modern turkeys known to live near maize fields, suggests access to relatively large quantities of maize. It is possible that accidental maize waste would not provide sufficient resources for these birds, and in fact, Ontario Iroquoian peoples probably left a certain amount of maize waste in fields on purpose after harvest, creating a cold-weather feeding space for several species, including wild turkeys.

Providing food security for wild turkeys is not unheard of in modern contexts and it is possible to conclude that the ancient peoples of Ontario did the same thing. What may have begun as an observation that turkeys preferentially selected maize fields for fall fattening and winter food sources, therefore creating predictable hunting zones, may have shifted to food provisioning by ancient humans. This behaviour may explain why a great number of the turkeys from the central southwestern Ontario area sites (n=12 of 32) have $\delta^{13}C$ values indicative of maize consumption. However, the provisioning of turkeys appears to be limited geographically to central southwestern Ontario. At sites west of this region, such as the Western Basin tradition Inland West Pit sites, and east of the region, such as Thorold, turkeys ate in an exclusively C_3 environment. The question to consider is how and why this practice may have developed.

Tending fields and harvesting was considered women's work among the Iroquois-speaking nations (Heidenreich 1971; Thwaites 1896–1901 65; Tooker 1991; Wrong 1939). Carr (1883:36) recounted the words of Parker, an Iroquoian general, describing the Six Nations Iroquois:

"Among all the Indian tribes, especially the more powerful ones, the principle that a man should not demean himself or mar his dignity by cultivating the soil or gathering its product was most strongly inculcated and enforced. It was taught that a man's province

was war, hunting, and fishing. While the pursuit of agriculture, in any of its branches, was by no means prohibited, yet, when any man, excepting the cripples, old men, and those disabled in war or hunting, chose to till the earth, he was at once ostracized from men's society, classed as a woman or squaw, and was disqualified from sitting or speaking in the councils of his people until he had redeemed himself by becoming a skillful warrior or a successful hunter."

As women were responsible for harvesting crops, it may also have been the women and perhaps elderly men, who created a garden hunting niche by leaving behind maize in fields. Prior to 1200 A.D., turkeys may have been actively hunted in the forest by men (Dickson 1992; Engelbrecht 2003) but the opportunistic and supplemental turkey meat may have been managed by women. With decreasing winter hunting and greater opportunistic hunting, a shift to turkey hunting closer to fields and villages may have evolved.

Wright (2004) has noted that the Middle Ontario Iroquoian phase was also a time of considerable ceremonial activity. Therefore the emphasis on a predictable turkey source may not have been for meat, but for feathers, an important component of medicine bundles, and ritual headdresses and cloaks.

While turkey provisioning appears to have commenced during the Middle Ontario Iroquoian tradition, it continues at Neutral sites, which were distinguished not only by increasing populations, long-term habitation and maize exploitation but also climate change in which the Medieval Warm Period (MWP, ~A.D. 800 to 1200) was followed by the cooling effect of the Little Ice Age (LIA, ~A.D. 1450 to 1800). The impact of these major climatic events on northeastern North America would have been a shift from a notably longer growing season to a shorter growing season beginning at the end of the Middle Ontario Iroquoian stage and continuing throughout the Neutral (Bernabo 1981; Campbell and Campbell 1989; Dean 1994:7; Foster 2012; Gajewski 1988; Mullins et al. 2011; Viau et al. 2012). The consequences of climate change to the Neutral include famine. The Jesuit Relations refer to famine during Historic Neutral times. In 1639, du Peron writes, *"[t]he famine this year is rather serious; but it is worse in the Neutral*

nation, where children are sold like slaves in order to procure corn" (Thwaites 1896–1901 15:157), and in 1642 Lalemant describes a three-year famine that ravaged Neutral peoples (Thwaites 1896–1901 21). During this Neutral stage a trade-off between maize collection and predictable protein sources may explain variation in the $\delta^{13}C$ values of turkey bones at different sites. For example, at two Neutral sites, Thorold on the Niagara Peninsula (A.D. 1620–1630) and Fonger located on the Grand River (A.D. 1580–1600), mean $\delta^{13}C_{col}$ values suggest dominantly wild C_3 diets. By comparison, Neutral sites such as Walker, Hamilton, Ball and Kelly-Campbell (Katzenberg 1989; 2006) contain turkeys that had continued to access maize. Although variation in the turkey $\delta^{13}C_{col}$ values may be the result of sample size, based on the current data, it appears that site and/or region specific food provisioning of wild turkeys, a unique activity, was used by many Ontario Iroquoian peoples during the Late Woodland.

3.5.5 Wild turkey for ritual and cold-weather feasting

Wild turkey remains recovered from "distinct" contexts might also provide further insight into cultural ideology. Two specific cases are explored: the ritual bundles from an Early Woodland component of the Bruce Boyd site, and cold-weather feasting at Middle Ontario and Neutral phase sites.

The two samples from an Early Woodland component (700 -400 B.C.) of the Bruce Boyd site (Table 3.7) were recovered from a human burial feature (Spence et al. 1978; M. Spence, *personal communications*). They have unexpectedly high $\delta^{13}C_{col}$ values (mean = –20.78±0.15‰) and slightly lower than expected $\delta^{15}N_{col}$ values (mean = 5.39±0.16‰). Although these turkeys were intended to provide a baseline for a C_3–only environment because the Bruce Boyd site pre-dates maize horticulture, these birds may have consumed small amounts of C_4 foods. This unexpected result could be explained by a much earlier entry of maize into Ontario than was previously known, an alternate C_4 resource (e.g., amaranth), and/or trade of bones or animal parts for ritually specific purposes from a location outside of Ontario (i.e., New York or Ohio) where maize was present much earlier (Allegreto 2007; Capella 2005; Crawford et al. 2006; Martin 2004). Exchange of animal remains with special properties, specifically of turkey wings as medicinal objects, is recorded in the Jesuit Relations; *"[*Saossarinon*, a healer] taught the*

secrets of his art and communicated his power,—as a token of which he left them each a Turkey's wing, adding that henceforth their dreams would prove true." (Thwaites 1896–1901 13).

Table 3.7: Summary of results from Bruce Boyd's Early Woodland component.

Site Name	Sample Name	$\delta^{13}C_{col}$ (‰, VPDB)	$\delta^{15}N_{col}$ (‰, AIR)
Bruce Boyd (AdHc–4)	BrB–02 (tibiotarsus)	–20.89	5.50
Bruce Boyd (AdHc–4)	BrB–03 (humerus)	–20.68	5.28

The Ontario Iroquoian annual maize harvest took place in the early fall (i.e., late August, September and/or early October), but its timing fluctuated from year-to-year because of climatic and seasonal variation (Heidenreich 1971; Tooker 1991). The evidence of fall turkey hunting and the simultaneous disposal of multiple birds, which were apparently also eaten following the fall maize harvest, strongly suggests cold-weather feasting activity (see Hayden 1996), such as thanksgiving ceremonies (which was held after the harvest [Heidenreich 1971]) or the White Dog Ceremony (a ceremonial feast held in mid–winter) (Oberholtzer 2002). Characteristic faunal deposits resulting from feasting events and ceremonial use of animals (Hayden 2009) include burials of large numbers of birds together at Crawford Lake and Hamilton sites (including juveniles of known age at death), a winter house midden with turkey at the Walker Site (Wal-50) and a burial of a nearly complete large male turkey (Crf-051). Because there appears to be evidence of the ritual use of turkeys at Ontario Iroquoian sites, understanding their ideological role and categorization is important for understanding the relationship between humans and turkeys, as well as where turkeys fall on the spectrum of wild to domestic animals. Despite their use as food and in ritual, medicine and clothing, wild turkeys are not mentioned frequently in Great Lake stories, mythologies or clan names. Turkey remains may not have been treated the same way as those of mammals or hunted animals. Canid puncture marks on Middle Ontario and Neutral turkeys indicate that dogs were allowed to scavenge the birds, which is inconsistent with the taboo against allowing dogs to eat the remains of hunted animals (Thwaites 1896–1901 vol 44). Although parts of the wild turkey may have been important for feasting, ceremony, medicine and clothing (i.e., feathers for cloaks and the wing for healing), it might not have shared the same type of cosmology as species more frequently referenced in Great Lakes mythology (i.e., wolves,

bears, foxes, eagles and beavers) and on effigy pipes (owls, crows, ravens, ducks and eagles) (Mathews 1980; Noble 1979; Wonderley 2005).

It is possible, therefore, that wild turkeys were categorized differently than the more frequently depicted aquatic and predatory bird species in Eastern Woodland art and myth (Mathews 1980). For example, the "native taxonomy" of the American Bottom, (southwestern Illinois around the Mississippian floodplain), which is based on faunal assemblages and depiction in art, sorts species into those that are ideologically important and commonly represented in art (bears, snakes and spider) versus others that were only eaten or economically important and less frequently represented (such as deer and fish) (Zimmerman Holt 1996:100). In the American Bottom, according to Zimmerman Holt's categorization, turkeys could have been categorized with other opportunistically hunted terrestrial animals (i.e., muskrats and squirrels) or with the complicated category of birds. Based on the minimal imagery of turkeys in myths and on pottery, turkeys may have been categorized on their terrestrial nature (unlike aquatic or migrating birds), behavioural patterns (i.e., diurnal, flocking, non–migratory), and practical significance as a high reward-relatively low energy hunted species. There is a unique pattern of human provisioning that occurred in southwestern Ontario, not currently recognized elsewhere. The question remains whether this was a form of proto–domestication or simply a convenient hunting strategy for Late Woodland Ontario Iroquoian peoples.

3.5.6 Domestication status

Researchers in the southwest and Central America have hypothesized that the ceremonial uses of the turkeys (i.e. feather production and role in ritual) led to their domestication (Breitburg 1993). Because wild turkeys in southwestern Ontario appear to have been used for both feasting and ceremony from the Early (Bruce Boyd) to Late Woodland periods (Crawford Lake and Hamilton), it is possible that they were on a continuum to domestication for this reason as well. There is isotopic evidence at the Hamilton site that at least one Neutral wild turkey (Ham-05) was held in captivity within the village and purposefully fed. Likely the most important site within the Grand River region, the Hamilton village was occupied at the height of the Neutral famine (1638 to 1651) (Lennox 1977). Ham-05 was recovered from a small midden within the village and had

access to maize year round. Because it must have been kept in captivity, this bird was either raised for food or kept as a pet. The keeping of small mammals and birds as pets has been recognized in ethnohistoric accounts of the Neutral (Galton 1865; Wrong 1939), as well as in the practice of specifically capturing and raising turkey poults in other regions (Schorger 1966). Pet keeping has been argued by some researchers as a precursor to domestication given appropriate economic pressures (Serpell 1989). The close relationship between humans and turkeys that is implied by the purposeful feeding of a captive bird may mark a phase of raising turkeys within the village walls,. Overall, there was not enough evidence to support a theory of proto-domestication, but it is clear that there was a unique relationship between turkeys and humans at Ontario Iroquoian sites involving provisioning, cold-weather feasting and/or ritual use, purposeful feeding and captivity. Further, this relationship is variable and dynamic, changing regionally and temporally.

3.5.7 Tracing hunting ranges using $\delta^{18}O_{sc}$ values

Because wild turkeys are non-migratory and their habitats must include access to water, usually within 2.4 to 3.2 kms of their roost (Schorger 1966), their $\delta^{18}O_{sc}$ values should reflect those of the local water they drink. Based on this hypothesis, it may be possible to determine if turkeys were hunted locally (i.e., near sites) or away from sites.

To estimate what the available $\delta^{18}O$ values of water available to turkeys may have been at each of the sites sampled in this study, annual average oxygen isotopic compositions for precipitation ($\delta^{18}O_{precipitation}$) were interpolated based on sixteen water stations across the Great Lakes region (IAEA/WMO 2013; Longstaffe *unpublished data*) see discussion Chapter 1, Section 1.3.4, Figure 1.2 and 3.11). The range of $\delta^{18}O_{precipitation}$ values for the region with available turkeys is less than 2%. The $\delta^{18}O$ values of the turkeys' structural carbonate was converted to phosphate following Iacumin et al. (1996:4):

$$\boldsymbol{\delta^{18}O_{phosphate} = 0.98(\delta^{18}O_{sc}) - 8.5} \qquad \textbf{[Equation 3.1]}$$

The bone phosphate values were converted to precipitation values following Luz et al.'s (1990:1724) formula:

$$\delta^{18}O_{phosphate} = 34.63 + 0.6506(\delta^{18}O_{precipitation}) - 0.171(humidity)^{17} \text{ [Equation 3.2]}$$

and statistically compared to the interpolated $\delta^{18}O_{precipitation}$ for each site

The results show no statistical relationship between turkey $\delta^{18}O_{sc}$ values and predicted $\delta^{18}O_{precipitation}$ values based on a Pearson's correlation for either the archaeological turkeys (mean = 20.66±1.14‰, range = 18.06 to 22.16‰) or modern wild turkeys (mean = 20.18±1.64‰, range =15.12 to 21.40‰).

There are several explanations for this lack of correlation. The most likely explanation is the limitations of the current precipitation model, based on a very small range of $\delta^{18}O_{precipitation}$ values for the geographic region of interest.

There may be other contributing factors affecting the lack of correlation between $\delta^{18}O_{sc}$ values and predicted $\delta^{18}O_{precipitation}$ values, such as different ages-of-death of the turkeys. As bone represents a lifetime average, depending on the metabolic rate and age at death, the turkeys' structural carbonate could reflect different numbers of summers or winters survived. The seasonal effect on $\delta^{18}O_{precipitation}$ values can be quite significant in Ontario due to changing temperatures and air mass sources. Alternatively, the lack of correlation could be explained by changing water sources throughout the year. For example, in the winter turkeys may access spring–fed streams essential for cold weather survival (Schorger 1966), and which often include ground water, which may not directly reflect $\delta^{18}O_{precipitation}$ values (Darling et al. 2003). During the warmer months of the year, turkeys are able to access ponds, streams and rivers fed by local precipitation, more readily.

[17] humidity was estimated at 85%, based on an Ontario average.

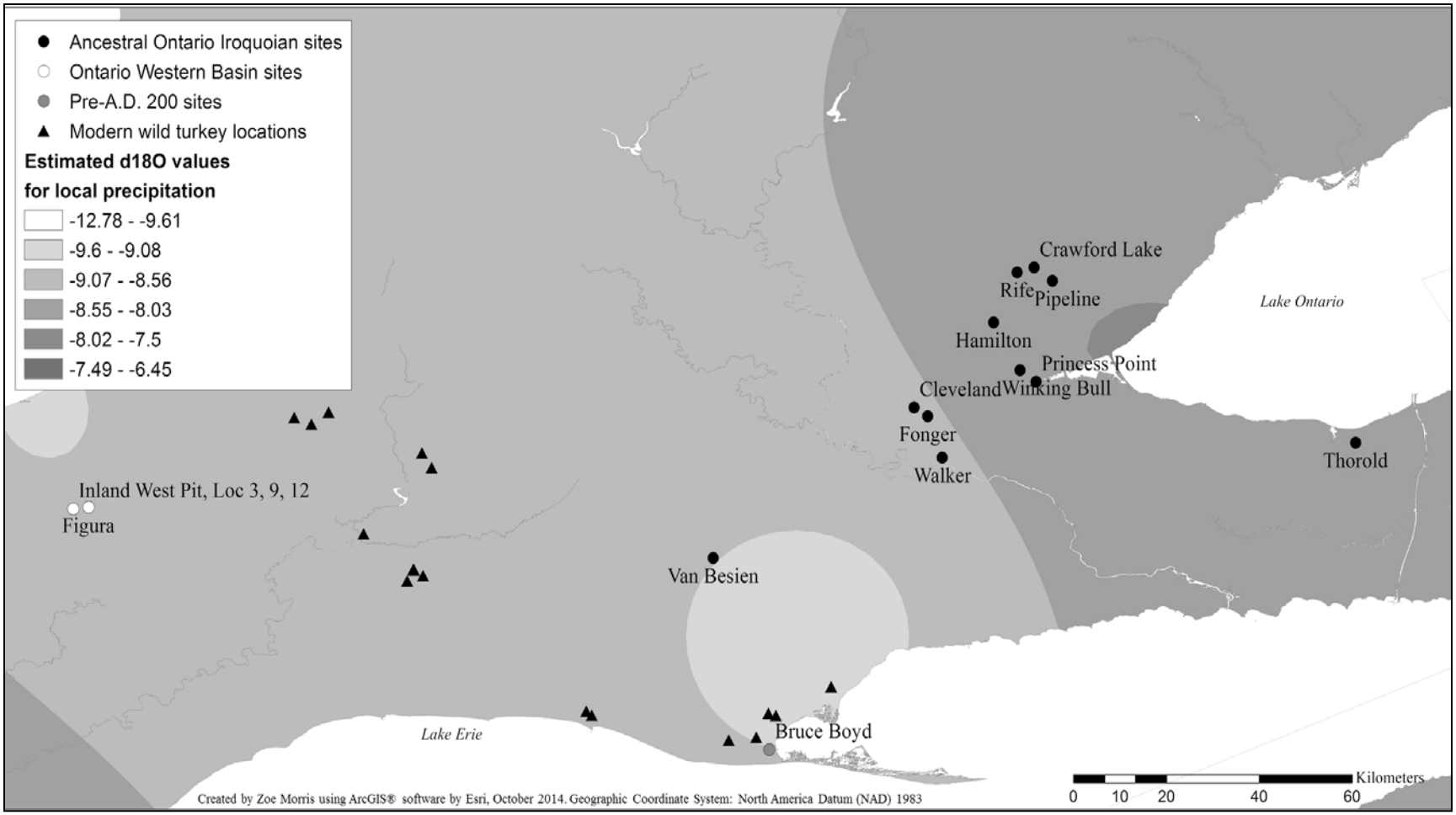

Figure 3.11: Modern and archaeological turkey locations overlaid on the interpolated $\delta^{18}O_{precipitation}$ values (IAEA/WMO 2013; Longstaffe *unpublished data,* Figure 1.2)

3.6 Conclusions

This study has demonstrated the importance of using modern species as comparative models for understanding human-animal interactions in the past, and that $\delta^{13}C_{sc}$ values for birds can be used to expand on traditional dietary $\delta^{13}C_{col}$ studies. The carbon and nitrogen isotopic data also provide insight into: (1) dietary adaptations of turkeys to changing environments; (2) varying behavioural patterns of past humans related to subsistence practice, and (3) the complexity of the relationship between humans and animals. Further, cultural differences in landscape and animal management used by Ontario Iroquoian and Western Basin peoples and responses by turkeys to environmental change were explored through regional comparison of turkey carbon-isotopic analyses. Although full domestication of wild turkeys is not part of the spectrum of human-animal relationships in southern Ontario, this study has shown an interaction between wild turkeys and Ontario Iroquoian people that is currently unique in the North American archaeological literature.

The carbon isotopic composition of wild turkey remains from Grand River basin sites indicates that turkeys began consuming maize more consistently in the Middle Ontario Iroquoian phase. This behaviour continued into the historic Neutral period at some sites, along with evidence of year–round, purposeful feeding of at least one turkey at the Hamilton site. Age-at-death analysis of juvenile turkeys and burial context provided direct evidence of cold-weather turkey hunting, supported by previously established zooarchaeological and ethnohistoric descriptions of fall and winter hunting of wild turkeys in Ontario. The increasing number of turkeys that consumed maize combined with the decreasing numbers of turkeys in faunal assemblages starting around A.D. 1200 may represent a shift to opportunistic, near-settlement hunting at Ontario Iroquoian sites. Based on the results, it is suggested that turkeys hunted at Late Woodland Ontario Iroquoian sites were purposefully provisioned with maize, post-harvest, ensuring the availability of turkey for food, feasting, ritual, and medicine during the colder months. Because the Iroquoian maize harvest was the responsibility of women, it is proposed that they were responsible for creating the garden-hunting niche by leaving surplus maize in fields and possibly hunting the turkeys there as well.

The use of $\delta^{18}O_{sc}$ values of turkey bones to confirm near-site hunting does not appear to be a useful method for tracking the geographic hunting ranges of Late Woodland hunters because of a lack of variation in local precipitation $\delta^{18}O$ values within the geographic region.

Our understanding of the wild turkey and its relationship to Ontario archaeological peoples should be expanded in future work by increasing the sample size, particularly for the Western Basin region, and incorporating multiple tissue analysis in order to better understand the influence of seasonality on human–animal interactions.

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Chapter 4

4 White-tailed deer

4.1 Introduction

"Perhaps it was the ever present problem of food, clothing and shelter from the earliest times that prevented the white-tailed deer from sharing much of this reverence and sanctity. For an animal of such utilitarian value could not carry the cultural impedimenta that go with totem and taboo, such as are found in the case of the black bear, and still be of so much value as a source of food, clothing, and shelter."

Curtis 1944:273

Great Lake Woodland economies and life-ways were dependent on game, particularly white-tailed deer (*Odocoileus virginianus*), as food and raw materials for clothing and tools as well as social cohesion through meat sharing, hunting, and trade. In southwestern Ontario, neighbouring Western Basin and Ontario Iroquoian cultural groups both hunted deer extensively, regardless of changing settlement patterns and increasing importance of cultigens. Corresponding approximately with the onset of the Late Woodland (A.D. 1000), Ontario Iroquoian settlement patterns shifted, reflecting greater sedentism and exponential population growth relative to the more variable settlement patterns seen at Western Basin sites. Many Western Basin sites appear to have been used only part of the year, with people following the movement of seasonally available resources, while contemporary Ontario Iroquoian sites were occupied year round for 10 and 20 years at a time. Despite these differences, starting around A.D. 1000, dedicated maize horticulturalism increased and year-round maize consumption is inferred from stable isotopic compositions of both Iroquoian and Western Basin humans (Dewar et al. 2012; Harrison and Katzenberg 2003; Katzenberg et al. 1995; Pfeiffer et al. 2014; Schwarcz et al. 1985; Spence et al. 2010; van der Merwe et al. 2003; Watts et al. 2011). In this study, isotopic analysis of enamel serial sections and bulk dentine along with paired bone collagen and structural carbonate samples are used to provide a more nuanced understanding of the feeding behaviour of white-tailed deer. These data enable the use of deer in reconstructing hunting patterns and tests their use as proxies of landscape change

(i.e., introduction and expansion of maize fields). Post-mortem cultural practices related to the processing and/or disposal of deer remains are also inferred. A clearer understanding of the long term relationship between humans and deer has significance for archaeological and paleoecological research, as well as modern wildlife management.

Differences in the ability of deer to access maize fields are hypothesized to be related to time period, region and cultural affiliation. Variation in maize consumption has been hypothesized in previous studies in the Maya region as a means to identify deer browsing at field edges or purposeful feeding of deer for ritual sacrifice (Emery et al. 2000; White et al. 2001, 2004b). Collagen analysis of modern deer from the lower Great Lakes suggested that δ^{13}C values higher than –21‰ indicated agricultural field browsing, and δ^{13}C values higher than –12‰ indicated captive, purposefully maize-fed deer (Cormie and Schwarcz 1994). Using these parameters, analysis of deer bone may provide evidence of maize consumption by ancient Ontario deer, which may be associated with field expansion by Ontario peoples and reflect tolerance of field pests and/or hunting patterns, such as hunting of deer in or near maize fields. Modern studies in the region indicate deer will preferentially use agricultural fields for food, which reflects the behaviour of both deer and humans (i.e., major alteration of the landscape including extensive use of maize and other crops). The absence of maize consumption reported previously for archaeological Ontario deer (Katzenberg 1989; 2006; Ketchum et al. 2009; Pfeiffer et al. 2014) can similarly indicate that deer were avoiding maize fields because of predators (human hunters) and/or that humans were either protecting their maize fields from deer and other pests or hunting deer in the wild.

In order to explore these possibilities, the bones and teeth of white-tailed deer from 25 sites from southwestern Ontario, spanning 3000 years, were analysed isotopically. The analysis of radiographs of juvenile deer and enamel serial sections of mandibular dentition were used to determine the mineralization chronology of permanent, posterior mandibular dentition. The season of enamel mineralization during the first year of life was predicted using 150 radiographs and verified using $\delta^{18}O_{sc}$ and $\delta^{13}C_{sc}$ values of the structural carbonate preserved in the enamel from ten deer. Bulk bone collagen and structural carbonate of sixteen modern deer and 81 archaeological deer were used to

determine average life time diet ($\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$) and to explore human geographic (hunting) range ($\delta^{18}O_{sc}$).

4.2 Background

4.2.1 White-tailed deer ecology and physiology

White-tailed deer are the most ubiquitous and adaptable of the North American cervids with a range extending from the Canadian Shield to the jungles of Central America (Dobbyn et al. 1994; Hesselton and Hesselton 1982:878; Miller et al. 2003:906). Their wide range reflects flexibility in habitat use, social behaviour and food exploitation. White-tailed deer are ruminants but because they have relatively small rumen they need higher quality food, a requirement they meet with an "uncanny" ability to maximize nutritional selections (Hesselton and Hesselton 1982:883; Miller et al. 2003:1912). When food is plentiful, deer will select plants with the highest nutritional value and only become generalists when food is scarce. Anecdotal evidence has shown deer will select fertilized over non-fertilized foods, plant parts with higher nutritional values and foods with more quickly digestible nutrients (Hesselton and Hesselton 1982; Miller et al. 2003). White-tailed deer consume a wide range of mast, forbs and browse, including fruits, berries, nuts, mushrooms, leaves, twigs, and digestible grasses. Their nutritional and habitat requirements shift seasonally with behavioural changes (Table 4.1), particularly in northeastern North America, where seasons are more extreme and they are more affected by temperature and daylight changes (Hesselton and Hesselton 1982:884). Despite the variations in diet and food resource locations, deer are not considered a migrating species. In fact, their non-migratory nature led Cormie and Schwarcz (1994) to label them as ideal candidates for isotopic baseline studies.

Table 4.1: Summary of Ontario White-tailed deer annual life cycle, feeding, and activity patterns. Also shown; the archaeological Ontario maize annual cultivation and harvesting patterns (top row) and estimated sequence of tooth mineralization (bottom row).

	May	June	July	August	September	October	November
Maize Annual Cycle	late May: maize seeds planted	beans and squash added; growing	tasselling (modern stage deer predation)	maize fruit mature - corn harvesting			
White-tailed deer seasonal activity	*birth, breastfeeding, and increased feeding during spring "green-up"*		*weaning complete; doe and fawns increased movement*	*lower activity level during summer heat*	*winter fattening (adults and fawns) beginswith focus on high energy food such as acorns*		*mating season males: rut females: estrus*
White-tailed deer metabolic rate	high metabolism		slightly lower metabolism		high metabolism (peaks in September/October)		lower metabolism
Specialty food item (selected among wide range of browse)	*selective browsing and foraging: forbs, soft mast (i.e. berries and fruit), browse, mushrooms, and maturing corn if available*				*focus on increasing fat for winter: apples, grapes, mushrooms, hard mast (especially acrorns)*		
Tooth mineralization	M1			M2			

	December	January	February	March	April	
Maize Annual Cycle	waste maize in fields				clearing fields?	Heidenriech 1971
White-tailed deer seasonal activity	*low activity: winter yards in coniferous areas, low nutrition and minimal movement*			*males: antler growth starts females: fetal development increases*		Hesselton and Hesselton 1982; Miller et al. 2003
White-tailed deer metabolic rate	lowest metabolism during winter months to reduce energy needs; use of fat reserves			increasing metabolism		
Specialty food item (selected among wide range of browse)	*minimal energy expenditure at nutritional sacrifice: dried sticks, grasses, leaves, conifers (i.e. white cedar)*			*"green-up" foods such as buds and shoots*		
Tooth mineralization	M3			PM4		this study

During the spring all deer increase food intake after winter has depleted fat and muscle reserves. Spring is the only time period that deer routinely graze. Male deer begin to form antlers in late spring and for females, April and May are the last trimester of their pregnancies and when 90% of fetal growth takes place, making spring forage very important. In Ontario, fawns are usually born at the end of May or in early June (Smith and Verkruysse 1983). During the first few weeks of life, does and fawns stay hidden and isolated, usually within woodlots. By six weeks, fawns are weaned and accompanying mothers in the search for food. The growth rate of fawns is affected by sex, population density and soil fertility, with females maturing more quickly than males (Miller et al. 2003). To permanently stunt growth it takes extreme nutritional deficiencies (i.e., less than 5% protein), as deer are able to recycle up to 90% of urea in cases of low dietary protein (Robbins et al. 1974). Urea recycling might result in low $\delta^{15}N_{col}$ tissue values (Ambrose 2002).

During the summer, deer consume carbohydrates for energy, eating leaves and seedlings of a wide range of wild trees, shrubs, and in some areas, crops. Fall is a critical time period for fattening so that the deer will be able to endure the mating season (especially males entering rut) as well as harsh winters in the northeast (Smith and Verkruysse 1983). A shift in daylight hours signals a hormonal change commencing rut and mating, and is followed by an exponential increase in fawn growth (Miller et al. 2003). The fall hormonal change also signals a peak in the intake of high energy foods to compensate for these activities; for example high energy hard masts, particularly maize, may constitute up to 70% of the fall diet. Ripening fruits are also an important dietary component at this time (Smith and Verkruysse 1983). Mushrooms, a major protein source, are also preferentially consumed during the fall, comprising up to 15% of the diet (Miller et al. 2003:913). During the winter, deer survive primarily on their fat reserves but also consume available browse, including twigs, branches, needles, and bark and they dig through the snow to get to underlying grasses (Armstrong et al. 1983; Smith and Verkruysse 1983). Deer adapt their metabolism to extreme temperatures, and through much of the winter, their metabolism drops significantly (Holter et al. 1976; Mautz et al.

1992; Silver et al. 1969). In order to minimize energy expenditure during this time period, less nutritional food may be consumed if it is closer at hand.

As a prey species, deer are highly adapted to predator avoidance. For example, does with young fawns will sacrifice nutrition for isolation. Rue (2004) also noted that bucks are more likely to exploit deeper, wood lot environments and that once fawns are able to travel, doe-fawn families will venture closer to open areas more frequently than bucks. Does may have higher δ^{13}C values because they consume more maize crops, and bucks may have lower δ^{13}C values because of a canopy affect created by forested environments (Loken et al.1992). Deer cannot live exclusively in deep forests, however, because of a lack of browse, and all deer need a variable landscape provided by use of forest edges, open spaces and wood lots. Deer are important prey species for wolves, often dictating wolf ranges and densities. In many regions, however, coyotes have largely replaced gray wolves as the major non-human predator of deer. Cougars, bobcats, domestic dogs, and black bears may also prey on deer, especially fawns and elderly or injured deer (Ballard 2011; Starna and Relethford 1985; Wolverton 2008). Further, white-tailed deer are not only vulnerable to predators but also severe winter starvation as well as parasites and diseases because they will not disperse with increasing population size (and associated resource depletion) and actually aggregate in the winter when food is most scarce (Armstrong et al. 1983). While white-tailed deer can live up to 15 years, however, mean life expectancy for wild deer is typically 5.5 years for females and 3.5 years for males (Hesselton and Hesselton 1982:916; Miller et al. 2003:917; Smith and Verkruysse 1983).

4.2.2 Modern white-tailed deer and humans

White-tailed deer are regarded as one of the most important modern game animals in North America, particularly the Midwest (Arnold and Torgersen 1980; Hesselton and Hesselton 1982; Knoche and Lupi 2012; Smith and Verkruysse 1983). Millions of deer are hunted annually in the United States alone (Craven and Hygnstrom 1994), the revenue for which is estimated to be hundreds of millions of dollars (Hesselton and Hesselton 1982; Knoche and Lupi 2011). As wild deer populations continue to rise in many areas, some researchers have suggested a need for increased hunting in order to bring deer densities below carrying capacity, and protect forest ecosystems and more

sensitive species in competition with them (McShea 2012; VerCauteren et al 2011). Understanding deer habitat use throughout the year is essential for making management policy as well as survey and harvest regulations, important foci for state and provincial wildlife agencies (Creed and Haberland 1980:83 Roseberry 1980). Stable isotopes offer one means of tracking animal movement and seasonal patterns related to food access.

The tolerance of deer for human altered landscapes has produced three major problems. First, as crop pests, white-tailed deer have economic and social implications. Hesselton and Hesselton (1982:883) noted that since 1900 deer have readily adapted to agricultural landscapes in regions such as the "corn belt" of the American Midwest, where they eat maize, alfalfa and soybeans. Although deer preferentially select a mosaic landscape of woodlots and open fields, a shift to significant crop consumption is reported to have occurred *after* heavy logging and landscape changes necessitated adaption by the deer in those regions. White-tailed deer cause more crop damage today than any other wildlife species in the US (see also Brittingham et al. 1997; Conover and Decker 1991; Craven and Hygnstrom 1994; Hewitt 2011; Tzilkowski et al. 2002), with staggering implications. For example, they can destroy up to 2/3 of a maize harvest (Harlen 1972, cited in Hesselton and Hesselton 1982:885) and some US states report crop damage in excess of $30 million (Craven and Hygnstrom 1994: 39). Crop dependence also results in higher reproduction and heavier deer, which further compounds the problem. In Ontario, both raccoons and deer are mainly responsible for damage to maize crops, with raccoons responsible for the majority of damage.

Vehicle collisions are a second major problem related to shared space between white-tailed deer and humans, causing millions of dollars in damages in the US and Canada each year (Heselton and Heselton 1982), and up to 3% mortality of deer populations in some regions (Munro et al. 2012). However, improved access to food and reduced numbers of predators in modern agricultural landscapes appear to outweigh the risk of collisions resulting in net population growth of deer in these shared landscapes (Munro et al. 2012). Lastly, deer can play a role in the transmission of disease to livestock. High population density and congregation in food habitats appear to be linked to bovine tuberculosis (*Mycobacterium bovis*) Kjær et al. 2008).

4.2.3 Ancient white-tailed deer and humans

Late Holocene changes in hunting strategies are recognized by a shift from broad spectrum hunting to a focus on white-tailed deer in many areas of North and Central America (example Wolverton et al. 2008), which reflects the fact that deer became one of the most important species hunted for food, clothing and tools, as well as social cohesion and ritual across much of North and Central America. White-tailed deer remains (bone, teeth and/or antler) are common in North and Central American archaeological sites (*Mesoamerica:* Flannery 1966, Santley and Rose 1979, Emery et al. 2000, White et al. 2001, Rosenwig 2006, ; Hamblin 1984; *Southeast United States:* Bolstad and Gragson 2008; *Midwestern United States:* Zimmermann–Holt 1996, Hedman et al. 2009, Nelson 1999; *Eastern Woodland:* Curtis 1952, Foreman 2011, Gramly 1977, Katzenberg 1989, 2006; Prevec and Noble 1983; Stewart 2000; Turner and Santley 1979, Warrick 2000, Madigral and Zimmerman Holt 2002).

As one of the largest and most common mammals in the faunal record, deer were clearly an important protein source for many pre-contact peoples, but ethnohistoric, archaeological and zooarchaeological evidence suggest that white-tailed deer were also prized for their hide, antlers, bone and sinews during the Woodland period in Ontario, (Gramly 1977; Katzenberg 1989; Ketchum et al. 2009; Prevec and Noble 1983; Stewart 2000; Turner et al. 1979). With growing human populations, there was probably competition over deer hunting territories, which was likely linked to social and economic change (Theler and Boszhardt 2006) as well as hunting territory expansion, primarily into the uninhabited lands (Turner and Santley 1979; Webster 1979). Deer were fundamental to the economies of both Western Basin and Ontario Iroquoian traditions between A.D. 1000 to 1600, dominating most faunal assemblages (Foreman 2011:74; Prevec and Noble 1983; Wrong 1939:225).

The ubiquity of white-tailed deer in faunal assemblages and their essential role for Late Woodland survival does not preclude them from playing a significant cosmological role in Great Lakes mythology and iconography. According to Menomini (Algonkin) myths, both the bear and deer ruled the underworld. However, Curtis (1952) speculated that the utility (and necessity) of deer for meat and skin would always out-weigh its ritual or

social value, and meant that they could *not* achieve the reverence, and therefore sanctity, of the black bear. It is similarly postulated that the economic importance of deer in the American Bottom (southwestern Illinois around the Mississippian floodplain) relegated them to a separate economic and non-ritual category in the "native taxonomy" of that area (Zimmerman-Holt 1996). This kind of ideology could explain the representation of Ontario Iroquoian and Western Basin deer as a food resource, rather than an anthropomorphized character in clan names, pipe effigies, and pottery (Matthews 1980), as well as in myth and legends, but it does not preclude their role in taboos and feasts. There are numerous references to specific taboos related to the disposal of deer. For example, Sagard states that;

"[*t]hey [the Neutral] have the same superstition in hunting deer, moose and other animals, believing that if any of the fat drops into the fire, or any bones are thrown into it, they will be unable to get any more,"* (Wrong 1939:187), and from the Jesuit Relations; *"they consider it a sin to throw the bones to the dogs; they either burn them in the fire or bury them in the ground. For, they say, if the bears, beaver, and other wild animals which we capture in hunting should know that their bones were given to dogs and broken to pieces, they would not suffer themselves to be taken so easily"* (Thwaites 1896–1901:1:283, from the Jesuit Relations).

The taboos indicate specific depositional requirements for certain hunted species, including deer. Deer are also mentioned as key components of feasts, including the sharing of flesh and boiling of deer heads (Wrong 1939:111). Fenton (1953:106–107) summarizes the evolution of Great Lakes' traditional ceremonies:

"Feasts on an animal head echo an earlier ceremonial cannibalism. The Huron, Mohawk, and Oneida tribes held feasts where the head, frequently the head of an enemy captive after torture, went into the kettle and then as a choice morsel went first to the chiefs. In the war feast the head, often a dog's head cooked in the soup, was presented to the captain who carried it in his hands inciting others to enlist. By the middle of the eighteenth century, the accounts refer to whole hogs being boiled in the maize soup and warriors successively danced with the hog's head in their hands. Thus, pork replaced the

dog as the war feast food, and later it supplanted the bear and venison in all feasts, until today the pig's head is the ceremonial head, the pièce de résistance."

4.2.4 Stable isotopes

Isotopes are variants of an element that differ in their number of neutrons and, therefore, in atomic weight. The differences in atomic weight cause isotopes to behave differently in chemical and physical reactions, resulting in variations in the ratios of one isotope to another. For example, as water evaporates, the lighter isotope of oxygen, ^{16}O, is preferentially evaporated over the heavier isotope, ^{18}O, resulting in the evaporated moisture being isotopically lighter relative to the source water. Organisms will incorporate the environmental isotopes into their tissues through the foods they ingest, air they breathe and water they drink. The isotopic compositions of animal tissues will, therefore, reflect their environment and are expressed as δ–values of the heavy to light isotope in per mil (‰), using the formula:

$$\delta = (R_{sample}/R_{standard}) / R_{standard}$$

where $R = {}^{13}C/{}^{12}C$, ${}^{15}N/{}^{14}N$ or ${}^{18}O/{}^{16}O$ (McKinney et al. 1950:730; Coplen 2011) . Carbon isotopic compositions are standardized to Vienna PeeDee Belemnite Limestone (VPDB) (Coplen 1996; 2011). Nitrogen isotopic compositions are standardized to AIR (Mariotti 1983). Oxygen isotopic compositions are standardized to Vienna Standard Mean Ocean Water (VSMOW) (Coplen 1996; 2011). An expanded description of stable carbon, nitrogen, and oxygen isotope analysis is proved in Chapter 1, Section 1.3.

4.2.4.1 Previous isotopic studies of deer

The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of bone collagen from 33 archaeological white-tailed deer from five southwestern Ontario sites tightly cluster around –22.1±0.9‰ and 6.4±0.8‰, and are interpreted as consistent with terrestrial herbivores consuming non-leguminous plants in a C_3 only environment (Katzenberg 1989; 2006). Almost identical means ($\delta^{13}C_{col}$ = –22.4±1.0‰ and $\delta^{15}N_{col}$ = 5.9±0.9‰) were reported for dentine collagen of 45 more archaeological southwestern Ontario white-tailed deer (Pfieffer et al. 2014:341). A commonly considered upper end point for a C_3 only diet is –21.4‰ (van der Merwe 1982; Cormie and Schwarcz 1994; Katzenberg 1989; 2006). Deer with $\delta^{13}C_{col}$ values

lower than this could also have been feeding in more deeply wooded areas i.e., a canopy effect (Bonafini et al. 2013; Drucker and Bocherens 2009). Most studies of deer show $\delta^{13}C_{col}$ ranges from –22.5 to –19.5‰ (Bergh 2012 for southeast US; Loken et al. 1992 for Nebraska; Emery et al. 2000, White et al. 2001, 2004b for Mesoamerica), which are generally interpreted as reflecting C_3 dominant diets, with the exception of some deer who had consumed small amounts of maize probably obtained by browsing at the edge of agricultural fields. Cormie and Schwarcz (1994) suggested a range of –21 to –16‰ to reflect C_3 dominant diets with some degree of maize consumption (uncorrected for the Suess Effect for modern wild deer with access to maize), which mirrors the –21.5‰ cut off suggested by van der Merwe 1982 for a C_3 only diet. Taking the Suess effect into consideration, a more conservative upper end value of –20.5‰ will be used to indicate a C_3 only diet in this study. It will be assumed that deer with $\delta^{13}C_{col}$ values between –20 and –18‰ have consumed some C_4 resources, and those with higher values have consumed significant amounts.

Cormie and Schwarcz (1994) analysed the effect of climatic variables, such as aridity, on the $\delta^{15}N_{col}$ values of modern white-tailed deer bone collagen across North America, including southwestern Ontario and Michigan. They noted that the $\delta^{15}N_{col}$ values from the Great Lakes region were relatively low, which they attribute to any combination of high precipitation, consumption of legumes, consumption of fertilized agricultural produce or plants growing in soil affected by agricultural inputs from fertilization and/or nitrogen fixing by agricultural legumes. The published archaeological deer data from the Great Lakes region have higher $\delta^{15}N_{col}$ values compared with the modern deer, suggesting that extensive agriculture inputs, not differences in precipitation, may be the primary cause for the low $\delta^{15}N_{col}$ values of the modern deer.

There are a few published white-tailed deer structural carbonate oxygen and carbon isotopic results, though overall, such data for structural carbonate are not as frequently reported as for collagen (but see Booth et al. [2011] for bone collagen-carbonate pairs from Late Woodland Ontario deer, Loken et al. [1992] for collagen-carbonate bone pairs from archaeology sites in Dakota, and Repussard [2009] for bone structural carbonate of Maya deer [Table 4.2, summarized Figure 4.1]).

Luz et al. (1990) mapped variations in the $\delta^{18}O$ values from the phosphate ($\delta^{18}O_{phosphate}$) of deer bone across North America, including portions of the Great Lakes, finding minimal variation between animals from the same region, which is interpreted as $\delta^{18}O_{phosphate}$ values reflecting local environments. Precipitation across the Great Lakes region is only minimally affected by latitude or altitude. There is, however, longitudinal variation in $\delta^{18}O$ values across southwestern Ontario with a 2‰ decrease in $\delta^{18}O$ values moving east from Lake St. Clair to the western tip of Lake Ontario (IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2).

4.2.5 Post-mortem alteration

After death, the tissues of the body begin to change. Post-mortem alteration of bones and teeth can be due to any combination of factors including the natural breakdown of body tissues, environmental and human induced taphonomic changes and diagenetic alteration of chemical structures (Berner 1980:3; DeNiro 1985; Koch et al. 1997; Sandford 1993; Sillen 1989). The protein, collagen, in bones and the dentine of teeth is quite resilient (Collins et al. 2002; Lee-Thorp and van der Merwe 1987), but can be altered by either microbial attack or hydrolysis (Hedges 2002). In anaerobic, water-logged conditions or dry environments (e.g., caves) microbial attack is less likely to occur but is rapid in hot, humid conditions (Hedges 2002; Nielsen-Marsh and Hedges 2000; Stuart-Williams et al. 1996). Collagen loss can also cause the remaining tissue to be contaminated with non-collagenous substances, usually lipids or soil humic acids, resulting in low $\delta^{13}C$ values and high carbon to nitrogen ratios (Ambrose and Norr 1992). Collagen content and the ratio of carbon to nitrogen are used to determine whether bone and dentine collagen have been altered. Collagen loss is believed to occur relatively early after death and may result in increased porosity, which reduces histological integrity (Nielsen-Marsh and Hedges 2000) and can contribute to the alteration of the inorganic portion of the bone (Hedges 2002). Von Endt et al. (1984) also demonstrated that within a site, depth of burial and size of bones will contribute to post-mortem alteration, with bones buried closer to the surface exhibiting great alteration.

Table 4.2: Summary of previously published archaeological deer collagen and structural carbonate data.

CULTURAL COMPLEX	SITE NAME	Mean $\delta^{13}C_{col}$	SD	n	Mean $\delta^{15}N$	SD	n	Mean $\delta^{13}C_{sc}$	SD	n	$\Delta^{13}C_{col-sc}$	Source
Neutral Ontario	SW Ontario, multiple sites	-22.1	0.9	33	6.4	0.8	33					Katzenberg 1989: Table 3; 2006: Table 19.1
Neutral Ontario	SW Ontario, multiple sites	-22.4	1.0	45	5.9	0.9	45					Pfieffer et al. 2014
Neutral Ontario	SW Ontario, multiple sites	-23.1	2.7	4	5.4	0.7	4	-10.5	0.8	4	12.6	Booth et al. 2011
Late Archaic	Indian Knoll, Kentucky	-21.0	0.9	10	4.3	1.1	10					Ketchum et al. 2009: Table 1
Middle Mississippian	Angel Site, Indiana	-21.2	1.3	11	4.3	0.9	11					Ketchum et al. 2009: Table 1
Mississippian	St. Catherine's Island, Georgia	-21.6	0.8	26	4.7	1.1	26					Bergh 2012: Table 8.3
Woodland	Dakota Site, Nebraska	-20.5	1.5	11	5.6	0.9	11	-12.2	2.1	9	8.7	Loken et al. 1992: Table 2
Maya	Aguateca	-20.5	1.4	12								Emery et al. 2000: Table 3
Maya	Arroyo de Piedra	-20.7	0.8	10								Emery et al. 2000: Table 3
Maya	Bayak	-20.5	0.3	5								Emery et al. 2000: Table 3
Maya	Colha Preclassic-	-21.1	0.8	16	5.0	1.7	16					White et al. 2001: Table 3
Maya	Copán Late Classic	-20.0	1.6	20	4.9	1.4	20					White et al. 2004b: Table 9.1
Maya	Copán Valley	-20.4	1.6	5	3.8	1.3						Whittington and Reed, 1997: Figure 12.1
Maya	Cuello Preclassic	-20.5	0.9	5	5.8	1.3	6	-12.4	1.5	4	8.1	van der Merwe et al., 2002: Table 2.1
Maya	Dos Pilas	-20.5	0.3	16								Emery et al. 2000: Table 3
Maya	Lagartero Late Classic	-18.2	5.4	8	5.4	0.9	8					White et al. 2004b: Table 9.1
Maya	Lamanai							-10.2	1.0	14		Repussard 2009: Table 5.7
Maya	Lamanai Historic Sprocket Deer	-21.8	0.3	2	4.5	0.3	2					White and Schwarcz 1989
Maya	Maya region Classic	-21.1	0.9	46	4.4	1.3	44	-10.4	0.8	16	9.2	Gerry, 1997: Table 2
Maya	Motul de San Jose							-10.5	1.0	10		Repussard 2009: Table 5.7
Maya	Pacbitun Classic	-19.2	3.9	5	8.1	4.1	4					White et al., 1993: Table 4
Maya	Piedras Negras							-10.6	1.0	67		Repussard 2009: Table 5.7
Maya	Punta de Chimino	-20.8	0.9	7								Emery et al. 2000: Table 3
Maya	Tamarindito	-20.5	0.7	3								Emery et al. 2000: Table 3
Maya	Tikal Classic	-19.7	2.8	9	5.0	1.2	9					White et al. 2004b: Table 9.1

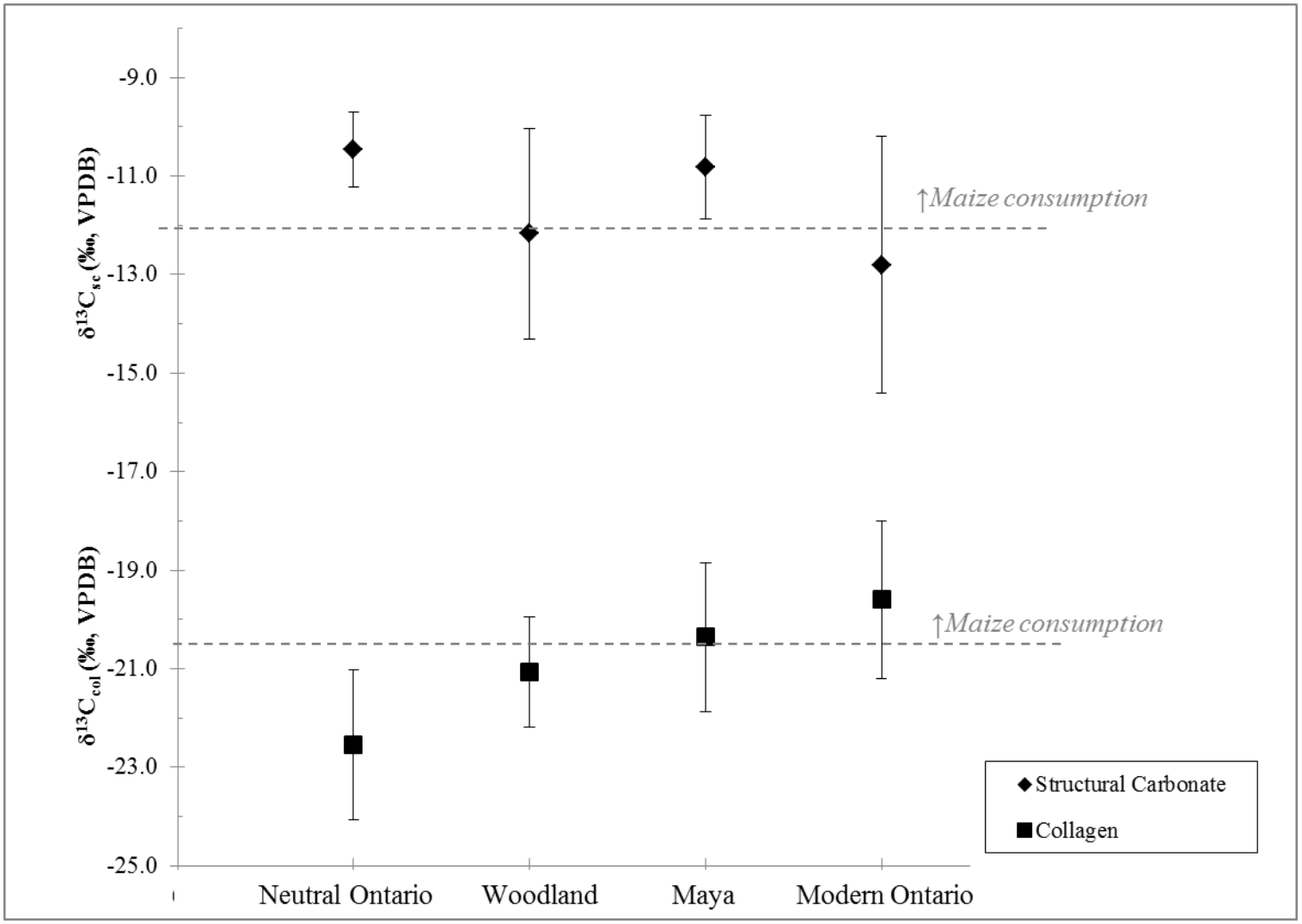

Figure 4.1: Summary of previously published $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values. See Table 4.2 for references.

The crystalline structure of the hydroxyapatite may be altered post-mortem by the uptake of F^- and CO_3^- from ground and soil water, the alteration of hydroxyapatite to brushite, and/or the dissolution and re-precipitation of hydroxyapatite under post-burial conditions (Hedges and Millard 1995; Hedges 2002; Wright and Schwarcz 1996). Some researchers have argued that the structural carbonate of bone (and in some cases dentine) may be unacceptably susceptible to contamination by environmental carbonates and, therefore, should not be considered a reliable tool for reconstructing past diets (Ketchum et al. 2009; Kolodny et al. 1983; Shemesh et al 1983; Schoeninger and DeNiro 1982). Other archaeologists have argued that the information available in structural carbonate is valuable (Harrison and Katzenberg 2003; Koch et al. 1997; Lee-Thorp and van der Merwe 1987; Wright and Schwarcz 1996). As with collagen, there are methods for determining the presence of alteration, either by the uptake of secondary carbonates or by re-crystallization. Fourier transform infra-red (FTIR) analysis is used to identify re-crystallization using the crystallinity index (CI), as well as the presence of peaks from secondary calcite or brushite (Nielsen-Marsh and Hedges 2000). Wright and Schwarcz (1996:934) and White (2004) stress that because structural carbonate is prone to alteration it is essential that each specimen be evaluated for alteration, after which the appropriate cleaning treatments (i.e., acetic acid wash) should be implemented. The high crystallinity and low porosity of tooth enamel makes it less susceptible to diagenesis than bone. Thus in cases where bone may be altered, enamel can provide a viable alternative sample source (Koch et al. 1997; Lee-Thorp and van der Merwe 1987; LeGeros 1981; Yang and Cerling 1994).

The effects of human-induced bone changes (i.e. cooking or defleshing) on post-mortem alteration continues to be studied (Nielsen-Marsh and Hedges 2000; Pijoan et al. 2007; Roberts et al. 2002). Under laboratory conditions (i.e., boiling in distilled water), DeNiro et al. (1985) and Munro et al. (2007; 2008) found that boiling had no effect on either bone collagen or bone carbonate isotopic values. Sustained boiling, however, may mimic diagenesis through re-crystallization (Roberts et al. 2002), and/or make buried bones more susceptible to exchange with soil carbonates due to increased porosity (Pijoan et al. 2007). Extended boiling (beyond nine hours) should be recognizable in bone, as it should

reduce collagen yields (<2%), produce poor C:N ratios (>3.6) and result in high CIs (>4.5) (Roberts et al. 2002). Heating of bone for shorter periods cannot be identified with post-mortem alteration tests for either collagen (collagen concentration and C:N ratio) or structural carbonate (CI index) unless the heat is over 350º (Munro et al. 2007).

4.2.6 Bone and dental tissue formation

Bioarchaeologists are limited to those tissues that preserve post-mortem, and usually work with hard tissues such as bone and dentition. Bone is a dynamic tissue, and both the organic (collagen) and inorganic (structural carbonate) portions of bone continuously remodel throughout life. Estimating the rate of bone turnover has been a long-standing research question, but estimates suggest that humans have bone turnover rates of 15 to 25 years (Frost 1969; Hedges et al, 2007; Martin et al. 1998). While basal metabolic rate, habitat and diet can have a direct effect on tissue turnover, it is generally accepted that larger bodied animals have slower tissue turnover (Nagy 1987). As such, bulk collagen and structural carbonate of large-bodied mammals, including white-tailed deer, is generally believed to reflect a life time average, with higher contributions from the sub-adult growth stage (Hedges et al. 2007).

Dental tissues (Figure 4.2), such as enamel and dentine, typically reflect the time period of tissue formation. Enamel formation, amelogenesis, is initiated quite early in embryonic development for most mammals but may continue for several months or years after birth. Enamel formation of the crown is always completed prior to eruption of the tooth and takes place in two phases: the initial secretion of proteins and organic matrix by amelobasts, followed by the mineralization phase whereby ameoblasts transport proteins needed to complete mineralization (Davis and Mead 2013; Garant 2003; Passey and Cerling 2002). The crown mineralizes sequentially from the coronal (crown) surface towards the cervical region (cemento-enamel junction) of the tooth. The dual secretion/mineralization process of enamel mineralization may result in some averaging of the isotopic signatures at the time of formation (Passey and Cerling 2002), but with appropriate sampling can provide incremental isotopic information. The sequential isotopic analysis of enamel (phosphate and structural carbonate) has been successfully

demonstrated by several studies, see for example Balasse (2002); Balasse et al. 2003; Metcalfe and Longstaffe (2012); Passey and Cerling (2002).

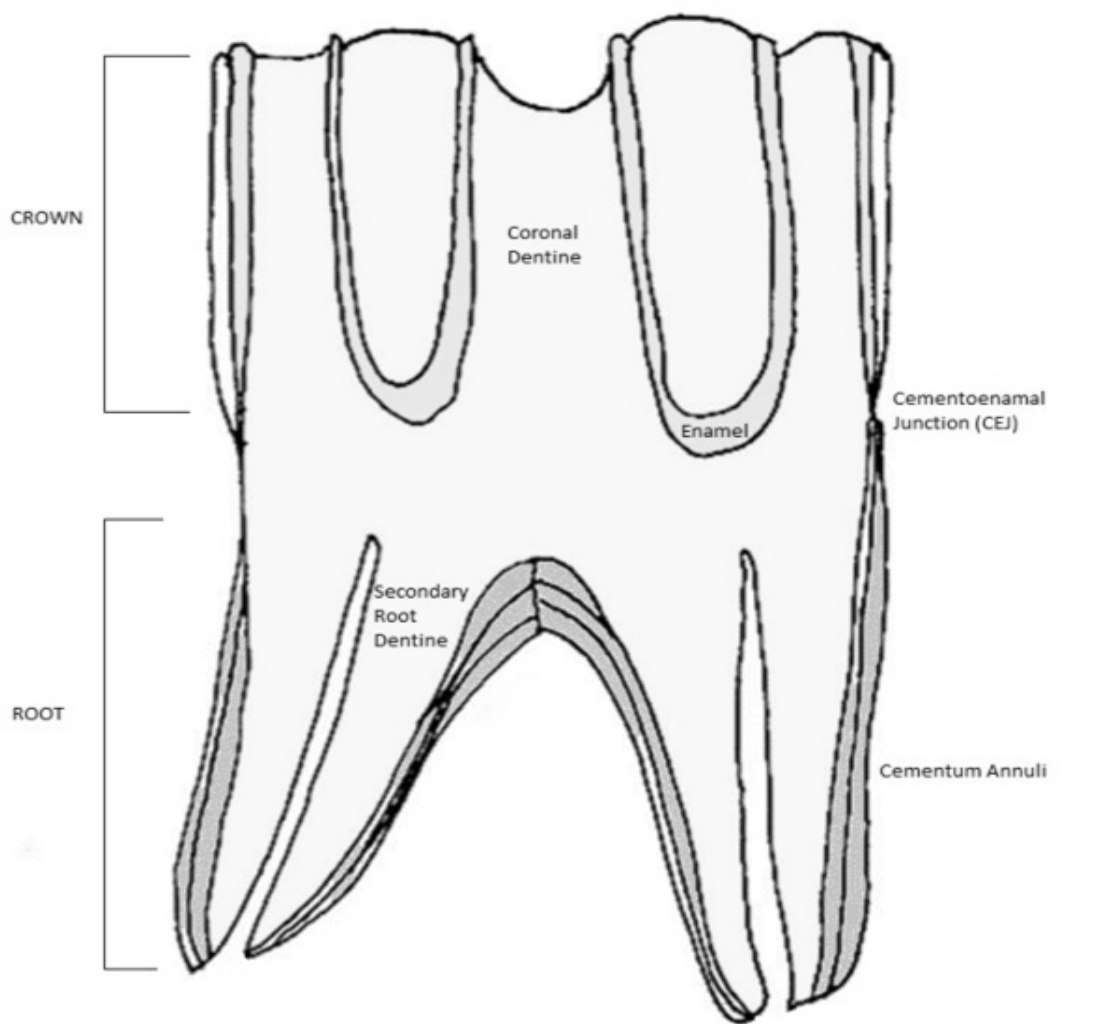

Figure 4.2: Cross section of a deer tooth.
Adapted from Stallibrass 1982: Figure 1, page 110.

Dentine also forms sequentially through a process known as dentinogenesis, initiated by mantle dentine and followed by primary dentine formation. The initial phases of dentine formation must occur prior to enamel formation (Spinage 1973). The mantle dentine forms along the coronal cusp surface from organic secretions by odontoblasts moving inward. At eruption the coronal dentine is formed, though secondary dentine continues to form after eruption by filling in around the pulp cavity of the roots (Garant 2003). In mammals, tertiary dentine (previously known as irregular secondary dentine) may form at

any stage of life on the coronal surface due to extreme wear or injury of the primary dentine (Spinage 1973).

While dental *eruption* studies have existed since the 1950s for white-tailed deer, there are no studies on their dental *mineralization*. In order to accurately determine the time period (i.e., month or season) of tooth formation as a means to link isotopic data with deer life stages, it is essential to determine the *mineralization* sequence for white-tailed deer teeth, specifically deer from northeast region as there is geographic variability in the development stages of deer across North America (Hesselton and Hesselton 1982). Because there are currently no published dental mineralization studies of white-tailed deer, two types of radiography are used here to provide this necessary information.

The use of dental eruption for determining age-at-death of Old World wild and domestic ungulates was first proposed in 1824 by Girard (McLean 1936; Spinage 1973). In general, determining age of juvenile white-tailed deer (and other ungulates, such as goat and elk) based on dental eruption and replacement is considered an accurate technique (Dirks et al. 2009; Gee et al. 1991; Gee et al. 2002; Hamlin et al. 2000; Hesselton and Hesselton 1982:881; Rees et al. 1966; Servinghaus 1949; Taber 1971), and is used by both wildlife management authorities (Deniz and Payne 1982; Miller et al. 2003; Ryel et al. 1961) and zooarchaeologists (see for example, Kay 1974 and Payne 1973). After two years of age, wear patterns, crown height (Gilbert and Stolt 1970; Hamlin et al. 2000; Klein et al. 1981; Ryel 1961; Taber 1971) and cementum annuli counts (Gilbert 1966; Hamlin et al. 2000; Lockard 1972; Low and Conwan 1963) have been used to determine age of mature white-tailed deer and other cervids. Unfortunately, these methods produce inconsistent results, regardless of species.

4.3 Materials and methods

This study included several methodologies, including (1) determining ages of modern, juvenile white-tailed deer based on dental *eruption*, (2) radiographic analysis of the same deer to determine the dental *formation* sequence, (3) the identification and selection of archaeological deer fragments from several Ontario archaeological sites, (4) the isotopic analysis of bone collagen and structural carbonate of modern and archaeological deer,

and (5) the isotopic analysis of the dentinal collagen and structural carbonate from enamel serial sections. The serial sections of enamel were manually removed from four mandibular teeth (fourth premolar, first, second, and third molar) and the dentine was separated for each of the four teeth.

4.3.1 Age determinations based on dental eruption

The age of each deer collected for radiography was determined by visible appearance of dental eruption. Each juvenile deer was assigned to one of nine age categories, adapted from previous white-tailed deer dental eruption sequences established by Servinghaus (1949) and revised by Knight (2001) and Taber (1971). The nine age categories represent distinct gross morphological changes with two to three month age spans, such as the emergence of a tooth above the bone, mid-eruption, and full eruption of teeth (e.g., Holly 2007). Appendix J includes descriptions and example photographs of the nine categories used to age the white-tailed deer. In total, one hundred and fifty–two white-tailed deer mandibles were assigned to an age category (Table 4.3).

Table 4.3: Summary of juvenile deer by estimated age and donating institution.

	CMN, Gatineau	ROM, Toronto	UWO Biology – teaching	UWO Biology – Griffith Island	UWO Anthro – Faunal Lab	Archaeological Samples
Fetal	7	5				2
0 to 1 month	2					
3 to 4 months				5		
5 to 6 months		3	1	24	1	2
6 to 7 months			1	31	1	4
7 to 9 months		3		21		4
10 to 13 months	5		2	3	2	3
15 to 17 months	1	3		3		3
18 months			1	2		3
19 to 22 months		1				1
Total	**15**	**15**	**5**	**89**	**4**	**22**

To confirm the repeatability of age assignment, intra- and inter-observer age estimates were performed on a sub-set of mandibles. Appendix L includes age estimates for all juvenile deer. To determine the degree of intra-observer error the author repeated the estimate process several months later for 12% (n=22) of the sample. To determine the

degree of inter-observer error a faunal expert and a non-expert estimated the age of 12% (n=22) of the sample. The intra- and inter-observer age estimations were compared using a 2–tailed, paired sample Student's *t*-test, following Divljan et al. (2006). There was no significant difference between the two sets of the author's observations (t=1.000, p=0.321), or between the author and the expert (p=0.331) and non-expert (p=0.186). The slightly higher error rate for the non-expert is most likely due to inexperience with the material. In all cases when a deer was categorized differently, it was only different by one category. Further, those deer that were categorized differently were at the "cusp" of their age categories. For example mandibles GI 10a and GI 10h, ZM1/2 were categorized as "closer to 9 months," compared to the expert observer, who categorized them at the young end of 10 to 13 months. Overall, the intra- and inter- observer tests suggest high reliability in categorizing juvenile deer by dental eruption, especially for those with experience. Therefore, the age of the juvenile deer as estimated by the author are accepted as a valid.

4.3.2 Age determination based on radiography

Juvenile white-tailed deer mandibles were acquired from several sources in Ontario including the Canadian Museum of Nature (n=15); Royal Ontario Museum (n=15); The University of Western Ontario Department of Anthropology zooarchaeology reference collection [n=4], Department of Biology teaching collection [n=5], and the Griffith Island Collection [n=89] (see Table 4.4). An additional twenty-two archaeological samples were radiographed from Ontario Iroquoian and Western Basin sites. Chemical film and computed radiographs were used to capture the images (Table 4.4, see Appendix K for details). A small subset of the zooarchaeology lab and archaeological samples were radiographed twice to compare the chemical versus computed radiography. It was determined that while the computed radiography provided higher resolution images, the technique ultimately did not affect the ability to interpret dental mineralization. Only mandibular, posterior dentition is presented in this study.

One hundred and fifty individuals were successfully radiographed. All film radiographs were digitized and all the digitized radiographs were imported into Picassa® so that the degree of mineralization could be determined for each adult posterior, mandibular tooth.

Each tooth was scored with one of the following categories: not present (X); not formed (NF); crypt only; partial crown mineralization (C0.1 to 0.9, based on relative completeness); complete crown (C); partial root mineralization (R0.25 to 0.75, based on relative completeness), complete tooth (based on root closure). Deciduous premolars were scored only on presence. Appendix M provides a complete list of radiographs with mineralization analysis of each tooth as well as radiograph specifications and estimated age based on dental eruption.

Table 4.4: Summary of radiographed modern and archaeological deer samples.

Sample Source	Total	Location Radiographed	Type of Radiograph
UWO Anthropology – Faunal Laboratory	4	Department Anthropology, UWO	Faxitron 43855D Chemical Development
UWO Biology – Teaching Collection	5	Department of Anthropology, UWO	Faxitron 43855D Chemical Development
UWO Biology – Griffith Island Collection	89	Sustainable Archaeology Ancient Images Lab	Faxitron 43855F Scan–X CR Scanner/ Phosphor Plate
Archaeological Samples	22	Department of Anthropology, UWO	Faxitron 43855D, Chemical Development
Royal Ontario Museum, Toronto	15	Royal Ontario Museum	GE–Medical Systems Kodak ACR–2000i Scanner/ Phosphor Plate
Canadian Museum of Nature, Gatineau	15	Canadian Museum of Nature	Security Defense Systems Orec PcCR812 HS Scanner/Phosphor Plate
Total White-tailed deer Radiographed	**150**		

The results were then compared with the age-at-death categories assigned to each mandible based on dental eruption. There is a high degree of correlation between the sequence of mineralization and dental eruption. Therefore, by comparing the mineralization sequence with the expected age of the deer (in months), the predicted *season* of formation was made for each tooth. For example, the second permanent molar begins forming two to three months after birth and is complete by six months of age. Using an average birth date between late May and early June for Great Lakes deer (Smith

and Verkuysse 1983), the second molar is predicted to mineralize sequentially between August and November.

4.3.3 Sampling for isotopic analysis

Archaeological white-tailed deer were sampled from previously excavated faunal collections housed at various institutes from across southwestern Ontario representing deer spanning 3000 years (Table 4.5), including the Department of Anthropology, McMaster University; Department of Anthropology, The University of Western Ontario; Ontario Museum of Archaeology; and D.R. Poulton and Associates Inc. Site descriptions may be found in Appendix A. Modern samples were donated by several individuals, including Monica and Greg Maika, Ted Barney, Richard Baskey, Mike Boyd, and Jim Keron, from several Ontario locations as hunted or road kill deer. Figure 4.3 includes the locations of archaeological sites in Ontario discussed in the text as well as approximate locations from which the modern deer came.

Table 4.5: Number of white-tailed deer remains analysed by cultural stage.

Pre–A.D. 200	**Total 8 Deer**	
Archaic	~8000–800 B.C.	3
Early Woodland	~900 – 0 B.C.	4
Middle Woodland	300 B.C. to A.D. 500	1
Ontario Iroquoian	**Total 51 Deer**	
Princess Point Phase	A.D. 700–1000	8
Early Ontario Iroquoian Period	A.D. 900–1300	7
Middle Ontario Iroquoian Period	A.D. 1300–1450	7
Late Iroquoian/Neutral	A.D 1450–1650	29
Ontario Western Basin	**Total 21 Deer**	
Riviere au Vase Phase	A.D. 600–900	2
Younge Phase	A.D 800–1200	17
Springwells Phase	A.D 1200–1400	2
Wolf Phase	A.D. 1400–1550	0

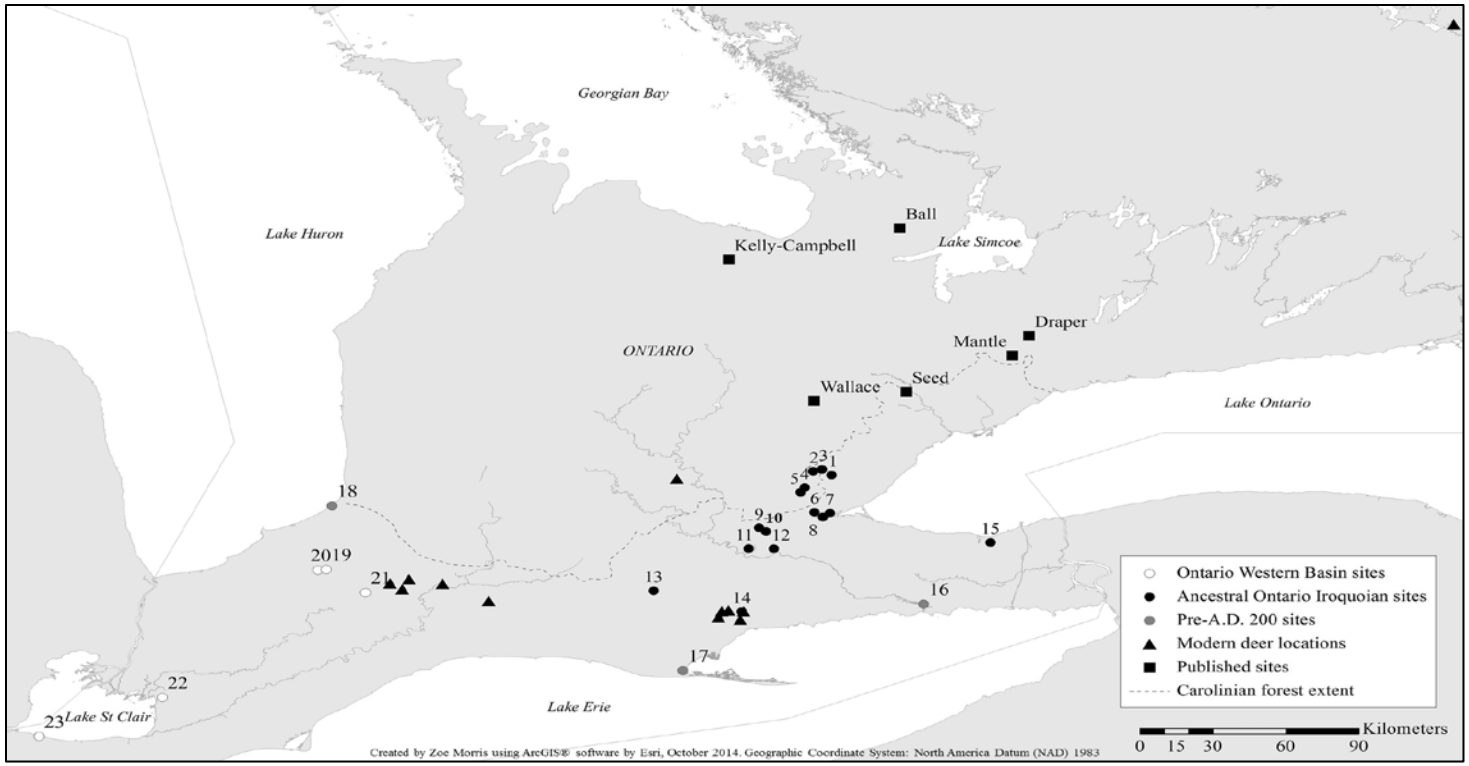

Figure 4.3: Map of all Ontario locations of deer for which isotopic analyses of deer bone and teeth were completed. Modern deer collection/hunting locations are marked with a black triangle. Archaeological sites from this study[18] (circles) and published sources (black squares) (Katzenberg 1989; 2006; Pfieffer et al. 2014).

[18] Ancestral Ontario Iroquoian Sites: 1. Pipeline; 2. Rife; 3. Crawford Lake; 4. Bogle II; 5. Hamilton; 6. Winking Bull; 7. Old Lilac Garden; 8. Princess Point; 9. Cleveland; 10. Fonger; 11. Porteous; 12. Walker; 13. Van Besien, 14. Slack-Caswell; 15. Thorold. Pre–A.D. 200 sites: 16. Cranberry Creek, 17. Bruce Boyd, 18. Davidson; Western Basin Sites: 19. Figura, 20. Inland West Pits site 3, 9 and 12, 21. Liahn 1, 22. Montoya, 23. Silverman.

4.3.4 Bulk bone selection and identification

Bulk bone samples were collected from 95 white-tailed deer for collagen analysis, including sixteen modern deer. The structural carbonate of 50 of the 95 deer was also analysed (Table 4.6). Specimen identification of the archaeological remains was completed by the author, Dr. Lindsay Foreman and Dr. Lisa Hodgetts. Identification was conducted in the UWO Zooarchaeology Laboratory, which includes white-tailed deer skeletons of various ages. Other cervids with historic ranges in southwestern Ontario include the elk or wapiti (*Cervus Canadensis*) and moose *(Alces alces*), both of which are significantly larger than the white-tailed deer (Dobbyn et al. 1994) (Figure 4.4).

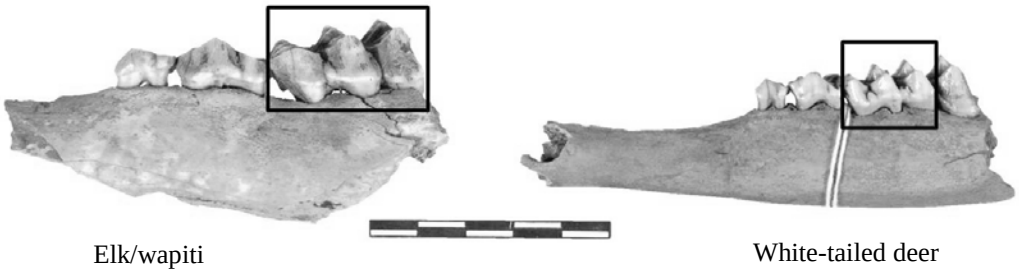

Figure 4.4: Comparison of elk/wapiti and white-tailed deer mandibles.
Both cervids are juveniles from the Cleveland site. Note the size difference of the mandible and third, deciduous premolar between the two species.

Mandibles from faunal collections were always preferentially selected when available because they were easy to identify and often associated with dentition. Complete foot bones (for example, phalanges or astragali) were selected where mandibles were not available because they are identifiable and often better preserved than other bones. Long bone fragments were only selected where mandibles and foot bones were not available. Fleshed, modern deer mandibles were cleaned at the Zooarchaeology Laboratory, Department of Anthropology, The University of Western Ontario.

Table 4.6: Summary of collagen and carbonate samples by cultural affiliation.

	Pre–horticulture pre A.D. 200 (sites, n=3)	Ontario Iroquoian A.D. 900–1600 (sites, n=15)	Western Basin A.D. 900–1600 (sites, n=7)	Modern White-tailed deer (locations, n=5)	Total Deer Analysed
collagen	8	52	21	16	**95**
carbonate	6	22	10	14	**50**

4.3.5 Enamel serial section sampling

Dentitions from ten white-tailed deer mandibles were serially sampled (hunted modern deer, n=2; Early Woodland, n=1; Late Woodland, n=7). All teeth were from adults and fully erupted, with the exception of an eighteen-month-old modern deer (Mod–deer-7) from which a bulk sample of a deciduous premolar was collected. Due to limited availability of complete mandibles among the Western Basin samples, Montoya 8 did not have a third molar.

Serial sampling was completed using a Dremel 545 Diamond Wheel mounted on a Dremel rotary tool. The wheel was cleaned by sonicating in distilled water between cuts to prevent contamination between serial sections. The three to five serial samples were taken along the lingual aspect of the four posterior teeth: premolar 4 (PM4, also referred to as premolar 3 in some texts), molar 1 (M1), molar 2 (M2) and molar 3 (M3), for a total of 116 sections. Only half the tooth (lingual surface) was sampled to allow future, micro-sampling of the enamel (Figure 4.6). Enamel and dentine were manually separated for each serial section. The enamel was pretreated for structural carbonate analysis (for protocol see Chapter 2, Section 2.2.3.2.2) and collagen was extracted from 38 bulk dentine samples (for protocol see Chapter 2, Section 2.2.3.2.1).

Pieces of bone weighing between ~0.2–0.4g were collected for each sample. Trabecular bone was then manually removed using dental tools, and the remaining cortical bone was cleaned with distilled water and dried overnight. Once dry, the cortical bone was crushed with a porcelain mortar and pestle, passed through a set of sieves and powder was collected at several intervals.

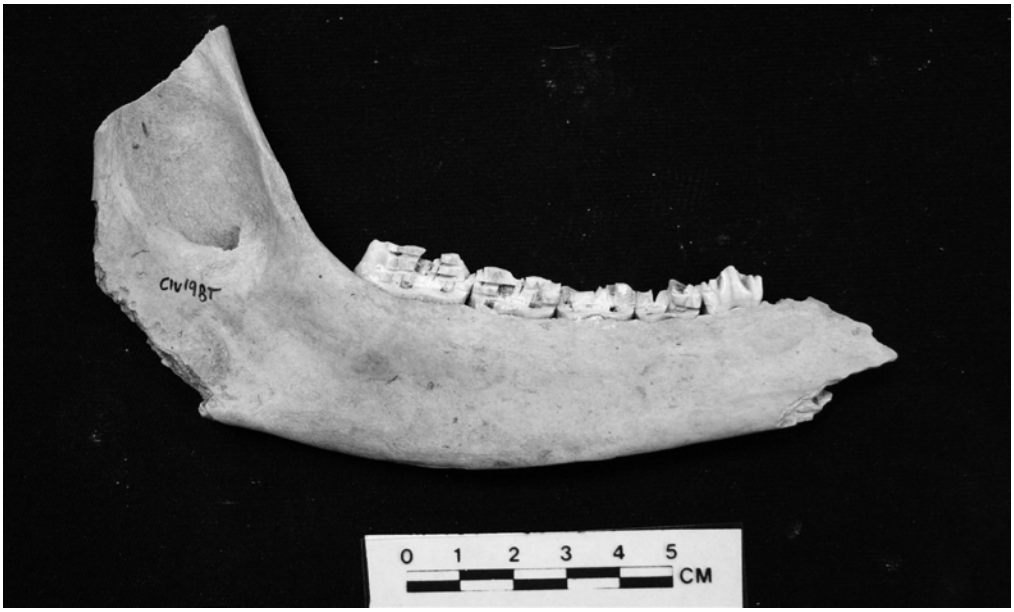

Figure 4.5: Example of manually serial sectioned posterior, dentition.

4.3.6 Analytical procedures

All isotopic analyses were conducted at the Laboratory for Stable Isotope Science, in the Department of Earth Sciences at The University of Western Ontario.

4.3.6.1 Extraction and analytical protocols

For complete collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$) and carbonate ($\delta^{13}C_{sc}$, $\delta^{18}O_{sc}$) extraction protocols see Chapter 2, sections 2.2.3.1 and 2.2.3.2 respectively.

The collagen analysis produces $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for both bone and dentine, as well as the carbon and nitrogen contents, which were used to calculate the C:N ratio. The $\delta^{13}C_{col}$ values were calibrated to VPDB using USGS-40, with an accepted value –26.39 ‰, and USGS-41, with an accepted value of +37.63‰. The $\delta^{15}N_{col}$ values were calibrated to AIR also using USGS-40 and USGS–41, with accepted values of –4.52‰ and +47.57‰, respectively (following Coplen 1994; Coplen et al. 2006). An internal laboratory standard (Keratin #90211, MP Biomedicals) was analysed approximately every tenth sample to provide a measure of the accuracy and reproducibility of the collagen analysis. The accepted keratin value for $\delta^{13}C_{col}$ is –24.04‰ and for $\delta^{15}N_{col}$ is 6.36‰, which compared well with the mean $\delta^{13}C_{col}$ value produced of –24.07±0.08‰

(n=107) and a $\delta^{15}N_{col}$ value of 6.29 ± 0.17‰ (n=106). Method duplicate pairs ((i.e., a different extraction and analysis of collagen on the same sample) were performed on 25% of samples with a mean reproducibility for $\delta^{13}C_{col}$ of ±0.03‰ and for $\delta^{15}N_{col}$ of ±0.08‰. The analytical precision of duplicate (i.e., replicate analyses of the same collagen extraction) analyses was ±0.03‰ for $\delta^{13}C_{col}$ and ±0.05‰ for $\delta^{15}N_{col}$.

The analysis of the bone structural carbonate provided $\delta^{13}C_{sc}$ and $\delta^{18}O$ values, for which $\delta^{13}C_{sc}$ values were calibrated to VPDB, following Coplen (1994), using NBS-19, with an accepted value of +1.95 ‰ and Suprapur, with an accepted value of –35.28 ‰. The $\delta^{18}O$ values were calibrated to VSMOW, following Coplen (1994), using NBS-19 and NBS-18, with accepted values of +28.60 ‰ and +7.20 ‰, respectively. An internal laboratory calcite standard, World-Standard 1 (WS-1) was analysed approximately every fifteenth sample in order to assess the accuracy of the carbonate isotopic data, which produced a mean $\delta^{13}C_{sc}$ value of 0.79 ± 0.22‰ (n=32) and mean $\delta^{18}O_{sc}$ value of 26.26 ± 0.19‰ (n=32), comparing favourably with the accepted WS-1 values of 0.76‰ and 26.23‰, respectively. Method duplicates and duplicates were performed for ~10% of the deer samples. Method duplicates had a mean reproducibility for $\delta^{13}C_{sc}$ values of ±0.12‰, and for $\delta^{18}O_{sc}$ values, ±0.15‰. Duplicate precision for $\delta^{13}C_{sc}$ values was ±0.08‰ and for $\delta^{18}O_{sc}$ values, ±0.09‰.

4.3.7 Fourier transform infra–red spectroscopy (FTIR)

Prior to pre-treatment, Fourier transform infra–red (FTIR) spectroscopy was conducted for the 50 white-tailed deer bone samples Due to the small sample size of enamel serial sections, it was not possible to perform FTIR analysis of all serial sections. For complete description of the Fourier transform infra–red spectroscopy (FTIR) procedures, see Chapter 2, Section 2.2.3.3.

4.4 Results

4.4.1 Dental mineralization

The results of the dental mineralization study show a clear, staggered formation pattern for the mandibular molar crowns, which corresponds with previously published data for

other deer species (Reese et al. 1966). By correlating the radiographic mineralization data with the age-at-death data it was possible to determine that the first permanent mandibular molar (M1) begins to form in utero and crown mineralization has finished by two months after birth. The second, permanent mandibular molar (M2) begins forming after the M1 is finished, approximately two months after birth, and the crown is completely mineralized between five and six months. The third permanent mandibular molar (M3) begins to form at approximately five to six months, and the crown is completely mineralized between nine and ten months after birth. The three permanent mandibular premolars (PM2 through PM4) start forming at approximately nine months and the crowns are completely mineralized by fifteen months (Table 4.7, 4.8).

4.4.2 Sample integrity

The mean CI for the archaeological white-tailed deer bone was 2.87±0.28 (range=2.20–3.91) (Table 4.9), and for the enamel samples it was 3.30±0.26. The mean C/P for the archaeological deer was 0.42±0.13 (range = 0.24–0.69), which is within the generally accepted range (0.3 to 0.6) for well preserved samples (King et al. 2011; Nielsen–Marsh and Hedges 2000; Pucéat et al. 2004; Thompson et al. 2009). All modern deer samples had C/P ratios above 0.6 with a mean C/P ratio of 0.72±0.15. It is believed that the untreated modern deer bones contained a high percentage of organic components (probably lipids) that interfered with the FTIR analysis. The mean C/P ratio of the modern deer bone after carbonate pre-treatment was 3.6±0.10, within the expected range (Table 4.9).

The FTIR profile of each sample was also examined for unexpected peaks, such as francolite at 1096 $cm^{-1}$and calcite at 711 cm^{-1} (Nielsen–Marsh and Hedges 2000). Two archaeological samples (Por–9 and Pip[1]–157) were rejected for carbonate analysis based on the presence of calcite peaks both before and after pre-treatment, and their high C/P ratios (0.71 and 0.98, respectively). All other modern and archaeological deer samples were accepted for carbonate analysis based on their combined CI, C/P ratios and peak profiles.

The minimum collagen yield for results to be considered reliable is 1% (Van Klinken1999; Ambrose 1993). All archaeological samples had yields greater than 1% and the mean was 9.1±6.1% (range=1.8–22.6%). The mean yield for modern deer was 19.6±4.8%, which is similar to the predicted percent collagen by weight of 22% for modern bone (Van Klinken 1999). The average C:N ratio for all samples was 3.28±0.11, well within the expected range of 2.9 to 3.6 (DeNiro 1985; DeNiro et al. 1985). Only one sample, Win 157, had a C:N ratio higher than 3.6 and, therefore, its collagen isotopic compositions were not used in this study. Based on the percent collagen yield and C:N ratio, all other collagen samples analysed were accepted (Table 4.9).

Varying expected percentages of bioapatite in bone have been reported, ranging from 70 - 75% (Ambrose 1993; Sillen 1989) up to 90% (Lee–Thorp 1989). The percentage of bioapatie by weight was measured for each sample after pre-treatment, and averaged 70.8±12.2% for modern deer and 72.9±8.4% (range=54.7–84.1%) for archaeological deer.

The percentage of CO_3 released as CO_2 from bone bioapatite for pretreated samples should range from 2.0 to 7.9%, enamel having slightly lower and narrower values with a range of 4.5 to 4.1% ((Lee–Thorp 1989; Lee–Thorp and Sponheimer 2003; Rink and Schwarcz 1995; Wright and Schwarcz 1996). The mean percentage of CO_3 in the modern bone was within the expected range at 5.2±1.4%, as was archaeological bone at 6.2±1.3% (range = 3.5 to 8.7%). There was no difference between modern and archaeological enamel samples for this measure, which together had a mean of 4.6±1.1% (range=2.4–7.1%). Samples with CO_3 abundances higher than 8% (n=3) were regarded with caution, as this could indicate secondary carbonate that was not removed by the acetic acid pre–treatment. However, other parameters for those bone samples, (CI, C/P, FTIR peak profile) did not indicate the presence of secondary carbonates, and hence no samples were rejected.

Table 4.7: Summary of crown mineralization and predicted season of formation.

Estimates based on age-death and observed dental formation sequence from radiographic analysis of 150 deer.

Tooth (mandibular)	Mineral–ization	~Corresponding Month	Season	Activity
M1 begins (tip)	fetal	April to May/June	Spring	in utero/birth
M1 complete	2 months	July to August	late spring/summer	breast-feeding/weaning
M2 begins (tip)	2 to 3 months	August to September	Summer	Weaning
M2 complete	5 to 6 months	October to November	late summer/fall	prep winter
M3 begins (tip)	5 to 6 months	October to November	late summer/fall	prep winter/breeding
M3 complete	9 to 10 months	February to March	Winter	low quality food
PM4 begins (tip)	9 months	February to March	Winter	low quality food
PM4 complete	15 months	June to July	spring/summer	Fattening

Table 4.8: Summary of the predicted sequence of Ontario white-tailed deer posterior mandibular dentition.

Tooth mineralization	May	June	July	August	September	October	November	December	January	February	March	April
	M1			M2			M3				PM4	

Table 4.9: Summary of average sample parameters by time period and cultural affiliation.

	% Collagen by Weight (Range)	C:N Ratio (Range)	FTIR CI (Range)	FTIR C/P (Range)	% Bioapatite by Weight (Range)	% CO_3 by Weight (Td) (Range)
Pre–horticulture pre A.D. 200 (sites, n=3)	6.0±4.5 (2.6–15.8)	3.24±0.13 (3.10–3.43)	2.95±0.19 (2.57–3.10)	0.39±0.12 (0.31–0.63)	74.7±9.7 (63.5–84.1)	5.2±1.3 (3.5–7.3)
Ontario Iroquoian A.D. 900–1600 (sites, n=15)	11.0±6.2 (2.4–22.6)	3.25±0.11 (3.04–3.59)*	2.84±0.33 (2.20–3.91)	0.42±0.13 (0.24–0.68)**	75.1±6.7 (58.2–82.9)	6.4±1.3 (4.4–8.7)
Western Basin A.D. 900–1600 (sites, n=7)	5.7±4.1 (1.8–19.3)	3.3±0.10 (3.08–3.48)	2.88±0.20 (2.64–3.28)	0.43±0.13 (0.27–0.69)	66.2±8.6 (54.7–82.0)	6.2±1.2 (5.1–8.1)
Modern White-tailed deer (locations, n=5)	19.6±4.8 (5.5–25.2)	3.7±0.05 (3.31–3.49)	2.59±0.14 (2.39–2.83)	0.72±0.15 (0.46–0.98)	70.8±12.2 (52.5–92.7)***	5.2±1.4 (2.7–8.6)

* Win 157 C:N ratio 3.87 not included as collagen isotopic compositions were not accepted.

** Por 9 (CI =0.98) and Pip(1)–157 (CI=0.71) not included because of their high CI values and the presence of a 712cm^{-1} calcite peak in the FTIR spectrum

***Mod Deer–06 percent yield 26.1% not included in average and minimum/maximum because some sample powder was lost before weighing.

4.4.3 Isotope results

4.4.3.1 Dentine collagen: $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ results

The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of dentine collagen varied only subtly by tooth (Table 4.10 and Figure 4.6), which is expected as there is a greater averaging of isotopic composition over the course of tissue formation. Although dentine begins forming before enamel, secondary dentine can be laid down later in life, which may dampen seasonal signals. Even though only crown dentine was analysed, it may still represent several months of growth compared to the serial sections, which are hypothesized to represent several weeks of growth. The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values varied among individuals (Figure 4.6) obscuring possible changes from the first molar to the pre-molar. There were no correlations between tooth number and either $\delta^{13}C_{col}$ values or $\delta^{15}N_{col}$ values. There was also no correlation between $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values. Therefore, instead of comparing the mean isotopic values, the *difference* of the tooth value from that of the first molar (M1) was calculated (ΔM1 – tooth) (Table 4.11 and Figure 4.7).

The $\delta^{13}C_{col}$ values indicate that both modern deer were consuming C_4 foods after the formation of the first molar, which forms from *in utero* to the breastfeeding period. Both modern deer appear to reduce their C_4 consumption as their premolar begins forming (Figure 4.6 A). The $\delta^{13}C_{col}$ values of the archaeological deer also rise significantly after the formation of the first molar ($F=-0.630$, $p=0.000$), which is attributed to a shift from breastfeeding to solid foods (Williams et al. 2005; Wright and Schwarcz 1998). As would be expected for a weaning signal, the $\delta^{15}N_{col}$ dentine values decrease after the formation of the first molar (Figure 4.6 B), with the exception of two deer (Mod-deer-3 and Clv-17). After their removal from the data set, the difference for $\delta^{15}N_{col}$ dentine values between the first molar and the PM4, which forms after weaning, suggests a breast-feeding/weaning effect, but it is still much lower (ΔM1–PM4 = 0.67±0.43‰) than a trophic level. Nonetheless, the $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for the difference from M1 to PM4 ($\rho=-0.513$, $p=0.003$) are strongly correlated, which suggests that the dentine isotopic compositions do capture the shift from breast-feeding to a completely weaned diet, although the normally strong weaning pattern is probably obscured by the formation

of additional dentine on the crown of the teeth as the tooth wears in life, and the fact that no one tooth represents an exclusive period of breastfeeding.

Table 4.10: Summary of mean $\delta^{13}C_{col}$, $\delta^{15}N_{col}$ values, and $\Delta^{13}C_{enamel–dentine}$ spacing for each tooth: A. archaeological and B. modern deer.

A. Archaeological Deer Dentine (n=8 deer)				B. Modern Deer Dentine (n=2 deer)			
	$\delta^{15}N_{col}$	$\delta^{13}C_{col}$	$\Delta^{13}C_{enamel–dentine}$		$\delta^{15}N_{col}$	$\delta^{13}C_{col}$	$\Delta^{3}C_{enamel–dentine}$
M1 Mean	7.26	–23.27	6.66	**M1 Mean**	5.29	–20.81	4.79
SD	±0.54	±0.76	±0.57	***SD***	±2.01	±1.15	±0.22
M2 Mean	7.21	–22.97	7.25	**M2 Mean**	5.21	–18.86	6.01
SD	±0.61	±0.95	±0.31	***SD***	±1.35	±0.65	±0.29
M3 Mean	7.10	–22.43	7.87	**M3 Mean**	5.39	–18.17	7.65
SD	±0.71	±0.79	±0.51	***SD***	±0.82	±1.56	±0.27
PM4 Mean	6.69	–22.67	7.82	**PM4 Mean**	5.34	–19.89	6.84
SD	±0.79	±0.93	±1.34	**SD**	±0.98	±2.41	±0.01

Table 4.11: A. Mean difference for all individuals between the $\delta^{13}C_{col}$ (i.) and $\delta^{15}N_{col}$ (ii.) values for each tooth relative to M1.

Bi and Bii. Mean difference between the $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for each tooth relative to M1, with outliers removed.

	Ai. Mean $\delta^{13}C_{col}$ ΔM1 – tooth	Aii. Mean $\delta^{15}N_{col}$ ΔM1 – tooth	Bi. Mean $\delta^{13}C_{col}$ ΔM1 – tooth*	Bii. Mean $\delta^{15}N_{col}$ ΔM1 – tooth**
M1 Mean	0.00	0.00	0.00	0.00
SD	*±0.00*	*±0.00*	*±0.00*	*±0.00*
M2 Mean	–0.70	–0.01	–0.31	–0.09
SD	*±0.97*	*±0.37*	*±0.75*	*±0.04*
M3 Mean	–1.27	0.11	–0.84	0.34
SD	*±1.39*	*±0.64*	*±0.74*	*±0.50*
PM4 Mean	–0.68	0.41	–0.58	0.67
SD	*±1.36*	*±0.66*	*±0.72*	*±0.43*

*Mod Deer 3 and Clv 17 removed.

**Mod Deer 3 and 7 removed.

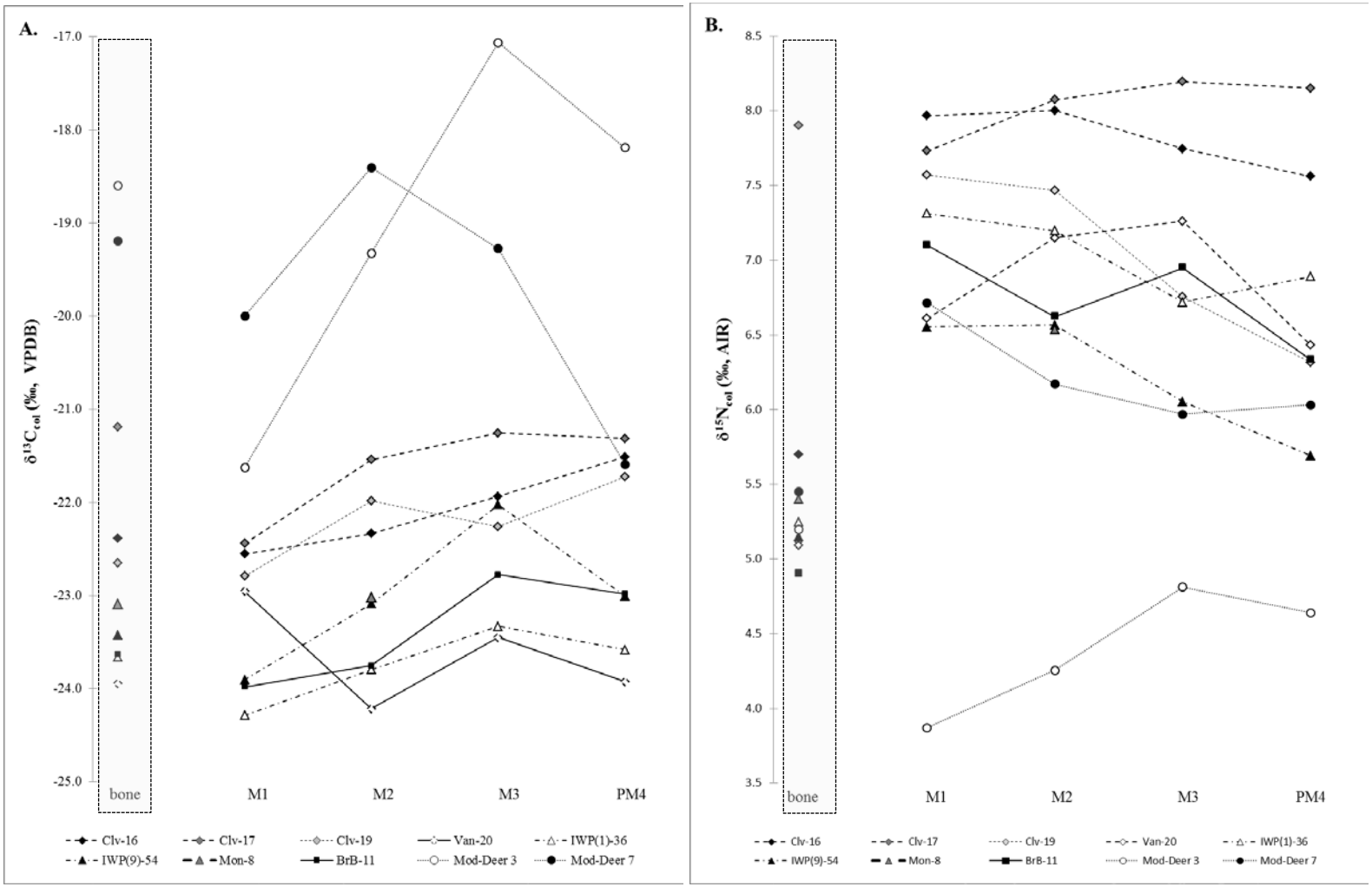

Figure 4.6: Individual $\delta^{13}C_{col}$ (A.) and $\delta^{15}N_{col}$ (B.) dentine values by tooth.

Bone isotopic results for each deer are also shown at left in gray box.

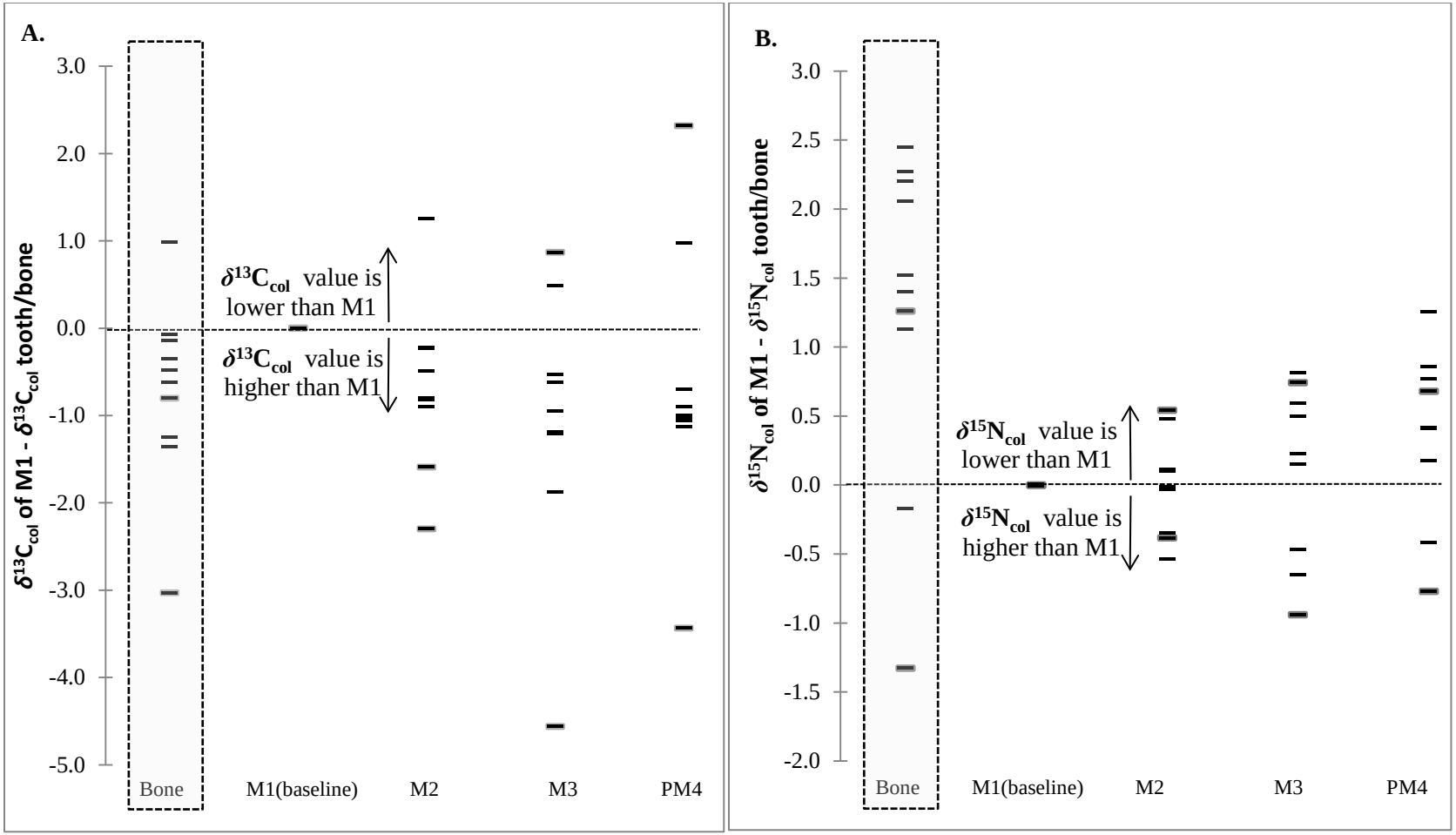

Figure 4.7: Mean difference in $\delta^{13}C_{col}$ (A.) and $\delta^{15}N_{col}$ (B.) values relative to M1 for individual bone (gray box) and dentine samples (graphed by tooth).

4.4.3.2 Bulk bone collagen: $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ results

The mean $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for the modern deer bone (n=16) are –19.50±1.83‰ (range= –22.96 to –17.29‰) and 4.70±1.39‰ (range= 4.70 to 7.53‰) (Table 4.12) and the $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values of bone are not significantly correlated. The mean $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for all archaeological samples (n=80) are –22.83±0.85‰ (range = –24.66 to –20.72‰) and 5.37±0.93‰ (range = 3.70 to 8.62‰) (Table 4.12), and there is a significant relationship between $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values (F=0.394, p=0.001).

A closer examination of deer by time period reveals no significant difference between the Late Woodland Ontario Iroquoian and Western Basin deer for either $\delta^{13}C_{col}$ or $\delta^{15}N_{col}$ values (Table 4.13), and neither varied significantly over time. Among the Ontario Iroquoian Late Woodland time phases i.e., Princess Point to Neutral, there was no significant difference in terms of their $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values. The difference between the $\delta^{13}C_{col}$ values of archaeological deer and modern deer is significant (Dunnett T3, p<0.000), but there is no significant difference in $\delta^{15}N_{col}$ values.

Table 4.12: Summary of mean bone $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values by time period

	$\delta^{13}C_{col}$ ‰ VPDB (range)	$\delta^{15}N_{col}$ ‰ AIR (range)
Pre–horticulture pre A.D. 200 (sites, n=3)	–23.09±0.83 (–23.92 to – 21.60)	4.75±0.67 (3.90 to 6.16)
Ontario Iroquoian A.D. 900–1600 (sites, n=15)	–22.83±0.84 (–24.66 to –20.72)	5.43±0.95 (3.70 to 8.21)
Western Basin A.D. 900–1600 (sites, n=7)	–23.00±0.80 (–23.66 to –20.72)	5.48±0.90 (4.43 to 8.62)
Modern deer (locations, n=5)	–19.50±1.83 (–22.96 To –17.29)	4.70±1.39 (1.73 to 7.53)

4.4.3.3 Bulk bone structural carbonate: $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ results

Bulk structural carbonate data for the modern deer are consistent with previously published modern deer from SW Ontario (Munro et al. 2008). For archaeological deer from this region there are few data (but see Booth et al. 2012 [Table 4.2], who present data for four deer with similar values [–10.46±0.77‰]). Published $\delta^{13}C_{sc}$ values for archaeological white-tailed deer from other regions, including Nebraska and the Maya region, are within the same range as the southwestern Ontario deer (Table 4.2).

The mean $\delta^{13}C_{sc}$ values for the modern deer (–12.90±2.57‰, range = –17.82 to –8.94‰, n=14) and all archaeological deer (–10.52±2.15‰, range = –14.20 to –5.97‰, n=38) are significantly different (Mann Whitney U, z = –2.429, p=0.015). There is no significant difference between mean $\delta^{18}O_{sc}$ values for modern deer (22.18±1.11‰, range = 20.16 to 23.93, n=14) and archaeological deer (21.47±1.03‰, range = 18.94 – 23.23, n=38). There is no significant difference among either $\delta^{13}C_{sc}$ or $\delta^{18}O_{sc}$ values for deer from Ontario Iroquoian and Western Basin sites or deer from pre-maize and Late Woodland sites (see Table 4.14 for summary). The only significant difference was noted when the cultural periods (Table 4.15) were examined by phase. There is a significant difference between Neutral deer (A.D. 1450–1650) and Middle Ontario Iroquoian deer (A.D. 1200–1450), where the later period Neutral deer have significantly lower $\delta^{13}C_{sc}$ values.

There was no significant correlation between the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values of archaeological deer; however the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values of modern deer show a strong, positive correlation (Pearson's, r=0.992, n=11, p< .001). Modern deer have significantly smaller (6.71±0.96) $\Delta^{13}C_{sc-col}$ values than archaeological deer (12.19±2.10, range=7.95 to 16.09) (t=–8.029, p<0.000). There are also significant differences in $\Delta^{13}C_{sc-col}$ spacing among the groups of archaeological deer (ANOVA, F=22.203, p<0.001). Among the Ontario Iroquoian Late Woodland deer, the Neutral deer (A.D. 1450 to 1650) had a significantly smaller $\Delta^{13}C_{sc-col}$ spacing than the Middle Ontario Iroquoian (A.D. 1200 to 1450) deer (Table 4.15), which had the largest $\Delta^{13}C_{sc-col}$ spacing of all the deer (13.59±1.08).

Table 4.13: Statistical summary (p-values) comparing $\delta^{13}C_{col}$, $\delta^{15}N_{col}$ and $\delta^{13}C_{sc}$ means by time period. Statistically different results are shown in bold–faced type.

		Late Woodland	Pre–AD 200
$\delta^{13}C_{col}$	Modern	**0.000**	**0.000**
	Late Woodland	–	0.837
$\delta^{15}N_{col}$	Modern	0.142	0.985
	Late Woodland	–	0.069
$\delta^{13}C_{sc}$	Modern	**0.014**	0.350
	Late Woodland	–	**0.020**
$\delta^{18}O_{sc}$	Modern	0.089	0.229
	Late Woodland	–	0.972
$\Delta^{13}C_{sc-col}$	Modern	**0.000**	**0.000**
	Late Woodland	–	0.931

Table 4.14: Summary of mean $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values by time period, as well as mean $\Delta^{13}C_{sc-col}$ spacing.

	$\delta^{13}C_{sc}$ ‰ VPDB (range)	$\delta^{18}O_{sc}$ ‰ VSMOW (range)	$\Delta^{13}C_{sc-col}$ ‰ (range)
Pre–horticulture pre A.D. 200 (sites, n=3)	–11.92±0.76 (–12.94 to –11.01)	21.37±0.50 (20.66 to 22.01)	11.35±0.93
Ontario Iroquoian A.D. 900–1600 (sites, n=15)	–10.21±2.16 (–14.20 to –5.97)	21.78±0.99 (20.05 to 23.23)	11.22±2.04
Western Basin A.D. 900–1600 (sites, n=7)	–10.31±2.49 (–13.99 to –8.08)	20.89±1.14 (18.94 to 22.56)	12.25±2.41
Modern deer (locations, n=5)	(–12.90 (–17.82 to –8.94)	22.46±1.01 (20.16 to 23.93)	6.64±0.96 (5.14 to 8.35)

Table 4.15: Statistical summary (p-values) comparing $\delta^{13}C_{sc}$ and $\Delta^{13}C_{sc-col}$ by Late Woodland Phase. Statistically significant results are shown in bold–faced font.

		Middle Ontario	Neutral
$\delta^{13}C_{sc}$	Early Ontario	0.313	0.128
	Middle Ontario	–	**0.004**
$\delta 18O_{sc}$	Early Ontario		
	Middle Ontario		
$\Delta 13C_{sc-col}$	Early Ontario	0.905	0.317
	Middle Ontario	–	**0.000**

4.4.3.4 Bone versus dentine $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values

For all deer, the bone $\delta^{13}C_{col}$ isotopic compositions approximately reflect the average of the dentine of the four teeth, with an average difference of only 0.34±0.17‰ (Table 4.16A). The $\delta^{13}C_{col}$ values of bone collagen and dentine (averaged) are strongly correlated (r^2=0.9789). There are two explanations for the similarity. The first year of bone growth may be more heavily reflected in the life-long average of the deer than the remainder of life, which is consistent with the fact that the deer grow very quickly to maturity and have relatively short life expectancies. A second possibility is that the crown dentine is heavily influenced by secondary dentine, which formed later in life. These two possibilities are not mutually exclusive. Examination of the dentine of individual teeth suggests that there is a small temporal change, consistent with the expected pattern of weaning but that the weaning effect is dampened.

The $\delta^{15}N_{col}$ values of dentine are poorly correlated with the bone isotopic compositions (r^2=0.2649) (Table 4.16B). The $\delta^{15}N_{col}$ values of bone are lower than those of the averaged dentine (mean difference = 1.47‰), with the greatest difference between bone and the M1 (average = 1.72±0.64‰). After the formation of M1, the $\delta^{15}N_{col}$ values generally decrease, but not by an entire trophic level, as might be expected. The dampening of the trophic difference may be related to the fact that no one tooth represents a period of only breastfeeding.

Table 4.16: Summary of average (A.) $\delta^{13}C_{col}$ and (B.) $\delta^{15}N_{col}$ dentine for all teeth for each individual deer, compared with their bone $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values.

	A. $\delta^{13}C_{col}$ bone	$\Delta^{13}C_{col}$ dentine average$_{M1–PM4}$	B. $\delta^{15}N_{col}$ bone	$\Delta^{15}N_{col}$ dentine average$_{M1–PM4}$
mod deer 3	–18.59	–19.05	5.20	4.39
mod deer 7	–19.20	–19.82	5.45	6.22
BrB 11	–23.63	–23.37	4.90	6.75
Clv 16	–22.38	–22.08	5.70	7.82
Clv 17	–21.19	–21.64	7.90	8.04
Clv 19	–22.65	–22.19	5.12	7.03
Van 20	–23.95	–23.64	5.09	6.86
IWP (1) 36	–23.66	–23.75	5.25	7.03
IWP(9) 54	–23.43	–23.01	5.15	6.22
Mon 8	–23.10	–23.02	5.40	6.53

4.4.3.5 Enamel $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ results

The means of $\delta^{18}O_{sc}$ values by serial section are summarized in Table 4.17A. A clear pattern emerged for those ten deer whose mandibular teeth were serially sectioned. The first molar has the highest $\delta^{18}O_{sc}$ values while the third molar has the lowest $\delta^{18}O_{sc}$ values (Table 4.17B, Figure 4.8). There is significant variation among serial sections over the time of tooth formation (ANOVA, F=23.022, p<0.000), and by tooth (i.e., the average of the serial sections for each of the four teeth) (ANOVA, F=71.058, p<0000). A post-hoc Tukey test groups the serial sections into six subsets that demonstrate successive change in $\delta^{18}O_{sc}$ values, i.e., adjacent serial sections are more similar than non-adjacent serial sections (Table 4.18A and B). There is a progressive lowering of $\delta^{18}O_{sc}$ values from the coronal tip of M1, which is first to form, to completion of M2 formation, after which point there is a progressive increase in $\delta^{18}O_{sc}$ values. The six subsets correspond closely with the predicted order of dental formation (i.e., M1 forms first, overlapping with M2, etc.), and provide evidence for climatic seasonality in the first year of life. The high $\delta^{18}O_{sc}$ values of the first molar may represent not only the warmer spring climate, but also a breast-feeding signal resulting from ^{18}O-enrichment relative to their mothers (Williams et al. 2005).

Table 4.17: Summary of (A.) mean $\delta^{18}O_{sc}$ values for each serial section and (B.) mean difference for each serial section relative to the tip of M1.

	A. Mean±SD $\delta^{18}O_{sc}$ (‰ VSMOW)				**B. Mean difference±SD from M1 tip $\Delta^{18}O$ (‰ VSMOW)**		
	Tip	Middle	CEJ*		Tip	Middle	CEJ*
Molar 1	24.69	24.54	23.84	**Molar 1**	0.00	0.18	0.76
	0.97	0.98	1.30		0.00	0.54	0.73
Molar 2	23.14	22.18	21.38	**Molar 2**	1.50	2.43	3.32
	0.63	0.71	1.06		0.43	0.79	0.74
Molar 3	20.55	20.54	21.29	**Molar 3**	4.05	4.13	3.52
	1.10	1.04	1.31		0.87	1.31	1.55
Premolar 4	22.73	23.08	23.35	**Premolar 4**	1.96	1.65	1.34
	1.05	0.97	0.95		1.47	1.27	1.17

*CEJ = cementum-enamel junction

Table 4.18: ANOVA output showing the statistically significant grouping of serial sections by $\delta^{18}O_{sc}$ values

Serial section	All Samples (for alpha = 0.05 Tukey HSD)					
	1	2	3	4	5	6
M1 tip	24.69					
M1 middle	24.54	24.54				
M1 CEJ	23.61	23.61	23.61			
M2 tip			23.09	23.09		
M2 middle				22.08	22.08	
M2 CEJ					21.42	21.42
M3 tip						20.51
M3 middle						20.39
M3 CEJ					21.38	21.38
PM4 tip			22.54	22.54	22.54	
PM4 middle		23.2	23.2	23.2		
PM4 CEJ	23.28	23.28	23.28	23.28		
Sig.	**0.086**	**0.352**	**0.189**	**0.22**	**0.398**	**0.051**

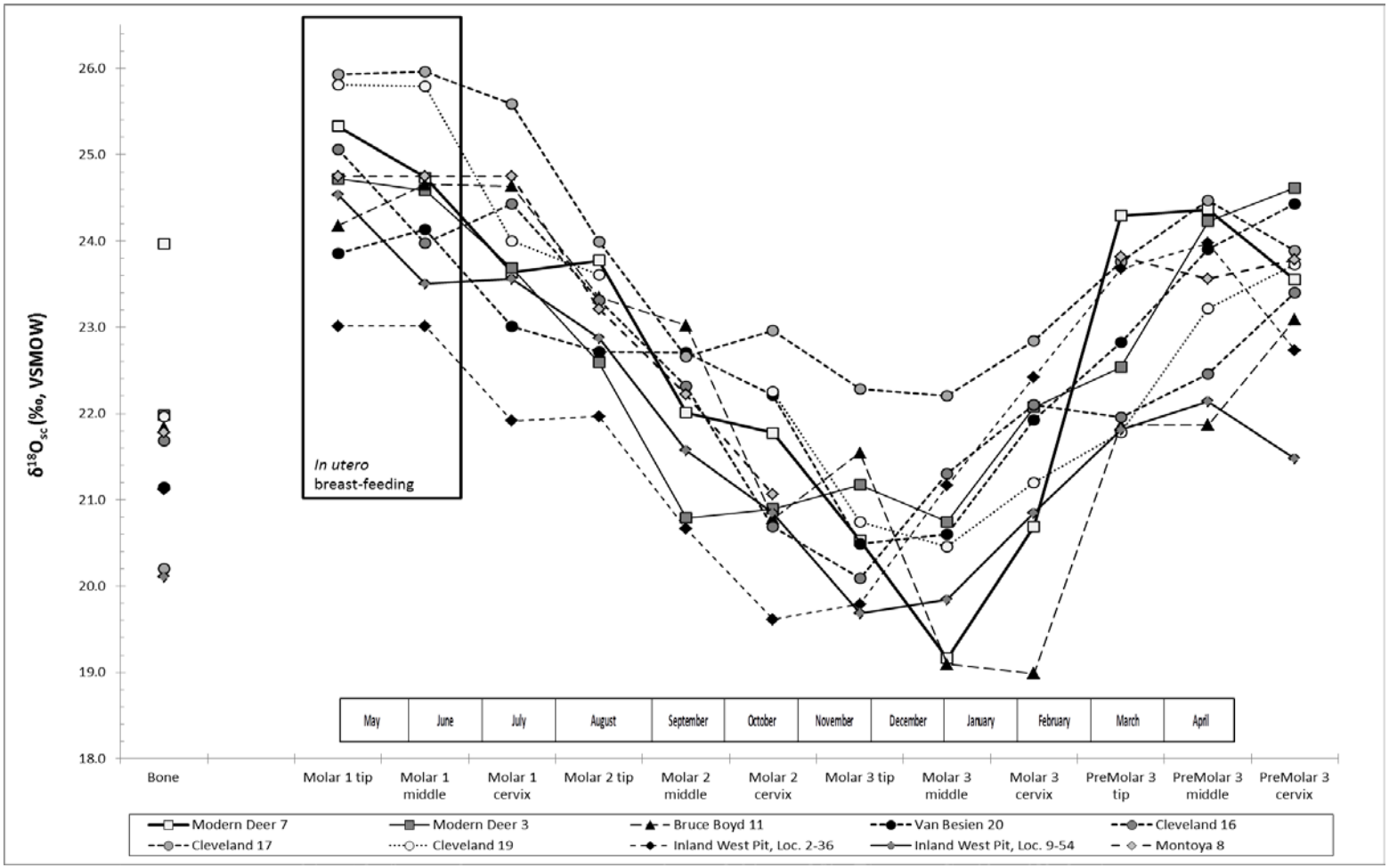

Figure 4.8: $\delta^{18}O_{sc}$ values of enamel serial sections for modern (squares), pre–A.D. 200 (triangle), Ontario Iroquoian (circles) and Western Basin (diamond) deer. Bulk bone $\delta^{18}O_{sc}$ values are indicated at the left. The $\delta^{18}O_{sc}$ values of enamel serial sections are associated with the predicted month of formation based on radiographic analysis of juvenile deer.

The $\delta^{18}C_{sc}$ values of the enamel serial sections for modern (Figure 4.12) and archaeological (Figure 4.8) samples also show a pattern across the period of enamel formation. Earlier forming serial sections, from M1 and M2, have lower $\delta^{18}C_{sc}$ values relative to later forming serial sections, i.e., M3 and PM4 (Table 4.19A). Unlike the seasonal pattern observed in the oxygen-isotope data, the $\delta^{18}C_{sc}$ values most likely reflect dietary changes. The diet of the two modern deer reflects the introduction of maize during the initial formation of M2, corresponding with weaning (Table 4.20A, Figure 4.12), increasing during the formation of M2 and M3, and decreasing with the formation of the premolars. Increasing $\delta^{18}O_{sc}$ values are strongly associated with increasing $\delta^{18}C_{sc}$ values (Pearson's r=–0.679, n33, p>0.001) in the two modern deer. This relationship likely reflects both the weaning of the young deer and the introduction of C_4 foods, probably maize, into their diet. Maize appears in the younger deer's diet in the late summer/early fall, increasing exponentially for one of the deer until December.

Table 4.19: Summary of mean $\delta^{13}C_{sc}$ values for each serial section (A.) and mean difference (B.) relative to the tip of M1.

	A. Mean±SD δ^{13}Csc (‰VPDB)				B. Mean difference from M1tip $\Delta^{13}C_{sc}$ (‰VPDB)		
	Tip	Middle	CEJ		Tip	Middle	CEJ
Molar 1	–16.70	–16.93	–16.35	**Molar 1**	0.00	0.12	–0.39
	0.46	0.75	0.98		0.00	0.34	0.76
Molar 2	–15.82	–14.97	–14.56	**Molar 2**	–0.94	–1.88	–2.26
	1.14	2.00	1.78		0.99	1.84	1.68
Molar 3	–14.78	–14.68	–14.16	**Molar 3**	–2.01	–2.23	–2.49
	0.76	0.00	0.60		0.54	0.54	0.48
Premolar 4	–14.63	–14.33	–14.55	**Premolar 4**	–2.06	–2.56	–2.29
	0.33	0.42	0.64		0.54	0.90	0.80

A post–hoc Tukey test for the archaeological deer alone suggests three subsets of $\delta^{13}C_{sc}$ values (Table 4.20B). The first includes the M1 and part of the M2, which have the lowest $\delta^{18}C_{sc}$ values and document the time period when the deer was *in utero*, breastfeeding, and weaning. Subset 2 is a transition phase, that is, post-birth and weaning as the deer shift to only solid foods. The third subset represents the post-weaning period and reflects a completely C_3 plant-based diet. While the first two dietary phases (*in utero* and breastfeeding) and the transition from weaning are evident for the modern and

archaeological deer, there is a clear separation between modern and archaeological deer as they shift to a plant-only diet. The modern deer consumed some C_4 plants, while the archaeological deer consumed only C_3 plants.

Table 4.20: ANOVA output showing the statistically significant grouping of serial sections by $\delta^{13}C_{sc}$ values, with (A.) modern deer and without (B.) modern deer.

A. Serial section	All samples (Subset for alpha = 0.05)			
	1	2	3	4
M1 tip	–16.70			
M1 middle	–16.93			
M1 CEJ	–16.25	–16.25		
M2 tip	–15.77	–15.77	–15.77	
M2 middle		–14.48	–14.48	–14.48
M2 CEJ		–14.56	–14.56	–14.56
M3 tip			–13.87	–13.87
M3 middle				–13.06
M3 CEJ			–13.72	–13.72
PM4 tip		–14.33	–14.33	–14.33
PM4 middle		–14.18	–14.18	–14.18
PM4 CEJ		–14.50	–14.50	–14.50
Sig.	**0.805**	**0.063**	**0.07**	**0.447**

B. Serial section	Archaeological samples only (Subset for alpha = 0.05)		
	1	2	3
M1 tip	–16.74		
M1 middle	–17.00		
M1 CEJ	–16.39	–16.39	
M2 tip	–16.13	–16.13	
M2 middle	–16.01	–16.01	
M2 CEJ		–15.23	–15.23
M3 tip			–14.61
M3 middle			–14.57
M3 CEJ			–14.35
PM4 tip			–14.67
PM4 middle			–14.26
PM4 CEJ			–14.61
Sig.	**0.195**	**0.059**	**0.22**

For the archaeological deer there is a significant correlation (Pearson's r=–0.278, n=110, p=0.003) between $\delta^{18}O_{sc}$ and $\delta^{13}C_{sc}$ values of the enamel serial sections, though it is not as strong as for the modern deer (Figure 4.9). The correlation is likely the result of

weaning as a slight increase in $\delta^{13}C_{sc}$ values marks the shift from feeding on the doe's tissues to a complete plant-based diet and the decrease in $\delta^{18}O_{sc}$ values marks both weaning and changing temperature. This change appears to begin during the warmest summer months (approximately July), which corresponds with the weaning of modern fawns by six weeks after birth (Smith and Verkruysse 1983).

The difference between the $\delta^{13}C_{col}$ values of dentine for each tooth and average $\delta^{13}C_{sc}$ values for the enamel serial sections (the $\Delta^{13}C_{enamel-dentine}$ spacing) for each tooth was compared to determine whether this relationship could capture a shift in trophic position (Table 4.21, Figure 4.10). The $\Delta^{13}C_{enamel-dentine}$ value between the M1 (6.25±0.97‰) and M2 (6.96±0.62‰) is the lowest, which is probably related to the fact that both teeth are formed partially during a time period of breast-feeding (i.e., a form of carnivory), compared with the herbivorous diet indicated by the larger overall $\Delta^{13}C_{enamel-dentine}$ value of 7.20±0.99‰. The larger spacing between the enamel and dentine of the M3 and PM4 (7.76±0.93‰ and 7.82±0.47‰, respectively), approximately 1.5‰ larger than that of the earlier forming teeth, suggests a clear temporal, and associated dietary, change over the year of dental formation.

Table 4.21: Summary of mean $\Delta^{13}C_{enamel-dentine}$ value for each tooth for the archaeological (n=8) and modern (n=2) deer.

Mean $\Delta^{13}C_{enamel-dentine}$ ±SD (‰, VPDB)	
Molar 1	6.25±0.97
Molar 2	6.96±0.62
Molar 3	7.76±0.93
Premolar 4	7.82±0.47
All teeth	7.20±0.99

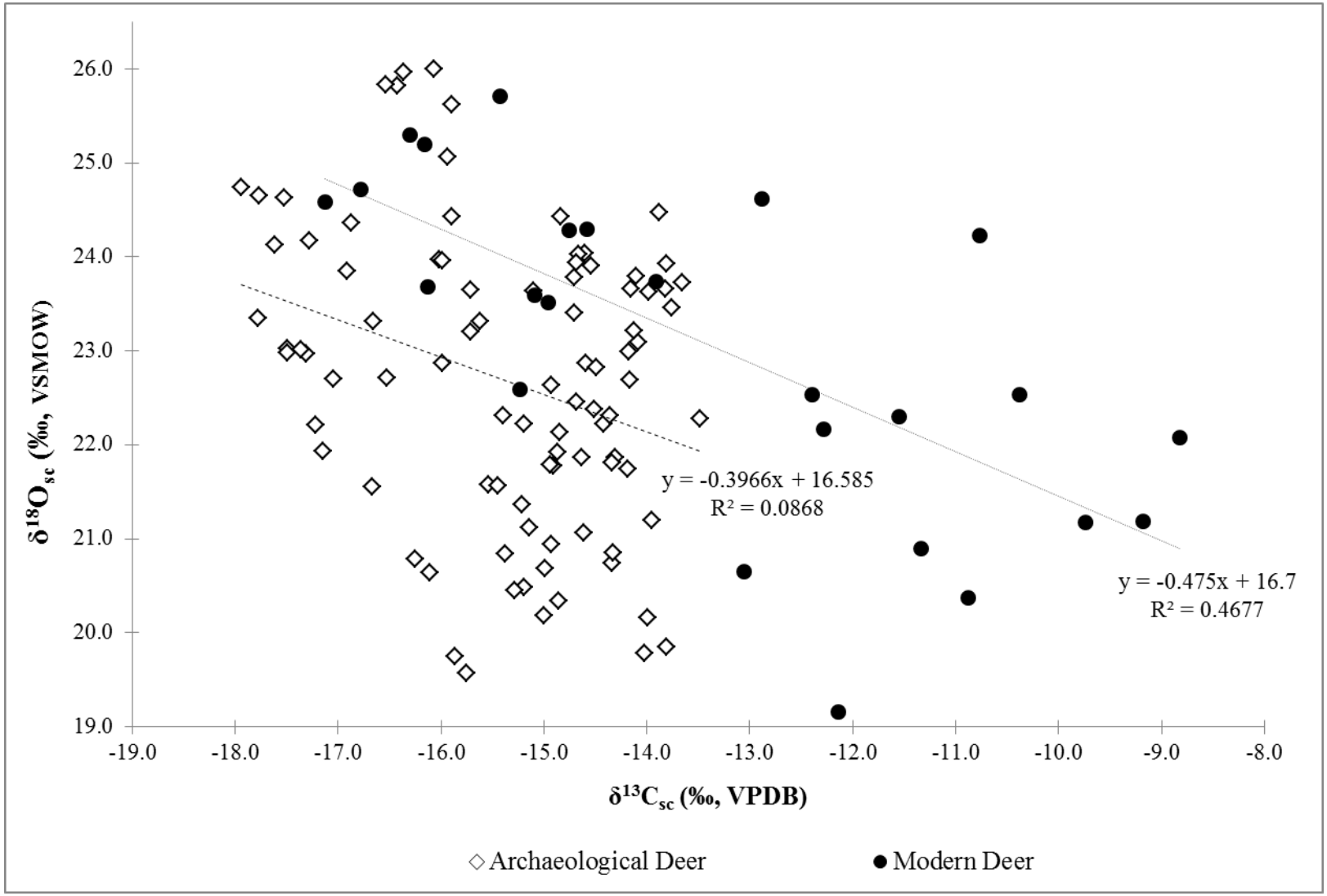

Figure 4.9: Relationship between $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values for modern and archaeological deer.

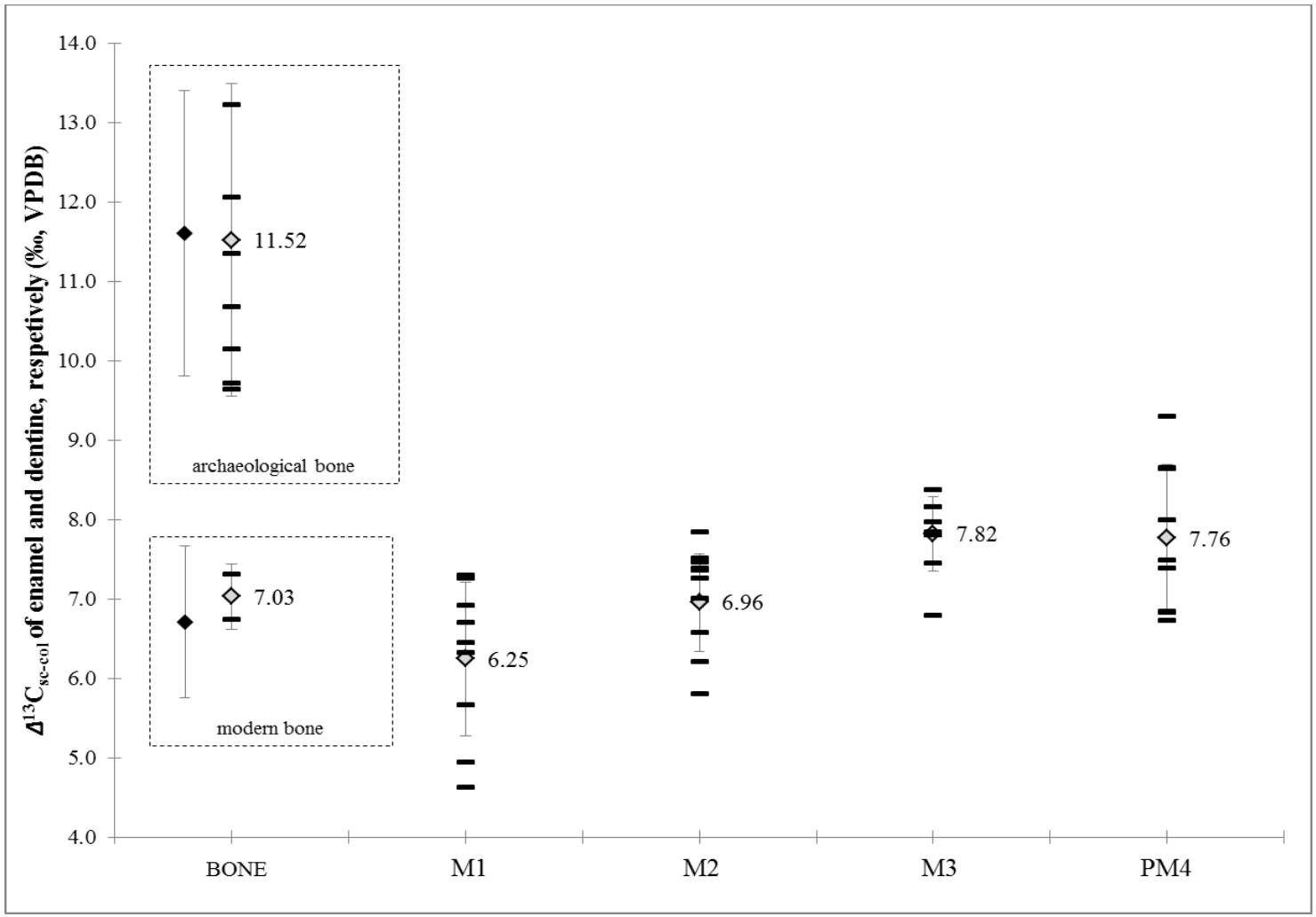

Figure 4.10: Average $\Delta^{13}C_{sc\text{-}col}$ of enamel and dentine, respectively, by tooth (compared to $\Delta^{13}C_{sc\text{-}col}$ of bone in the gray box). Grey diamonds are average for the 10 serially sampled deer, while the black diamonds are bone average for all deer.

4.5 Discussion

4.5.1 Modern and archaeological deer enamel ($\delta^{18}O_{sc}$): Linking seasonality with dental formation

Deer body water is a reflection of ingested waters, including water from foods, water taken directly from rivers, streams, ponds and puddles, and recycled body water, as discussed previously. The six significantly different subsets of enamel $\delta^{18}O_{sc}$ values are, therefore, a reflection of six subsets of body water composition (Table 4.18), which changes over approximately a one-year time period and thus corresponds with seasonal variation in $\delta^{18}O$ of meteoric water (Figure 4.8). Precipitation will have higher $\delta^{18}O$ values in warmer months and lower $\delta^{18}O$ values in colder months. The first molar, the upper crown of the second molar and part of the lower crown of the premolar, appear to have formed in warmer months. The lower crown of the second molar and top of the crown of the premolar formed during a more temperate period. The third molar appears to have formed during the coldest period. The lack of correlation between time period (i.e., modern deer vs. pre-maize deer) and $\delta^{18}O_{sc}$ values of deer indicates good continuity of body water composition over the 2000 year period represented in this study. The same continuity was observed in the $\delta^{18}O_{sc}$ values for canids and wild turkeys. These data suggest that climate fluctuations occurring during this time period were not significant enough to produce measurable differences in the $\delta^{18}O$ values of imbibed local waters. The enamel serial sections provide an accurate means to assess the first year of life of individual deer, establishing a link between the season of tooth formation and $\delta^{18}O_{sc}$ values. By determining when each tooth formed, it is possible to shed light on physiological patterns (i.e., weaning) and dietary changes (i.e., incorporation of maize into the diets of modern deer). In the proceeding sections, seasonality of each tooth is compared with its dentine ($\delta^{13}C_{col}$) and enamel serial section ($\delta^{13}C_{sc}$) values, as well as bulk bone ($\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$) results, to examine in detail the first year of life for the ten deer analysed in this study.

4.5.2 Modern deer: Proxies for maize access and consumption

The $\delta^{15}N_{col}$ values of the deer are consistent with those expected for an herbivore and are lower in modern deer relative to the archaeological deer. Although the difference is not significant, the lower modern deer results are similar to those observed by Cormie and Schwarcz (1994) and suggest the modern deer may have consumed some fertilized agricultural products.

The $\delta^{13}C$ values of bulk bone collagen suggest that some of the modern Ontario deer consumed maize, which is consistent with previous studies of modern deer from the region where $\delta^{13}C_{col}$ values greater than –20‰ were assumed to indicate a C_4 component in the diet (Cormie and Schwarcz 1994). Further, the three modern deer designated by the donating hunters as maize pests had among the highest $\delta^{13}C_{col}$ values (mean = –18.37±0.52‰), within the range of known crop pests from Michigan and Ohio (mean = –17.03±1.43‰) (Cormie and Schwarcz 1994). By contrast, the sample (Mod-deer-5) from a northeastern region of Ontario, where there is significantly less maize agriculture, has the lowest $\delta^{13}C_{col}$ value. Although several of the modern deer from this study were crop pests they were consuming proportionately less maize than modern turkeys in this study (15% versus 45%, Stable Isotope Analysis in R [SIAR]) (Figure 4.11). These results are surprising because these deer were known to eat maize throughout its growth cycle, and were collected from some of the highest maize producing regions in Canada. On the other hand, there are limitations to wild turkey maize access (see Chapter 3).

Because maize leaves can have $\delta^{13}C$ values several per mil lower than the grains (Tieszen 1991), the relatively low proportion of maize in the diets of modern deer may be explained by a preference for leaves that are available during warmer months of the growing season. For this explanation to be valid, deer would feed on leaves from spring until the harvest in the fall, which is consistent with (1) farmers' statements that crop damage occurs mainly during the growing phase of maize (June through September), (2) with modern behavioural literature (Groepper et al. 2013; Gabrey et al. 1991; MacGowan et al. 2008; Tzilkowski et al. 2002) and (3) a previous isotopic laser analysis of individual

osteons in deer bone, which indicates increasing C_4 consumption during warmer, summer months (Larson and Longstaffe 2007).

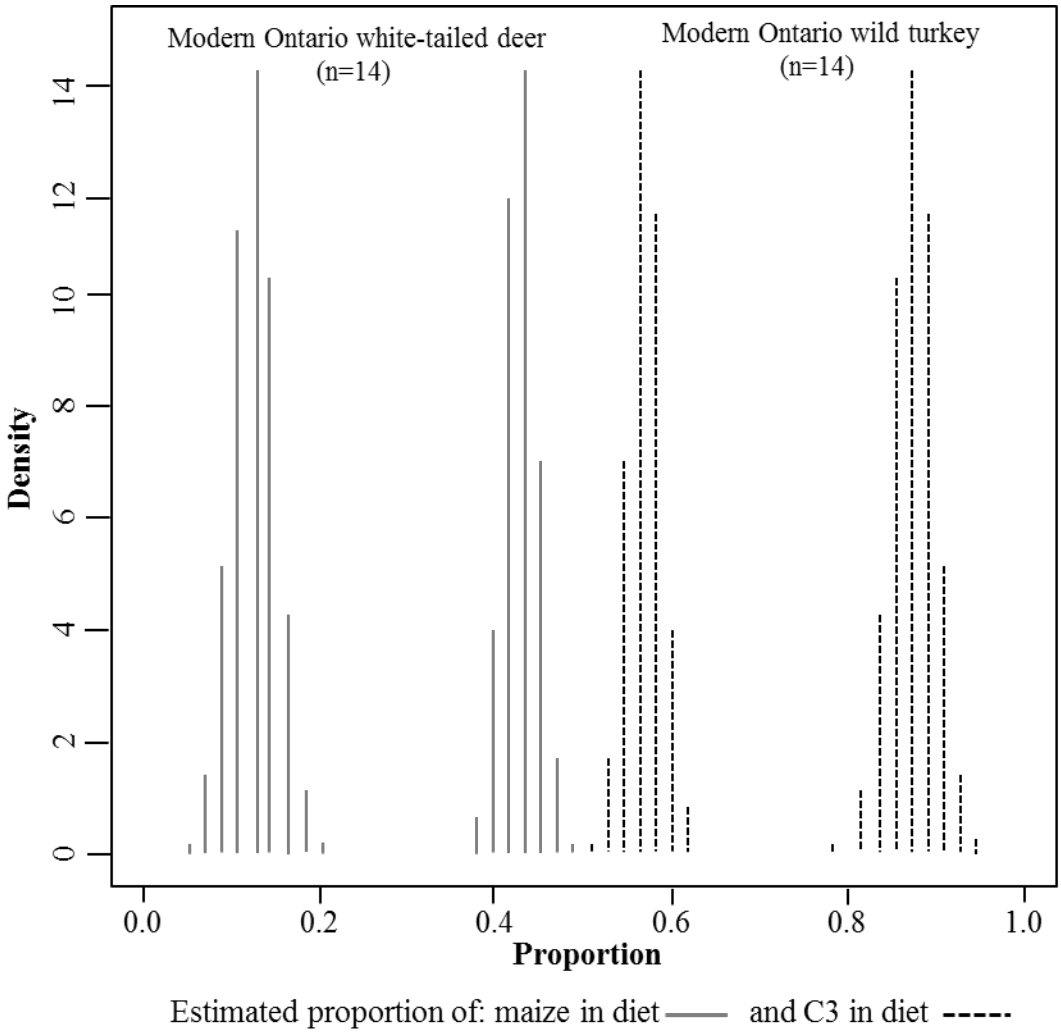

Figure 4.11: Estimated proportion of maize[19] in the diet of the modern deer (~15% maize to 85% C_3) compared with that of modern turkey (~45% maize to 55% C_3).

[19]Contributions of each food type (C_4 [maize] and C_3) were determined using the stable isotope in R (SIAR) package using $\delta^{13}C_{col}$, $\delta^{13}C_{sc}$ and $\delta^{15}N_{col}$. Trophic enrichment factors (TEFs) used to correct $\delta^{13}C$ values were diet to collagen (+5‰), diet to structural carbonate (+12‰) and for $\delta^{15}N_{col}$ (+3‰).

The mean bone structural carbonate $\delta^{13}C$ value for the modern deer is –13.21±2.70‰, and many of the deer are within the expected range for occasional C_4 consumption (Harrison and Katzenberg 2003). A strong correlation between collagen and structural carbonate $\delta^{13}C$ values of the modern deer (F=0.980, p=0.000) indicates that both the whole diet ($\delta^{13}C_{sc}$) and protein portion ($\delta^{13}C_{col}$) of diet reflect C_4 consumption in some deer. It is also consistent with the hypothesis that the relatively protein–poor maize would have a greater impact on $\delta^{13}C_{sc}$ values relative to $\delta^{13}C_{col}$ values if eaten in small quantities (Harrison and Katzenberg 2003). This relationship is evident in the modern deer in this study where there is only ~+1‰ increase in $\delta^{13}C_{col}$ values for every +2‰ increase in $\delta^{13}C_{sc}$ values; these data also fit along Kellner and Schoeninger's (2007) predicted C_3 protein line (Figure 4.12).

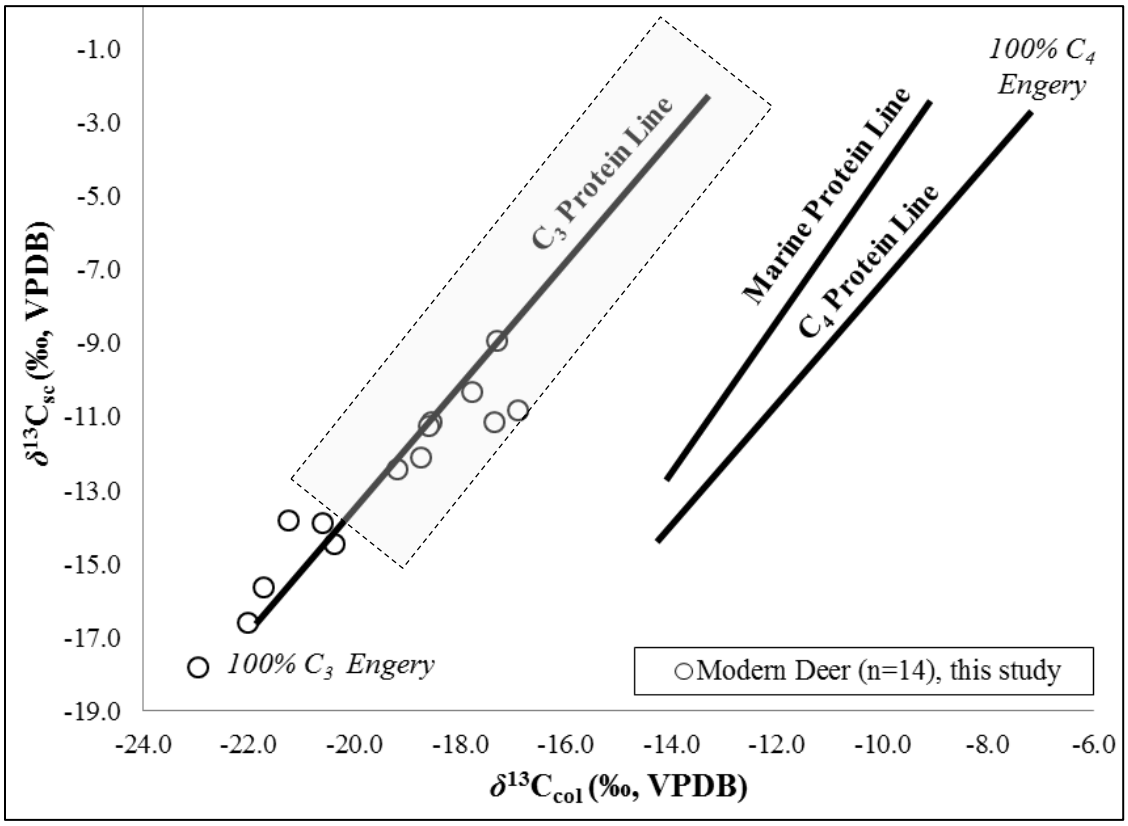

Figure 4.12: Model for the relationship between $\delta^{13}C$ values of structural carbonate and collagen for modern deer. The gray square indicates a diet primarily composed of C_3 protein with some C_4 energy (i.e., lipids and carbohydrates) sources. Developed by Kellner and Schoeninger (2007, Chart adapted from Figure 2B).

The mean $\Delta^{13}C_{sc-col}$ spacing for the modern deer is 6.71±0.96‰, which reflects a diet-collagen spacing of +5‰ and diet-structural carbonate spacing of +12‰, which is slightly lower than that proposed by Cerling and Harris (1999) for ruminants (+14‰). The difference may be due, in part, to the lower methane production of white-tailed deer compared with bovids and equids (Crutzen et al. 1986).

Compared to the previously published literature suggesting warm weather maize consumption, a very different seasonal pattern of maize consumption is suggested by the $\delta^{13}C_{sc}$ values of the serial-sectioned enamel data of modern deer, at least during the first year of life. For the modern deer in this study, C_4 plant consumption appears to increase significantly with cooling temperatures, starting approximately in September, and drops again in the spring (Figure 4.13).

The dentine $\delta^{13}C_{col}$ values for the modern deer were highest for the second and third molar (Table 4.10), thus corresponding with the $\delta^{13}C_{sc}$ values for the serial sections of the M2 and M3 (Figure 4.13). The second molar begins forming in August and third molar completes formation by March, covering the formation period of the fall through winter of the first year of life (Figure 4.10). Both dentine and enamel carbon isotopic compositions indicate some maize in the diet of these two deer but they may be exceptions, as they were hunted as pest deer. Alternately, as crop damage is generally self-reported by farmers, the presence of deer in winter fields may not be tracked and/or reported because it has little negative economic effect.

Mod-deer-7 is a yearling that has higher $\delta^{13}C_{sc}$ enamel values than its bone for almost half of its first year of life and its third molar, which forms between November and March, has the highest enamel $\delta^{13}C_{sc}$ value of –8.82‰, which is 4‰ higher than its bone. Although tissue-specific isotopic routing differences (Warinner and Tuross 2009) might account for some of this difference, there are three other plausible explanations. First, the difference may reflect consumption of C_4 foods (maize grains) during colder months i.e., after harvest when leaves are less available. Second, the isotopic composition of deer bone may be more heavily influenced by the period of major growth, i.e., the

spring/summer. The fact that deer bone is not a full trophic level lower than teeth formed during breast–feeding suggests that the majority of bone forms *in utero* and, in the first few months of life, during breast-feeding and weaning. The slowing metabolism of deer in the winter would also cause a reduction in bone turnover during colder months. If deer primarily consume maize during colder months, there may be a bias in the bone to reflect warmer (i.e., higher metabolism) diets. Mod-deer-3 is an adult so this single season of maize consumption may not reflect an annual pattern. Third, as deer are using fat and muscle tissues laid down in the late summer/fall fattening period to support cellular growth during colder months, the high $\delta^{18}C_{sc}$ values in the enamel may reflect the use of these tissues enriched in ^{13}C from a late summer and fall diet that included maize. Consequently, the bone of deer in Ontario may not be ideal for identifying small amounts of maize consumption if it occurs during colder months or after deer are fully grown.

4.5.3 Archaeological deer collagen ($\delta^{13}C_{col}$, $\delta^{15}N_{col}$): Tracking diet and canopy effect

The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ values for bulk bone collagen are consistent with previously published Great Lakes archaeological deer data that reflect herbivores in an entirely C_3 environment (Katzenberg 1989; 2006; Ketchum et al. 2009; Pfeiffer et al. 2014). On average, there is less than 2‰ variation among Ontario deer from sites spanning 3000 years, suggesting consistency in deer diet (i.e., a C_3 only diet) before and after the entry of maize into the region at least 1500 years ago (Capella 2005; Crawford et al. 1997; Crawford et al. 2006; Martin 2004; Warrick 2000).

Half of the deer (n=35) have $\delta^{13}C_{col}$ values lower than –23‰ (Figure 4.14), which could reflect browsing in more heavily forested areas, i.e., a canopy effect (Cerling and Harris 1999; Cormie and Schwarcz 1994; Bonafini et al. 2013; Druker and Bocherens 2009). The canopy effect is due to the depletion of ^{13}C from understory atmosphere relative to the general atmosphere because of restricted ventilation, recycling of CO_2 from leaf litter, and photosynthetic changes in plants abundant in the low light conditions (van der Merwe and Medina 1989; 1991; Vogel 1978). The result is that tropical and temperate plants growing in the lower canopy of a forested area will have relatively low $\delta^{13}C$ values compared to plants growing at forest edges or open environments (Bonafini et al. 2013;

Cerling and Harris 1999; Druker and Bocherens 2009; Vogel 1978). Drucker and Bocherens (2009) interpreted the $\delta^{13}C$ composition of ancient bovids to track the introduction of deep forests in France, while Bonafini et al. (2013) found a moderate canopy effect on roe deer living at the forest edge, as might be expected for animals living on plants both in open and closed environments. Both studies suggest that the canopy effect, well recognized for plants, may be also identifiable when moving up a trophic level to primary consumers.

Like the roe deer in Bonafini et al.'s (2013) study, the ecology of modern white-tailed deer would suggest that they may hide in forests if disturbed, but in general they eat in more open areas, and therefore a canopy effect is unlikely. Many of the archaeological deer, however, appear to have $\delta^{13}C_{col}$ values consistent with a canopy effect, as described by Cormie and Schwarcz (1994) and Bonafini et al. (2013). The implication is that these deer, hunted by ancient Ontario peoples, did not access C_4 (i.e., maize) plants, and further, may have browsed in more deeply shaded areas than their modern counterparts, avoiding open terrain. Modern deer are unable to move into deeply forested areas in southwestern Ontario because of deforestation over the last 200 years. Despite extensive Late Woodland maize agriculture, a large amount of the region would have remained closed forest before A.D. 1650. The collagen isotopic data indicate that the ancient deer may have actively avoided human predators and, therefore, foregone foraging in maize fields, despite its rich food resource potential. Deer hunting, therefore, likely occurred away from open and/or cleared lands. Because a large number of deer would have been required to support the food and clothing needs of past peoples, deer within the immediate vicinity of villages would have been quickly hunted out. According to Ripple and Breschta's (2003) "terrain of fear" theory, prey species, including ungulates, will alter their foraging patterns in order to avoid sites with higher risk of predation (see also Wolverton 2008). Any deer living near humans during the Late Woodland times may have either been immediately hunted out or fled the area, resulting in the need for Late Woodland hunters to go further afield to find enough deer to support growing populations. This theory is consistent with ethnographic descriptions of deer hunting among the Late Woodland Neutral people; "*game was scarce near villages and Indians*

had to travel considerable distances to obtain it" (Tooker 1991:65, summarized from the Jesuit Relations).

The theory that the deer were hunted away from the village sites where the deer remains were recovered (i.e., where they may have been eaten and/or used for clothing etc.) is explored further in Section 4.5.6. In this section, the $\delta^{18}O_{sc}$ values of bulk bone and dental enamel are compared with predicted precipitation values for the southwestern Ontario region in order to determine if there is a correlation (or lack of correlation) between *in vivo* geographic range of the deer and the sample's recovery location.

4.5.4 Archaeological deer enamel ($\delta^{13}C_{sc}$) and dentine ($\delta^{13}C_{col}$): Tracking seasonal diet

Serial sections of enamel suggest an entirely C_3-based diet for the first year of life of eight archaeological deer (pre-maize, n=1, Western Basin n=3, Ontario Iroquoian n=4), which is consistent with their bulk collagen isotopic results. A weaning signal is evident for all deer because breast-feeding results in slightly lower $\delta^{13}C$ values, which may be due to the lower $\delta^{13}C$ value of lipids. There is variation in the enamel $\delta^{13}C$ values as fawn diets shifted to plant foods during the formation of the second molar (Figure 4.15). The enamel serial section data are consistent with the $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ results discussed previously. From early winter (~November) until spring all eight deer maintained consistently uniform enamel $\delta^{13}C_{sc}$ values (–14.53±0.51‰) indicative of a C_3 diet. Like the collagen results, the serial sampling of the enamel suggests that archaeological deer did not consume maize during the first year of life. If the deer consumed maize after tooth formation was completed, the effect on bulk collagen could be negligible (as previously discussed) because the isotopic composition of the bone may be biased towards this earlier growth stage. Therefore, if archaeological deer that browsed on maize fields were hunted later in their lives, maize consumption may not be detected from bone and tooth data alone. The *adult* deer consumption of maize would be best revealed using the isotopic compositions of antler and cementum serial sections.

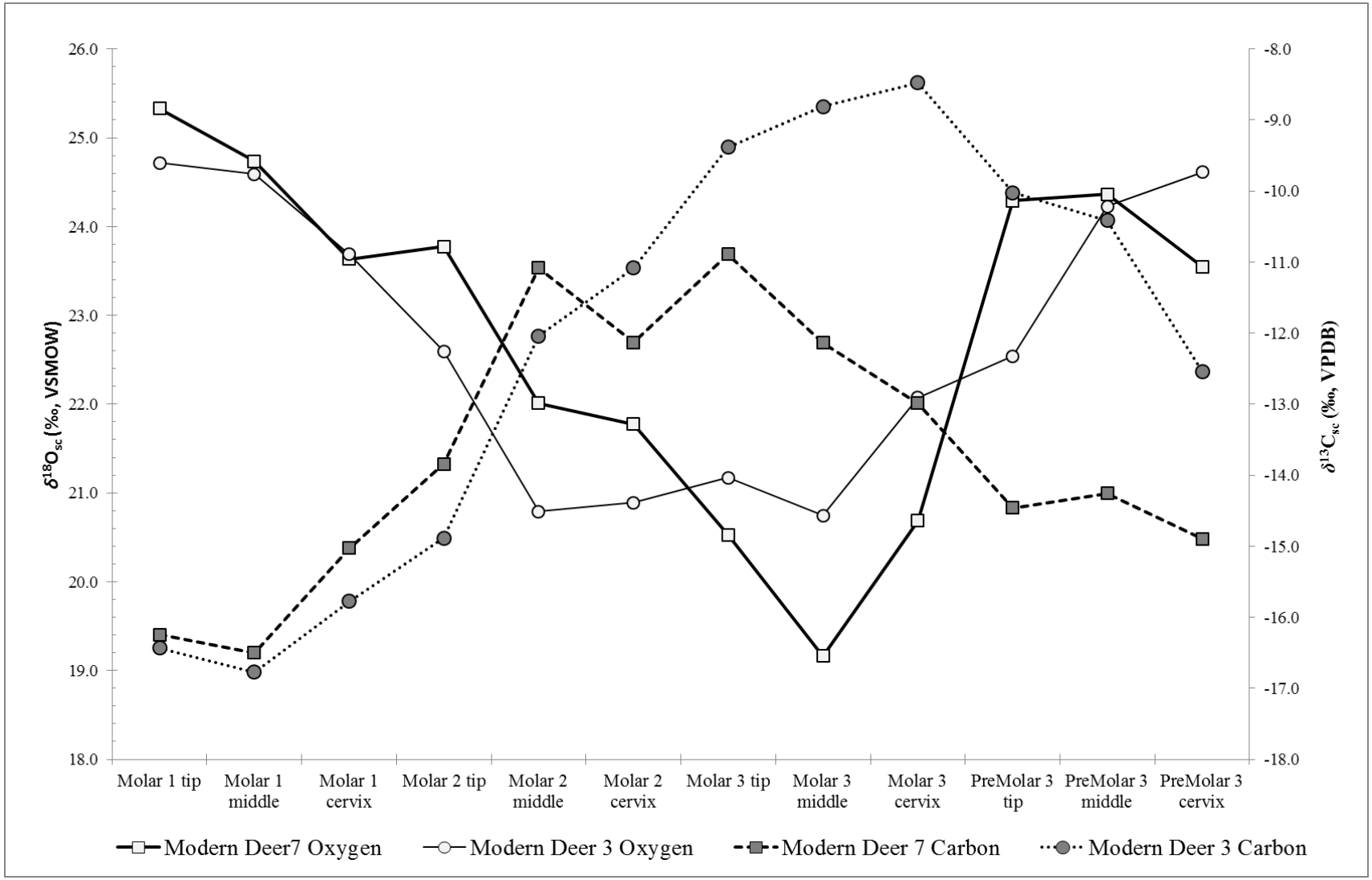

Figure 4.13: Comparison of Modern Deer 7 and Modern Deer 3 $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values obtained from enamel serial sections.

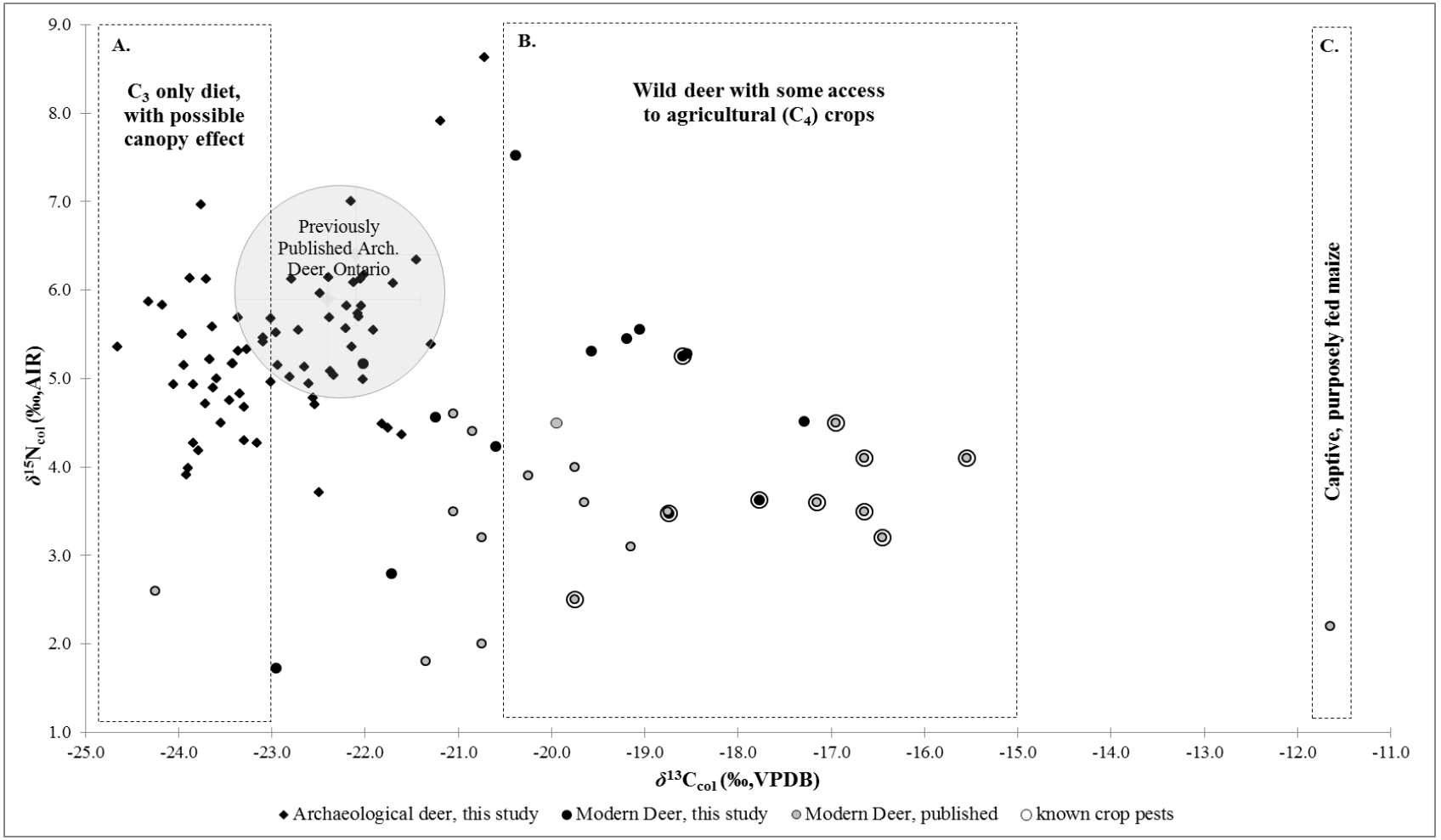

Figure 4.14: Comparison of $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ of modern and archaeological deer bone from the Great Lakes region. Boxes indicate Cormie and Schwarcz's (1994) proposed $\delta^{13}C_{col}$ ranges indicating: A. canopy effect, B. moderate C_4 consumption, and C. purposeful maize feeding.

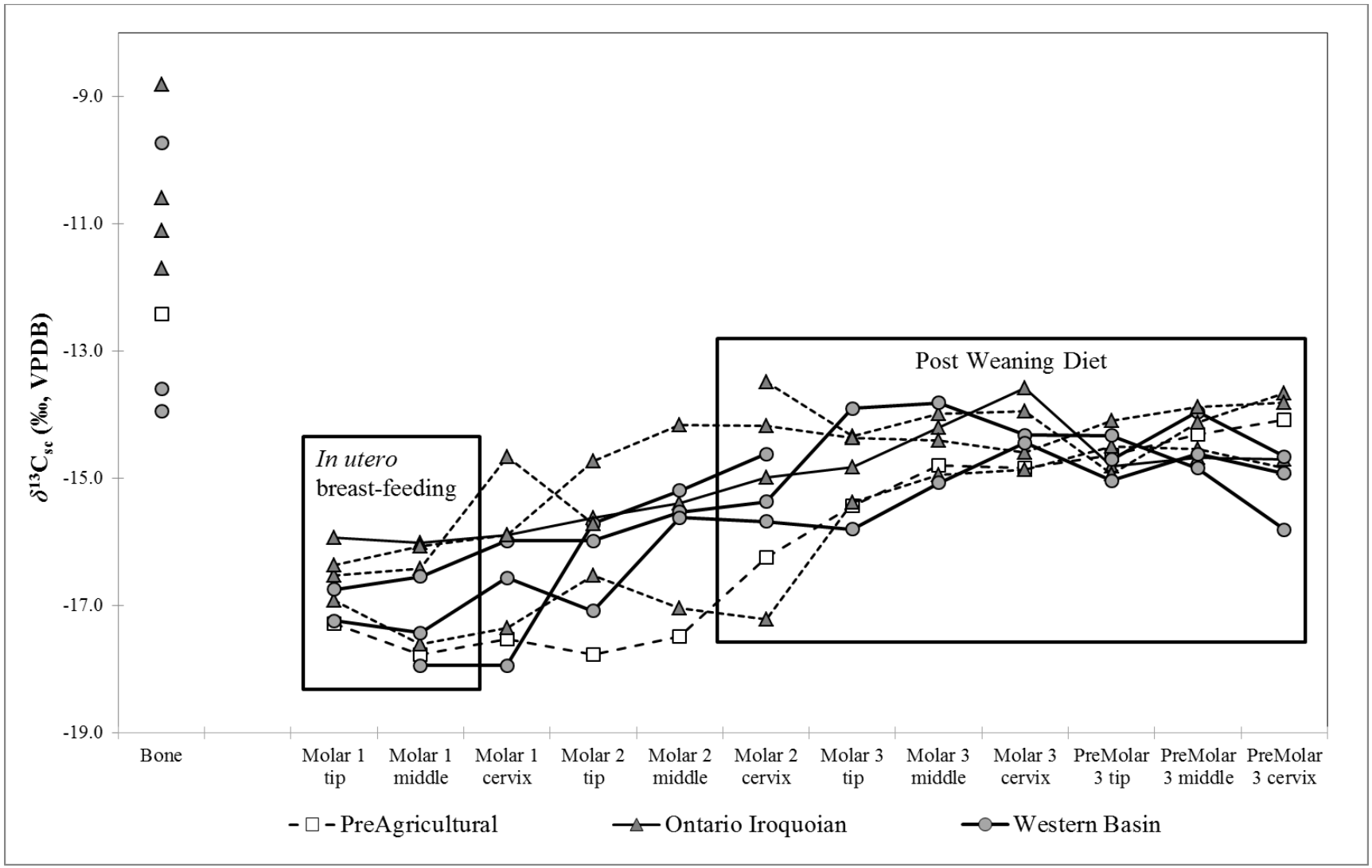

Figure 4.15: $\delta^{13}C_{sc}$ values of the archaeological deer serial sections and bulk bone.

4.5.5 Archaeological deer structural carbonate ($\delta^{13}C_{sc}$): Indication of maize access or post-mortem alteration?

Unlike the bulk bone and dentine collagen isotopic results and enamel serial section structural carbonate isotopic results, the bulk bone structural carbonate isotopic data tell a very different story; the bone $\delta^{13}C_{sc}$ values suggest that *all* archaeological deer were consuming maize, including the Davidson deer, which is pre-horticultural (dated to > 3000 years based on both stratigraphy and carbon-14 dating, *personal communication* Chris Ellis). Furthermore, archaeological deer from Late Woodland contexts have significantly *higher* $\delta^{13}C_{sc}$ values than modern deer (Dunnett T3, p=0.014). These results are not believed to reflect maize consumption by archaeological deer. First, there is no correlation between $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values as would be expected from published literature (Froele et al. 2010, 2012; Harrison and Katzenberg 2003; Kellner and Schoeninger 2007) and modern deer from this study (Figure 4.16). Second, the mean $\Delta^{13}C_{sc–col}$ value (11.63±1.99‰) is unexpectedly large, relative to both the modern deer in this study and published data for ungulates (Kellner and Scheoninger 2007; Krueger and Sullivan 1984; Lee–Thorp et al. 1989) (Table 4.14).

Western Basin deer had a higher mean $\Delta^{13}C_{sc–col}$ value (12.25±2.41‰) than Ontario Iroquoian deer (11.22±2.04), but the difference was not significant (Table 4.14). A more detailed analysis of the Late Woodland time period by phase (Table 4.15) reveals that the Middle Ontario Iroquoian phase deer (A.D. 1200–1450) had the highest $\Delta^{13}C_{sc–col}$ value (13.59±1.08‰) of any Iroquoian group, significantly higher than Neutral (A.D. 1450–1650) deer ($\delta^{13}C_{sc}$ = 10.60±1.13‰, Table 1.18, Dunnett T3, p=0.004).

The bulk structural carbon isotopic results and the results of the bulk bone collagen are contradictory; $\delta^{13}C_{col}$ values indicate *none* of the archeological deer were consuming maize while the $\delta^{13}C_{sc}$ values indicate *all* archaeological deer were consuming maize. Three hypotheses are proposed to explain these apparently contradictory results: (1) a specialized diet that alters the expected $\Delta^{13}C_{sc–col}$, (2) a species-specific difference in susceptibility to diagenesis, or (3) taphonomic alteration of the bone resulting from boiling. Metabolic or physiological differences between modern and archaeological deer

are rejected as an explanation because the modern and archaeological deer are the same species.

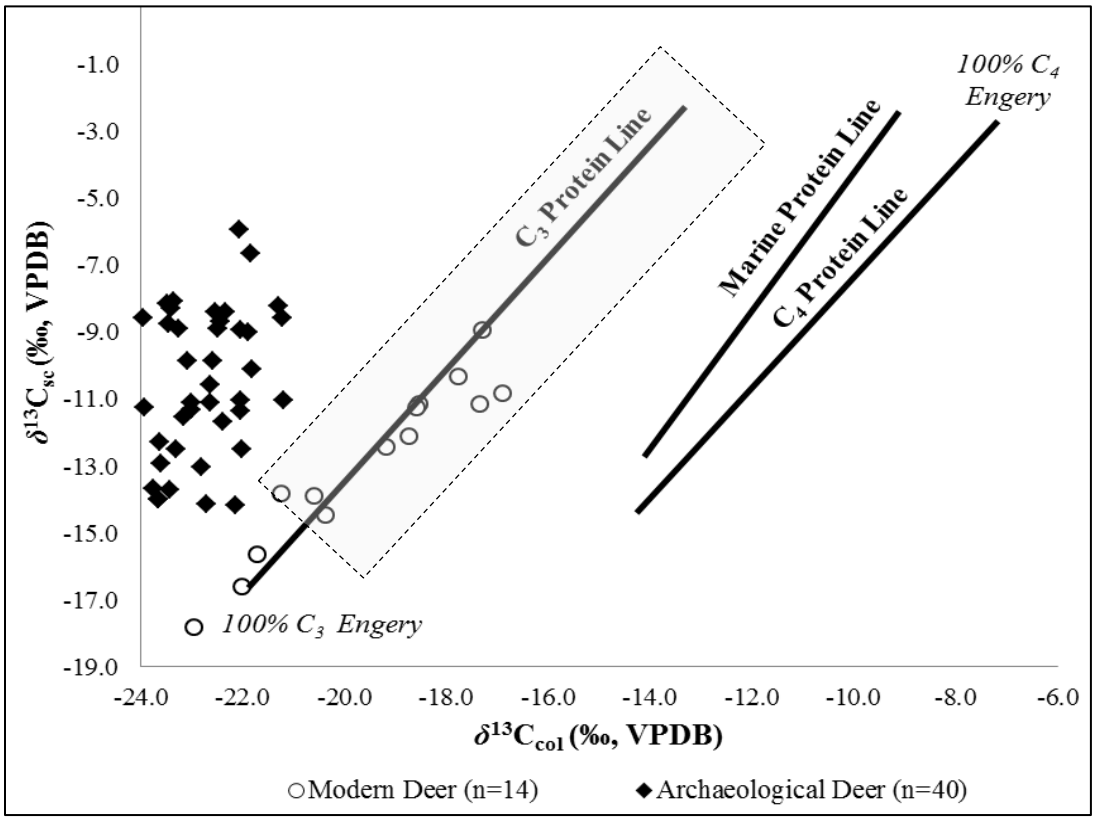

Figure 4.16: Model for the relationship between $\delta^{13}C$ values of structural carbonate and collagen for modern and archaeological deer.

The gray square indicates a diet primarily composed of C_3 protein with some C_4 energy (i.e., lipid and carbohydrate) sources. Developed by Kellner and Schoeninger (2007, Chart adapted from Figure 2B).

4.5.5.1 Specialized diet

Ambrose and Norr (1993) demonstrated that the $\Delta^{13}C_{sc-col}$ value could be increased by manipulating diet, specifically the macronutrients related to growth and maintenance (i.e., protein) versus those related to energy (i.e., lipids and carbohydrates). Theoretically, a diet that combines high $\delta^{13}C$ foods rich in energy macronutrients with low $\delta^{13}C$ foods rich in protein could artificially increase $\Delta^{13}C_{sc-col}$. Consumption of either raw maize, both its fruits and leaves, or wild C_3 foods available to deer in southwestern Ontario only fulfills the first condition for increasing the spacing i.e., a diet with high $\delta^{13}C$ values, rich

in carbohydrates and lipids but very low in protein. As modern deer do not display the large $\Delta^{13}C_{sc-col}$ value of archaeological deer, a differential macronutrient routing model would not likely explain the different spacing. Furthermore, the archaeological deer do not fit anywhere among the expected relationships of macronutrients in major dietary groups, whereas modern deer follow the expected pattern for C_3 protein consumption and variable C_4 access for free-ranging herbivores. For example, based on the calculations of Kellner and Schoeninger (2007, Figure 2: 1122), using the following models, where x = $\delta^{13}C_{col}$ values and y = expected $\delta^{13}C_{sc}$ values:

C_3 protein diet **y=1.74x+21.4** **[Equation 4.1]**

C_4 protein diet **y=1.71x +10.6** **[Equation 4.2]**

the expected $\Delta^{13}C_{sc-col}$ value for the archaeological deer eating an exclusively C_3 diet would be 4.58±0.57‰ (Figure 4.17). The predicted $\Delta^{13}C_{sc-col}$ value for the archaeological deer eating a diet with a C_4 component resulted in the impossible situation of predicted structural carbonate values being more negative than their collagen values.

4.5.5.2 Post-mortem alteration

The idea of an inherent, species-specific susceptibility to diagenesis seems unlikely in the case of deer, as there is no evidence that deer exhibit any differences in their tissue preservation relative to other large bodied mammals. In order to evaluate whether a post-mortem alteration pattern specific to deer could explain the results, the $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ values for all animals from this study were re-considered. Although some sites produced higher or lower collagen yields, all of the other animals from those sites shared similar collagen yields and similar $\Delta^{13}C_{sc-col}$ values. The archaeological deer examined in this study appear to have distinct $\Delta^{13}C_{sc-col}$ values relative to other Ontario animals, including humans (Harrison and Katzenberg 2003), dogs, turkeys, raccoons, and bears (*this study*) (Figure 4.18 –raccoons, dogs, and bears not displayed in figure). Only deer exhibit an unusually large $\Delta^{13}C_{sc-col}$ relationship (12.19±2.10, range=7.95 to 16.09). Because no statistical patterns were noted by element (i.e., mandibles vs. long bones), age of individual (adult vs. juvenile), site or burial contexts, the idea of a post-mortem alteration pattern specific to deer is rejected.

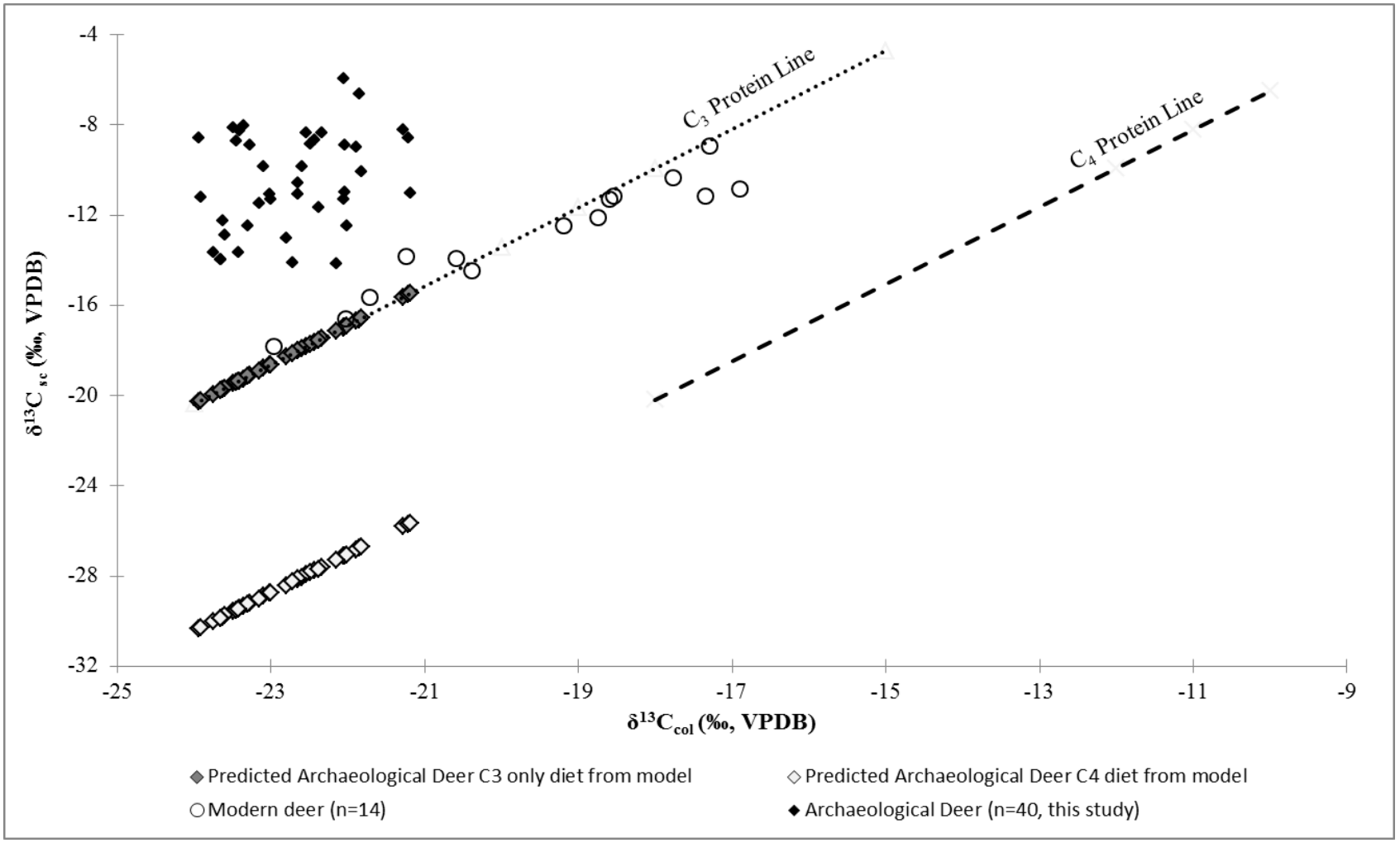

Figure 4.17: Predicted $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ relationship based on Kellner and Schoeinger's model (2007, Chart adapted from Figure 2B) for C_3-only (grey diamond) and C_4 (white diamond) protein diets.

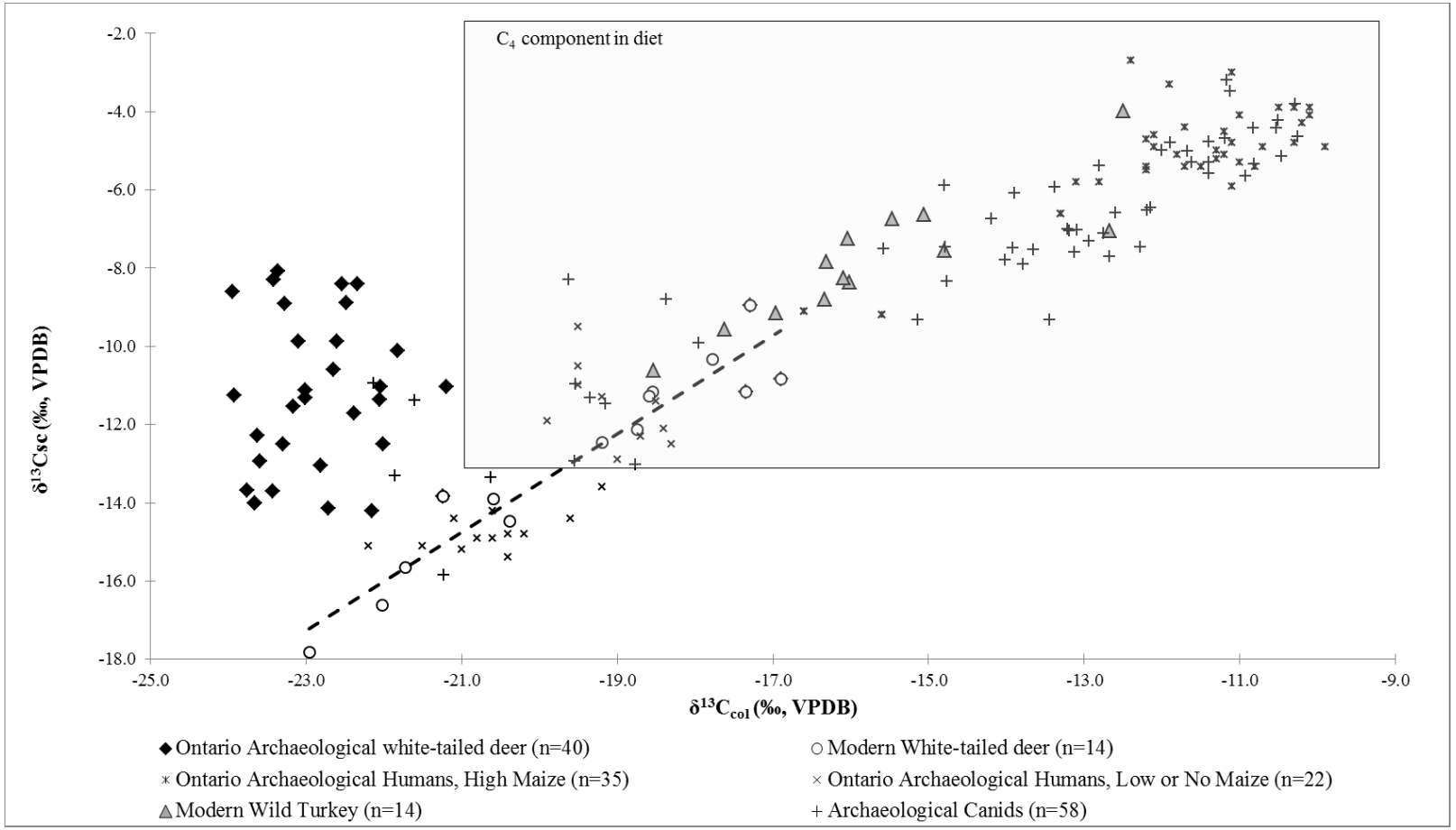

Figure 4.18: Comparison of $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values for modern and archaeological Ontario white-tailed deer, modern Ontario wild turkeys (*this study*) and southwestern Ontario archaeological humans (Harrison and Katzenberg 2003).

The gray square indicates range of values with a predicted C_4 component to the diet. The gray dashed line indicates the relationship between $\delta^{13}C_{sc}$ and $\delta^{13}C_{col}$ values for modern deer.

There are only a few published, comparable datasets for archaeological deer (i.e., paired collagen and structural carbonate analyses). Table 4.2 shows that average $\Delta^{13}C_{sc-col}$ values are much lower for deer from other North American archaeological sites.; i.e., mean $\Delta^{13}C_{sc-col}$ =8.7±2.14‰ (n= 9) at the Dakota site, Nebraska ((Loken et al. 1992) and mean $\Delta^{13}C_{sc-col}$=8.1‰ (SD not reported, n=4) at the Maya site of Cuello (van der Merwe et al. 2002). These spacings are more comparable to those reported for modern deer in previous work (Kellner and Schoeninger 2007) and for modern deer from this study. Isotopic data for deer from Dorchester, an additional southwestern Ontario Iroquoian site, had a mean $\Delta^{13}C_{sc-col}$ value of 13.71±0.80‰, n=3 (Booth et al. 2012). The Ontario archaeological deer appear to exhibit exceptionally large $\Delta^{13}C_{sc-col}$ values relative to other sites in North America.

To further explore whether post-mortem alteration of Ontario archaeological deer is contributing to the high $\Delta^{13}C_{sc-col}$ values, statistical analyses were performed for several post-mortem alteration checks. As discussed previously, the tests for preservation of structural carbonate, including CI and C/P, were normal. In fact, the pre-treatment C/P ratios measured for deer were better than those obtained for most other animals analysed in this dissertation, many of which had higher than acceptable C/P ratios prior to pre-treatment (see Chapters 2 and 3). All deer bones but one also had expected C:N ratios and acceptable collagen yields and did not differ from those of the dogs and turkeys described in Chapters 2 and 3, which had expected $\delta^{13}C_{sc}$ values and $\Delta^{13}C_{sc-col}$ relationships.

There were no statistically significant correlations between collagen isotopic values ($\delta^{13}C_{col}$ and $\delta^{15}N_{col}$) and C:N ratio, percent collagen by weight, percent bioapatite by weight, percent CO_3 by weight, CI or C/P. Similarly, there were no correlations among C:N ratio, percent CO_3, CI or C/P and $\delta^{13}C_{sc}$ and $\delta^{18}O_{sc}$ values. There is also no clear trend by time period/cultural affiliation for post-mortem indicators relative to the $\Delta^{13}C_{sc-col}$ spacing (Figure 4.19). There was, however, a significant correlation between $\delta^{13}C_{sc}$ values and collagen yield (Spearman's, F=–0.452, p=0.002). While collagen yields are well above the acceptable level for isotopic analysis of collagen, as collagen yield decreases, the $\delta^{13}C_{sc}$ values increase (Figure 4.19A and B).

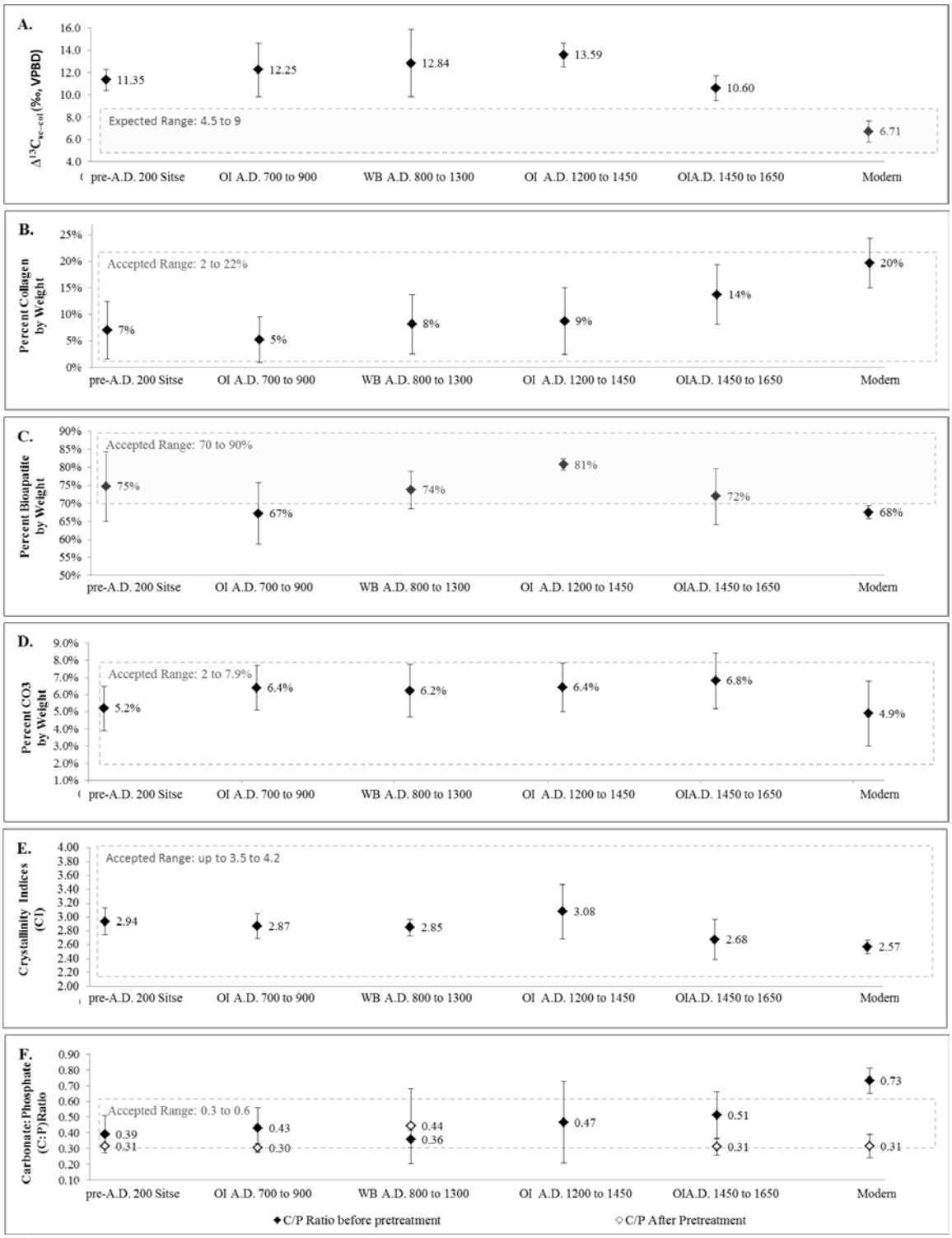

Figure 4.19: Comparison of (A.) mean $\Delta^{13}C_{sc-col}$ spacing, organized by time period, to post–mortem alteration indicators including: (B.) collagen yield, (C.) percent bioapatite by weight, (D.) percent CO_3 by weight, (E.) CI Index and (F.) C/P ratio. Gray box indicates accepted ranges for each parameter.

Further exploration reveals that there are also statistically significant differences in collagen yield (ANOVA, F=8.434, p=0.000) by sub-group of archaeological deer. Western Basin deer had the lowest yield (5.3±4.3%) relative to those from Ontario Iroquoian (11.1±6.3%) and pre-maize (7.1±5.4%) sites. Within the Ontario Iroquoian sites, there were also statistically significant differences (ANOVA, F=8.343, p=0.001) by time period, with Neutral deer having higher yields (13.96±5.70%) than the Princess Point/Early Ontario Iroquoian (7.93±5.14%) and Middle Ontario Iroquoian (8.21±5.37%) deer. While the $\delta^{13}C_{col}$ values are not related to collagen yield, the $\delta^{13}C_{sc}$ values are. The $\delta^{13}C_{sc}$ and $\Delta^{13}C_{sc-col}$ values mirror the collagen yield pattern, with the highest $\delta^{13}C_{sc}$ and $\Delta^{13}C_{sc-col}$ values found at Western Basin sites (1100 to 600 years old) and Middle Ontario Iroquoian sites (750 to 500 years old).

Diagenetic alteration of the structural carbonate of the bone over time can explain the low collagen yield at early sites (i.e., pre-A.D 200) and in specific burial conditions (i.e., Western Basin and Middle Ontario Iroquoian sites), and the higher than expected $\delta^{13}C_{sc}$ values. As collagen is lost due to microbial invasion or other diagenesis-inducing processes (e.g., regular flushing with water) bone porosity and permeability increases as a consequence of bioapatite dissolution; this provides an opportunity for precipitation of, or exchange with, secondary carbonates. Therefore, structural carbonate may become so altered that it no longer represents its original isotopic composition, unlike collagen, which generally maintains its isotopic integrity until there is less than 1% remaining. Environmental carbonates have high $\delta^{13}C$ values relative to biological carbonates, which can result in carbonate carbon isotopic compositions that mimic C_4 consumption (Ketchum et al. 2009; Kovda et al. 2006).

While the link between collagen yield and increasing $\delta^{13}C_{sc}$ values, and therefore $\Delta^{13}C_{sc-col}$, can be explained by post-mortem alteration due to dissolution, it does not explain: (1) why only the deer bone at these sites are affected, (2) why the diagenesis checks (CI and C/P) are not registering alteration, and (3) how the post–mortem conditions at Western Basin and Middle Ontario Iroquoian sites differ from other sites. The specificity of this pattern could suggest cultural intervention, i.e., differential treatment of deer bones at

certain sites, during processing, cooking and/or discard of the deer, resulting in this specific pattern.

4.5.5.3 Post-mortem processing of deer

The way in which deer are processed may hold the key to understanding the unusual pattern of post-mortem alteration seen here. There is ample evidence that, during the time periods of this study, meats were cooked before consumption. Although burn marks indicative of roasting were noted on turkey and canid bones, they were not found on any of the deer processed in this study. The cooking of deer may therefore, have been done by boiling. The stewing of meat is mentioned throughout ethnohistoric accounts (Thwaites 1896-1901 37:108; Peale 1872 see also Tooker 1991:68;70;73 and Fenton 1953). For example, Sagard (Wrong 1939:111) recounts "*if it's deer they say* Gagenon Youry, *and so with other kinds of food, naming the kind or the materials in the kettle one after another.*" The preferential boiling of deer, in general, could explain the higher $\delta^{13}C_{sc}$ values.

Although laboratory experiments on conventional boiling of deer bone (i.e., less than 8 hours) did not alter its isotopic composition or FTIR patterns, it did increase porosity (and permeability) (Roberts et al. 2002). Increased porosity should make bone more susceptible to post-burial diagenesis, which should be reflected in the CI and C/P ratios. The alteration of CI and C/P ratios is not seen here, possibly indicating post-mortem alteration, but not post-burial alteration (i.e., the bones were altered due to the boiling, not the burial). The previously reported boiling experiments all used *distilled* laboratory water (i.e., water with no dissolved inorganic carbon [DIC]) without any added ingredients such as one would expect in a stew. If ancient Ontario people were boiling deer in local waters along with maize (i.e., making of *saagamite*), there could have been fractionation and exchange between the water and bone. The predisposition of carbonates to precipitate under boiling conditions with the added presence of dissolved inorganic carbon (DIC) in river or lake water could have also changed the isotopic composition of the bones. The $\delta^{13}C$ values for DIC in river water (Grand and Thames Rivers) in southwestern Ontario is estimated to be between –11 to –8‰ (Yang et al. 1996), which could cause the high $\delta^{13}C_{sc}$ values and unusual $\delta^{13}C_{sc-col}$ spacing.

There are several reasons that deer may have been boiled. Low meat yield elements, such as the mandibles and foot bones that dominate the analysed samples, may have been boiled to extract marrow or grease. Foreman (2011) found evidence of grease extraction at Western Basin sites where there was extensive *fragmentation* of deer long bones. Church and Lyman (2003) argue that it was not necessary to pulverize bone to extract grease, but it was necessary to break the bones and boil them for approximately 2 to 3 hours. The majority of the mandibles analysed in this study were also broken (n=18, 90%), though not extensively fragmented. Although there are some differences in long bone fragmentation between Ontario Iroquoian and Western Basin sites (Foreman 2011), the mandibles used in this study were similarly broken with similar ranges in $\delta^{13}C_{sc}$ values. If low marrow/grease yielding parts of the deer are being boiled, extraction of grease or marrow may not have been the only reason for boiling deer elements. It should also be considered that since mandibles and foot bones were purposefully selected because they are readily identifiable as white-tailed deer, this may have inadvertently resulted in biased results if these elements were treated differently because of their low meat yield.

Ideology may also have played a role in the apparent special processing of deer. It was not uncommon for whole skulls of animals, including bears, dogs, and deer to be boiled for feasting events (Fenton 1953), which might suggest that all the deer mandibles recovered were associated with feasting activity. However, other animals analysed in this study, including bears and dogs, do not show similar $\Delta^{13}C_{sc-col}$ patterns.

Alternately, feasting activities might also have included the production of flesh-free animal parts (particularly skulls). References to animal skulls, specifically antlered animals, appear in the mythology of the Great Lakes. Descriptions of *wendigos*, for example, include terrifying imagery of a skeletal giant (from an Anishinâbe story, Johnston 2011:122): *"The Weendigo was gaunt to the point of emaciation, its desiccated skin pulled tautly over its bones. With its bones pushing out against its skin, its complexion the ash gray of death, and its eyes pushed back deep into their sockets, the Weendigo looked like a gaunt skeleton recently disinterred"* In creating tableaux or other forms of dramatization, the "mask"-like appearance of animal skulls may have been

coveted in rituals. Exploration of ritual site skulls should be investigated for unusual $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ relationships that could be explained by boiling animals skulls as part of ceremonial feasts or tableaus.

Another probable explanation for the specific boiling of deer skulls would be to access and liquefy the deer brains for tanning hides, a process known as brain-tanning. The most important and most commonly tanned animal hide in Ontario was without question the white-tail deer hide. According to Peale's (1872:330) observations in North America, "[t]*he material used for the preparation of the skins is principally the brains of the animal from which they were taken*." Baillargeon (2005:149) describes the most "common recipe" for tanning among First Nations cultures throughout North America is the incorporation of brains, possibly with fat from marrow and/or liver, boiled in water. Baillargeon (2005:1480-9) further notes that animal brains were important in the tanning process because they may have been considered restorative and transformative; "*The transformation that takes place in hide tanning centers around the belief that the soul or power (energy) of the animal resides in the brain… The use of the animal's own brain in the tanning process would be essential to bring about revival and the restoration of power/life.*"

Lewis H. Morgan recounts a story heard during his mid-1800's travels among the Iroquois, explaining the discovery of brain-tanning: "*A stiff deer skin was one day walking around from house to house through an Indian village, frightening everyone it visited. At last it went to the house of a man who was boiling deer's brains* [to induce] *a vomit. He did not propose to be frightened by this mysterious skin out of his house, and therefore he poured the hot water solution of deer's brains upon the stiff skin which at once softened it down, took away from it all power of motion, and flattened it to the floor. The people in fright had been shooting it with arrows. After it was softened they began to pull it and thus resulted the tanned deer skins*."

Richter and Dettloff (2002:307), in an experimental study recreating Midwestern Woodland brain-tanning as described at European contact, found that each deer's brain was sufficient to tan its hide, an expression repeated in much of the modern, tanning

guides. Although Richter and Dettloff did not describe how they obtained the brains, they noted that traditional means of accessing the deer brain included cracking of the skull to extract the brain or boiling the entire skull then using a stick to draw out the liquefied mixture (Elpel 2003:164; Richards 1997:43).

4.5.6 Modern and archaeological deer bone ($\delta^{18}O_{sc}$): Tracking hunting ranges with oxygen-isotopes

Deer were one of the most economically important animals of the Late Woodland. Because large numbers of deer were needed to feed and clothe growing populations, the need to hunt deer further afield may have increased, despite conflicts with fall harvest. Using every part of the deer, even low meat yield parts, may have increased with the growing Ontario Iroquoian populations. The pressure for tanned hides would also grow with increasing population size. The necessity to hunt further afield for deer, possibly in more closed shaded (i.e., forested) environments, may be visible in the oxygen isotopic composition of the deer. Very large hunting territories could result in a wide range of $\delta^{18}O_{sc}$ values among deer recovered from the same site. The $\delta^{18}O_{sc}$ values of bulk bone and $\delta^{18}O_{sc}$ of the dental enamel were therefore compared with predicted precipitation values for the southwestern Ontario region (Figure 4.20).

The precipitation station isotopic data were used to predict the annual precipitation $\delta^{18}O$ values for the locations of Western Basin and Iroquoian sites examined in this study (see discussion Chapter 1, Section 1.3.4, Figure 1.2 and 3.11). The deer $\delta^{18}O_{sc}$ values were converted to phosphate following Iacumin et al. (1996:4):

$$\delta^{18}O_{phosphate} = 0.98(\delta^{18}O_{sc}) - 8.5 \qquad \textbf{[Equation 4.3]}$$

The bone phosphate values were converted to precipitation values following Luz et al.'s (1990:1724) formula based on deer bone:

$$\delta^{18}O_{phosphate} = 34.63 + 0.6506(\delta^{18}O_{precipitation)} - 0.171(humidity)^{20} \qquad \textbf{[Equation 4.4]}$$

[20] humidity was estimated at 85%, based on an Ontario average.

and statistically compared to the interpolated $\delta^{18}O_{precipitation}$ for each site.

Based on an ANOVA of the bulk bone $\delta^{18}O_{sc}$ values there is no indication of a temporal shift in $\delta^{18}O_{sc}$ values over the 3000+ year study period.

In terms of geographic variation, modern bulk bone $\delta^{18}O_{sc}$ values did not correlate significantly with predicted $\delta^{18}O$ values of water based on site precipitation (Figure 4.21). This is not surprising given that deer consume much of their water from plants, and waters in leaves and stems can be significantly enriched in ^{18}O relative to local waters due to the effects of transpiration (Bryant and Froelich 1995; Yakir 1992; Wang and Yakir 1995). Dependence on plant water plus the limited variation in the average annual $\delta^{18}O$ values of precipitation over this region could obscure any geographic re-locations by deer. The $\delta^{18}O_{sc}$ bone values of archaeological deer were, however, correlated with predicted $\delta^{18}O$ values for precipitation (Spearman's ρ=0.977, p=0.015, n=41). Either deer bone reflects the local waters that the deer imbibed, or the $\delta^{18}O_{sc}$ values of the archaeological deer bone may have been altered post–mortem as were the structural carbonate $\delta^{13}C$ data, in this case via post-burial exchange with ground waters or evaporation and exchange during boiling.

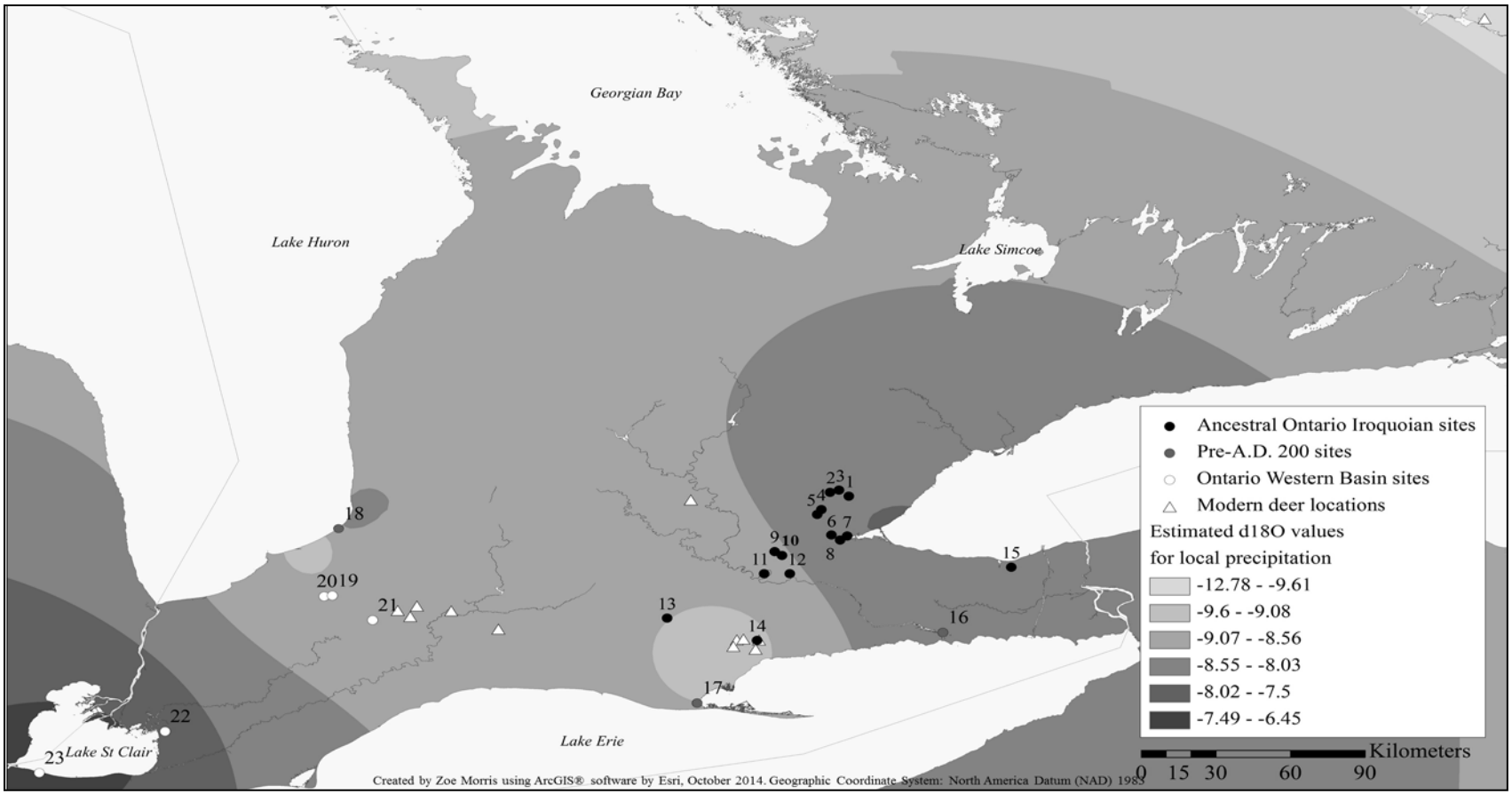

Figure 4.20: Archaeological and modern sites with deer remains overlaid on the interpolated δ^{18}O values for local precipitation from the previously described Kriging model (IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2).

Ancestral Ontario Iroquoian Sites: 1. Pipeline; 2. Rife; 3. Crawford Lake; 4. Bogle II; 5. Hamilton; 6. Winking Bull; 7. Old Lilac Garden; 8. Princess Point; 9. Cleveland; 10. Fonger; 11. Porteous; 12. Walker; 13. Van Besien, 14. Slack-Caswell; 15. Thorold. Pre–A.D. 200 sites: 16. Bruce Boyd, 17. Cranberry Creek, 18. Davidson; Western Basin Sites: 19. Figura, 20. Inland West Pits site 3, 9 and 12, 21. Liahn 1, 22. Montoya, 23. Silverman.

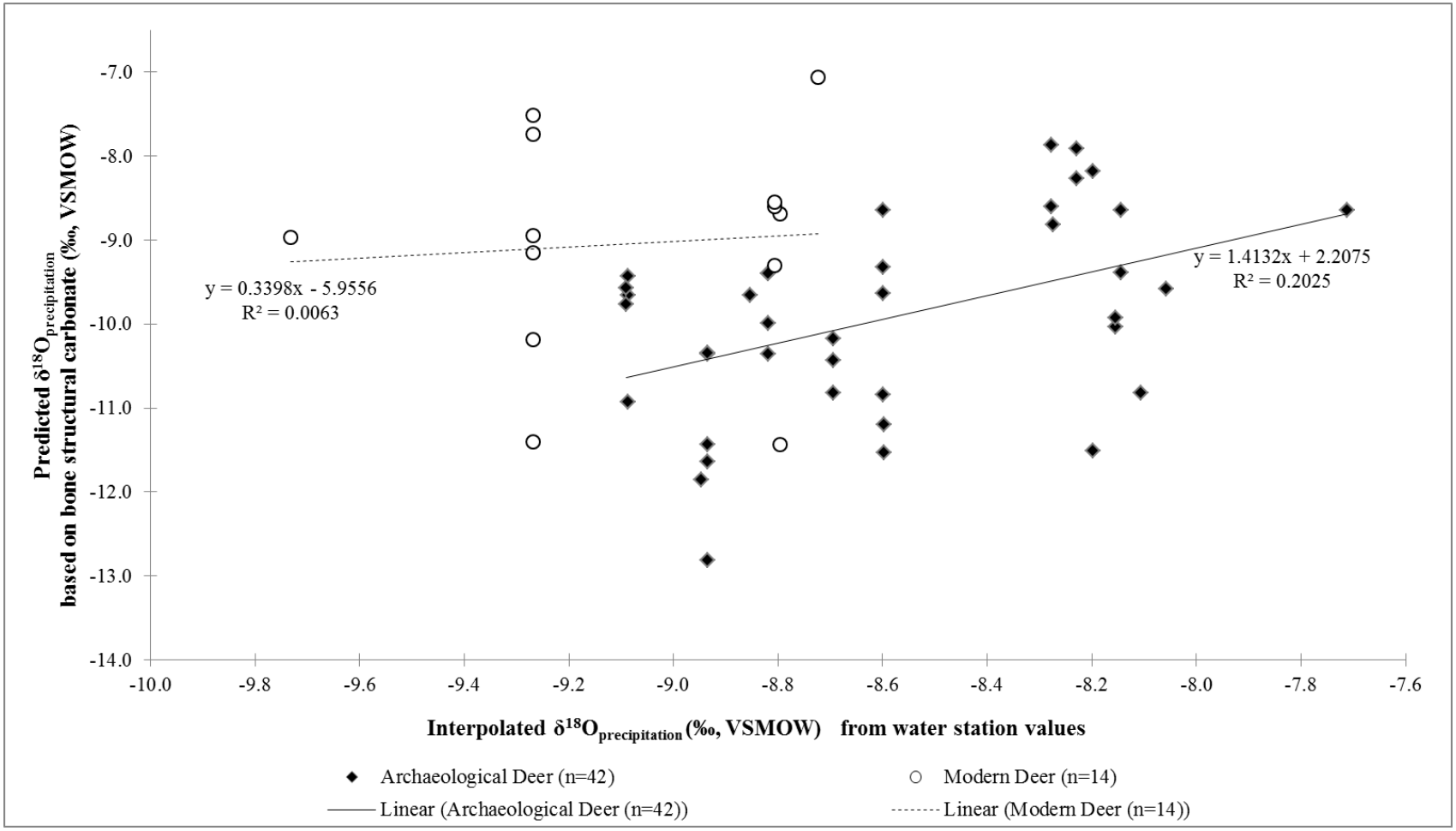

Figure 4.21: Predicted precipitation $\delta^{18}O$ values for modern and archaeological deer bulk bone $\delta^{18}O_{sc}$ values, calculated using the relationships presented by Bryant et al. (1996) and Luz et al. (1990), compared to the interpolated $\delta^{18}O$ values for local precipitation from the previously described Kriging model (IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2).

In order to explore this possibility in more detail, the deer bones were examined by time period, as older bones are more likely to have been altered. Examination of individual subsets of bone based on time period and culture reveals that pre-maize bones are highly, negatively correlated with their predicted $\delta^{18}O_{sc}$ values (Spearman's $\rho = -0.877$, $p=0.022$). By comparison, the Late Woodland (post-A.D. 900) bones were positively correlated with predicted $\delta^{18}O_{sc}$ values, though only Western Basin deer bulk bone is significantly correlated ($\rho=0.770$, $p=0.003$). In other words, at Late Woodland sites, increasing $\delta^{18}O_{sc}$ bone values are correlated with increasing interpolated $\delta^{18}O_{precipitation}$ values, and significantly so at Western Basin sites. As discussed previously, Western Basin deer appear to have been more heavily targeted for grease extraction (Foreman 2011). If these bones were boiled extensively, as hypothesized based on the $\delta^{13}C_{sc}$ results, the $\delta^{18}O_{sc}$ values may also have been altered towards local waters near sites used for boiling, as opposed to local waters imbibed by the deer. Unfortunately, these data make it difficult to use bulk bone structural carbonate isotopic data as a geographic proxy for the deer during life and, therefore, should not be considered a reliable indicator of hunting territories of Late Woodland people. The positive correlation between predicted and actual $\delta^{18}O_{sc}$ values may in fact lend support to the hypothesis that Late Woodland peoples were extensively boiling these low–meat yield parts. Whether boiling was done for grease extraction, hide-tanning, or other culturally specific practices still needs further study.

The mean $\delta^{18}O_{sc}$ value for all serial sections of enamel for one individual should represent a first-year average and the bone $\delta^{18}O_{sc}$ value should represent a lifetime average. Indeed, the mean enamel $\delta^{18}O_{sc}$ values do not correlate significantly with corresponding bone isotopic compositions. For nine deer, the mean enamel $\delta^{18}O_{sc}$ value average is higher than bone (+1.35±0.81‰) (Table 4.22). The difference could be due to a trophic level effect in the first molar as its enamel was forming partly *in utero* and during breast-feeding, which is consistent with observations that $\delta^{18}O_{sc}$ values may be high for breastfeeding juveniles relative to females within the same population (White et al. 2004a; Williams et al. 2005; Wright and Schwarz 1998). The difference might also reflect routing differences to these tissues, wherein enamel structural carbonate has $\delta^{18}O_{sc}$ values that are 1.7‰ higher than those of bone (Warinner and Tuross 2009).

Table 4.22: Comparison of mean $\delta^{18}O_{sc}$ values for all enamel serial sections relative to the $\delta^{18}O_{sc}$ values of bone.

	Mean $\delta^{18}O_{sc}$ enamel serial sections ‰ VPDB	$\delta^{18}O_{sc}$ Bone ‰ VSMOW	Difference ‰
Bruce Boyd 11	22.64±1.72	21.6	1.05
Cleveland 16	22.44±1.66	21.7	0.75
Cleveland 17	23.91±1.37	20.7	3.26
Cleveland 19	22.95±1.91	22.0	0.99
IWP(01)–36	21.92±1.44	21.07	0.85
IWP(09)–54	22.01±1.37	19.96	2.05
Modern Deer 3	22.87±1.44	21.98	0.89
Modern Deer 7	22.91±1.96	23.93	–1.02
Montoya 8	23.16±1.19	21.90	1.26
Van 20	22.72±1.31	21.7	1.04

The use of teeth as proxies of geographic location requires careful consideration because of trends related to breastfeeding/weaning, and seasonal changes in temperature and diet. Since bulk bone may be altered by processing, as discussed above with regard to $\delta^{18}O_{sc}$ values, consideration of the teeth as a geographic indicator is important. Hence, mean $\delta^{18}O_{sc}$ enamel values were compared to the interpolated $\delta^{18}O$ values of precipitation. Overall, there is a positive correlation between tooth $\delta^{18}O_{sc}$ value and the predicted $\delta^{18}O_{precipitation}$ value. The only significant correlation between enamel $\delta^{18}O_{sc}$ values and interpolated $\delta^{18}O_{precipitation}$ values is found for the first molar (Spearman's, ρ=0.511, p=0.0131) (Figure 4.22). However, because this analysis is based on only ten deer from sites with less than 1‰ variation in predicted $\delta^{18}O_{sc}$ values the validity of the statistically significant relationship is questionable. To better test whether teeth could be used as means to reconstruct the geographic re-location of deer, a larger sample from a significantly wider geographic sampling range (i.e., an interpolated $\delta^{18}O_{precipitation}$ range of several per mil) should be used to test the usefulness of deer to reflect geographic relocations. For example, based on the Kriging model used in this paper (Figure 1.2), if deer mandibles were collected from Chicago to Ottawa, there would be an approximately 6‰ range in $\delta^{18}O_{precipitation}$ values. This would provide excellent $\delta^{18}O_{precipitation}$ variation to test whether or not teeth accurately capture geographic variation and whether certain teeth (i.e., the first molar) better capture *in vivo* geographic location of the deer.

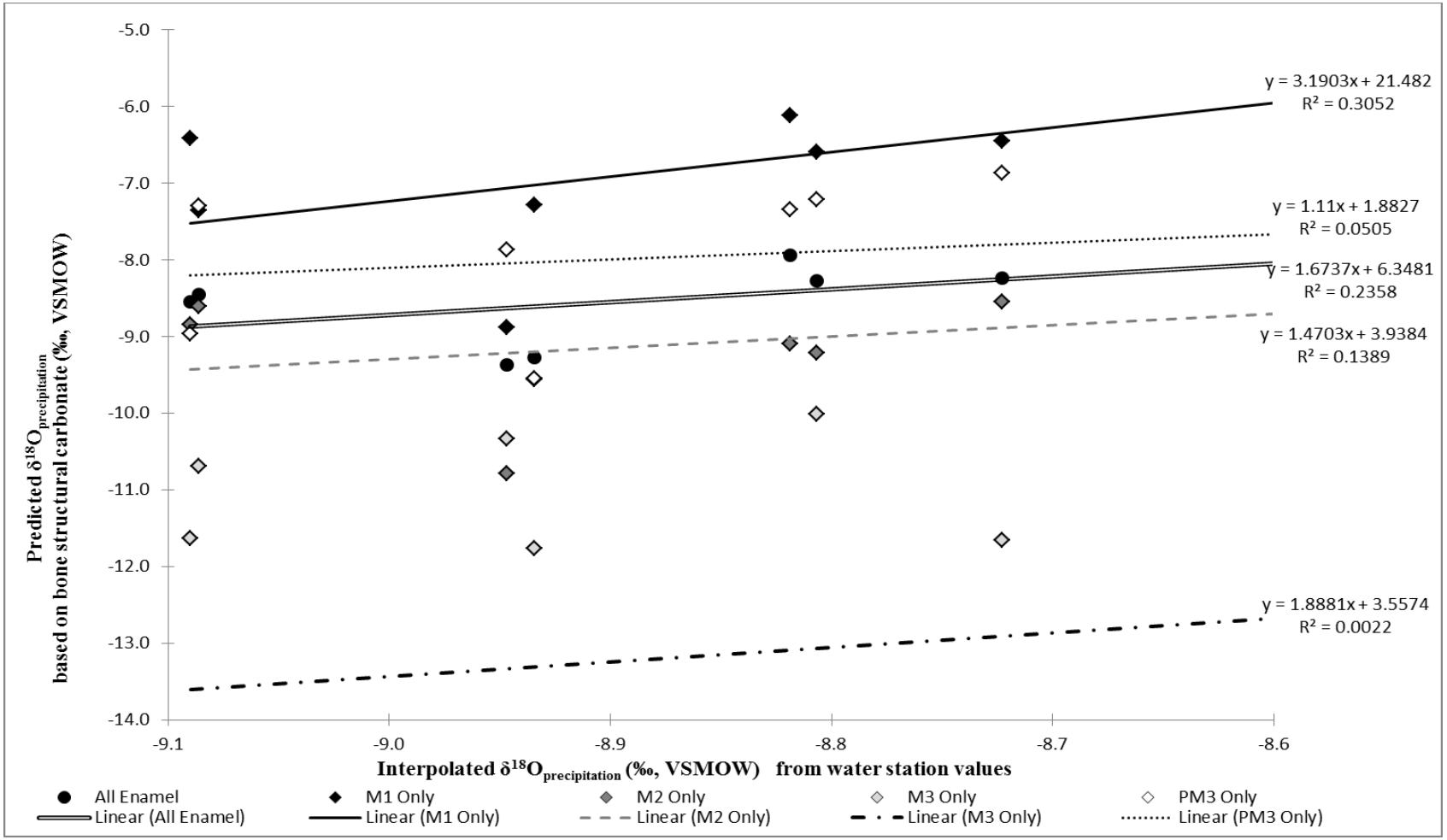

Figure 4.22: Predicted precipitation $\delta^{18}O$ values for modern and archaeological deer $\delta^{18}O_{sc}$ enamel values (averaged by tooth), calculated using Bryant et al. (1996) and Luz et al. (1990), compared to the interpolated $\delta^{18}O$ values for local precipitation from the previously described Kriging model (IAEA/WMO 2013; Longstaffe *unpublished data*, Figure 1.2).

4.6 Conclusion

By calibrating radiographic information on deer tooth mineralization with the enamel $\delta^{18}O_{sc}$ values it was possible to determine the season of formation for each tooth, and therefore access dietary information at a more detailed level. For example, the serial section data for both modern and archaeological deer provided evidence for a shift from breast-feeding to a plant-based diet within two months of birth.

Collagen and structural carbonate carbon isotopic data suggest that modern deer in southwestern Ontario consumed maize but in spite of the fact that they were living and eating in a region of almost unlimited access to maize, their bulk bone $\delta^{13}C_{col}$ values suggest relatively low quantities of C_4 consumption (~15%). The two modern deer whose teeth were serially sectioned began eating maize during cooler months and reduced their maize consumption in the spring, contrary to expectations that they would be consuming maize during the spring and summer. It is hypothesized that the decreased metabolic activity of deer during colder months inhibits the winter consumption of maize from being reflected in bone. Additionally, predation of maize leaves, which have lower mean $\delta^{13}C$ values, may not alter bone chemistry to the same degree as consumption of grain. The carbon isotopic composition of bulk bone collagen from white-tailed deer cannot be used as proxy for landscape change in Ontario as it does not appear to be sensitive enough to detect small dietary changes, such as the occasional inclusion of maize leaves.

The $\delta^{13}C_{col}$ and $\delta^{15}N_{col}$ data confirm that archaeological deer from southwestern Ontario sites spanning 3000 years (Archaic through to the Late Woodland contact periods) were consistently consuming plant material from a C_3 only environment, and that they were not supplementing their diet by browsing in maize fields. This conclusion is supported by the serial sampling of teeth from an additional eight archaeological deer that provided detailed foraging history for the first year of life. Not only were deer not consuming maize but, according to previous work, their low $\delta^{13}C_{col}$ values may be indicate a temperate “canopy” effect (Cormie and Schwarcz 1994; Bonafini et al. 2013), i.e., they were browsing in forested areas away from open fields, perhaps to avoid human predation. The hypothesis that deer were being hunted at a distance from the villages

because of human population growth was unsupported by the $\delta^{18}O_{sc}$ values and requires further investigation. The expected patterning was obscured by low variability in the oxygen isotopic composition of precipitation across southwestern Ontario, the fact that deer receive much of their water from plant leaves, which is enriched in ^{18}O due to transpiration, and relatively small sample size. Although the $\delta^{18}O_{sc}$ values of archaeological deer were correlated with the $\delta^{18}O_{precipitation}$ values, these data are interpreted as evidence of post-mortem exchange with local waters from either boiling of the bones in local waters or post-burial alteration.

Although maize consumption is suggested by the bulk bone $\delta^{13}C_{sc}$ values of the archaeological deer, the contradiction between $\delta^{13}C_{col}$ and $\delta^{13}C_{sc}$ data, the predisposition of structural carbonate to post-mortem isotopic alteration, and the unusually high $\Delta^{13}C_{sc–col}$ values, have led to the conclusion that, despite apparently normal FTIR values, the $\delta^{13}C_{sc}$ values of bone are unreliable because of post-mortem alteration of the structural carbonate. Boiling is hypothesized to explain: (1) large $\Delta^{13}C_{sc–col}$ values, (2), the correlation between high $\delta^{13}C_{sc}$ values and lower collagen yield, and (3) "normal" FTIR results. Boiling in river water or the production of *sagamite* may have caused replacement of the original structural carbonate in the bioapatite structure by new structural carbonate. The purposeful selection of mandibles and foot bones to ensure identification of the white-tailed deer may have inadvertently resulted in biased results, as these specific elements may have been treated differently because they have low meat yield. There are several practical reasons for boiling deer remains, which may include extraction of grease or marrow (particularly for low meat yield elements), facilitation of sinew removal, and extraction of marrow and brains for tanning of hides. There may also have been ideological reasons, such as the use of deer in specific ritual or feasting events, wherein presentation of a de-fleshed skull was central. Future work will be needed to test the boiling hypothesis by ascertaining the degree to which carbon and oxygen isotopic exchange takes place between bone structural carbonate and water during the boiling process. Testing this hypothesis may provide a new avenue for using isotopic investigations to understand the relationship between humans and animals; before death (i.e., what foods the animal ate in life), at death (i.e., season of hunting), and after death (i.e., why deer were processed differently than all other animals analysed in this study).

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Chapter 5

5 Conclusion

This thesis investigated the human-altered landscapes, hunting patterns, dietary preferences, and post-mortem animal processing methods of Late Woodland Ontario Iroquoian and Western Basin peoples using isotopic analysis of organic and mineral phases of various animal tissues. Carbon-, nitrogen- and oxygen-isotope analyses of modern and archaeological animal tissue were used to reconstruct dietary patterns and *in vivo* geographic location histories of animals recovered from archaeological sites. Long term (from bone) and short term (from serial sections of enamel) diets were compared to reconstruct seasonal access to maize and maize products. The main conclusions of the research are summarized in the following sections along with the contributions of this research to isotopic zooarchaeology and Great Lakes archaeology. Finally, future research directions are considered.

5.1 Research summary

This research examined how isotopic analyses of faunal remains can be used interpretatively with other lines of evidence, such as burial context, state of the remains, ethnohistory, mythology and zooarchaeology, to understand human-animal relationships. Particular interest was taken in human-animal ecologies related to subsistence behaviours, landscape use and change, and how the cultural meaning of dogs, deer and turkeys affected their treatment in life, at death, and even in the post-mortem processing of their remains.

A detailed examination of the role of domestic dogs from both Ontario Iroquoian and Western Basin sites revealed dietary parallels between humans and their canine companions, confirming the validity of using dogs from Ontario as proxies for human diets for both groups. Consequently, this research has significantly expanded our knowledge of human paleodiets at many sites without doing destructive analyses on human remains. Dogs from both Western Basin and Ontario Iroquoian sites clearly demonstrate the introduction and expansion of maize-dependent horticulturalism. Differences in protein source between the two traditions were also observed. Western

Basin dogs were eating at a higher trophic level than Ontario Iroquoian dogs, most likely because they were eating more freshwater fish. This difference in subsistence choices between the two cultural traditions may be related to geographic variation in resource exploitation and further evidence suggests that Western Basin peoples relocated to riverine and lacustrine resources during the year (Foreman 2011; Murphy and Ferris 1990).

Analyses of the Late Woodland Ontario Iroquoian dogs (A.D. 950 to 1650) provided nuanced differences by geographic region. Dogs from centrally located sites in the Grand River displayed an unexpected pattern, i.e., they consumed more maize during the Middle Ontario time period than during the later Neutral period. Several hypothesis were put forth to explain this shift, including; a peak in ceremonialism that involved more dog sacrifices during the Middle Ontario Iroquoian period, a shift in the types of freshwater fish consumed by humans (and therefore accessible to dogs), and individual variation in the treatment of dogs, possibly due to a general shift in the economic and spiritual role of Iroquoian dogs as population size and sedentism increased.

Western Basin sites consistently lack wild canids (i.e., foxes and wolves). The variation between the two neighbouring traditions in species presence in faunal assemblages and species access to maize suggests different hunting strategies. Isotopic analyses of the faunal tissue, paired with burial context and previous zooarchaeological research, has provided information on the hunting season (i.e., cold weather) and location of death (i.e., near or in maize fields). Analyses of raccoons, squirrels, wild turkeys, and foxes from Ontario Iroquoian sites consistently suggested that these animals were able to access maize and/or maize products from fields/middens from the Middle Ontario Iroquoian stage onward. Western Basin raccoons from faunal assemblages may have had access to maize, but the wild turkeys from Western Basin sites were clearly not accessing maize, and therefore were likely feeding in denser forested areas away from open fields. Seasonal dietary analyses inferred from age-at-death further indicate that Western Basin turkey hunting took place in cold weather away from summer maize fields. These data support the current understanding that Western Basin people used a different seasonal

subsistence strategy than the Ontario Iroquoian people despite the parallel expansion of maize dependency in both groups.

The data indicating maize consumption by wild turkeys at Ontario Iroquoian sites (despite the fact turkeys are not known crop pests [Greene et al 2010; Groepper et al 2013; Tefft et al 2005) is unexpected, and interpreted as evidence of purposeful food provisioning to create a winter hunting ground during colder months. This practice is not recognized elsewhere in Woodland archaeology, and may be evidence of a stage in the spectrum of human-animal relationships that could have led to domestication. A result of the relationship between humans and turkeys seems to be the opportunistic hunting of other predatory species, such as foxes, in the same fields.

The lack of maize consumption by large canids (i.e., wolves), white-tailed deer, and Western Basin turkeys was also informative. The diets of these animals were strictly based on C_3 foods, so they may have been exploiting a deep forest environment (Cerling and Harris 1999; Bonafini et al. 2013; Druker and Bocherons 2009). In the case of wolves, this pattern is not unexpected (Pimlott et al. 1967), but for deer and turkeys, who are known field edge browsers (Hecklau et al. 1982; Loken et al.1992), these findings were surprising and may suggest human hunting strategies that altered the behavior of the animals.

The white-tailed deer data are very intriguing, as deer recovered from both groups are not consuming maize despite the fact modern deer in Ontario are known crop pests (Hesselton and Hesselton 1982; Hewitt 2011). In fact, the $\delta^{13}C_{col}$ values of many of the deer from both Western Basin and Ontario Iroquoian sites suggest a canopy-effect, i.e., consumption of forest foods. As human populations increased in size and density, there would have been more demand for meat and skins, driving deer further from human settlements (Gramly 1977, Katzenberg 1989, Ketchum et al. 2009; Prevec and Noble 1983; Stewart 2000; Turner and Stantley 1979).

The $\delta^{18}O$ values of bones were used to determine whether it was possible to build a geographic profile of the animals' movement in life. These values were compared to expected $\delta^{18}O$ values of local precipitation for Ontario Iroquoian and Western Basin sites

using modern water station data from across the region (IAEA/WMO 2013; Longstaffe *unpublished data*). The low variability of δ^{18}O values of local precipitation in this region unfortunately inhibited the usefulness of this measure, and the variability of water sources (i.e., streams, plant waters, evaporated puddles etc.) likely used by the animals further confounded interpretation. Oxygen isotope analysis was, however, useful for the wild canids whose δ^{18}O values definitively correlated with those of local waters, and deer, whose teeth sampled in serial sections provided an excellent record of seasonal fluctuations in δ^{18}O values.

5.2 Contributions to zooarchaeology

This work has expanded isotopic zooarchaeology methodologically, and in ways that can also be used by ecology researchers in Biology or Environmental Science. Previous isotopic zooarchaeology focused on the reconstruction of local food webs used in the interpretation of human diets. The current research has shifted the focus to the use of animal diets and behaviour as in an indirect means to reconstruct human diet and behaviour, expanding the interpretive models available without the destructive analysis of human remains.

First, the enamel formation sequence of white-tailed deer has been clearly established and linked to monthly seasonal events. This information may be used for future studies examining both archaeological and modern deer to understand patterns of weaning and food access for the first eighteen months of life. Preliminary data for the tooth formation sequence of domestic dogs are also provided, and appear to capture the pre- and post-weaning period. Pairing this data with δ^{18}O values may provide insight into seasonal diets of dogs (i.e., differences and similarities in the cold versus warm weather diet of dogs), which can be used to further expand studies of human diet and behavior.

The use of modern animals known to exploit maize fields, notably white-tailed deer, wild turkeys and insects (grasshoppers and crickets) has enabled a better understanding of the effect of maize availability on the isotopic composition of faunal tissues. For example, wild turkeys will readily exploit maize when it is removed from standing stalks and left for them. By contrast, the bones of white-tailed deer, well known crop pests, are not as

heavily influenced by maize consumption as other species (e.g., turkeys), possibly due to short term consumption or lowered winter metabolism. Nonetheless, deer teeth can provide detailed seasonal maize consumption patterns for the first year and a half of life. Clearly the co-analysis of various tissues representing different time frames provides a more complete picture of an animal's dietary profile. Finally, this research expands the database for insects, which are often consumed by many animals, particularly small species. Grasshoppers and crickets do not appear to eat maize in the spring or early summer, despite their presence in maize fields throughout the year.

Oxygen isotope analyses of incrementally growing tissues (e.g., tooth enamel) have illustrated the presence of seasonal variation, but reconstructing the locational history of deer, canids and wild turkey from bone $\delta^{18}O$ values representing long term environmental experiences is more complicated. Because no statistical relationship could be established between $\delta^{18}O$ values of tissue and those expected for local precipitation, for either modern deer or turkey from known hunting locales, it can be inferred that this measure is of very limited use in this region. Oxygen isotope compositions of water vary by season (precipitation) plant type/part and water source (puddle, lake, river, etc.) all of which obscure the ability to successfully use $\delta^{18}O$ values as geographic markers for most species in this study. Finally, although many studies of animals have included the analyses of both the organic and inorganic phases of bone, there are few such studies for either modern or ancient birds. The strong relationship between collagen and structural carbonate δ-values for both modern and archaeological turkeys suggests that the two phases of bird bone behave similarly, which provides an additional avenue of research for future bird studies.

5.3 Contributions to Ontario archaeology

The research has expanded southwestern Ontario food webs geographically and temporally. Pre-horticultural and modern animals have been used to anchor our understanding of how maize horticulture changed landscapes, and the effects those changes had on both human and animal behaviour. This research has also demonstrated that faunal remains may be used to not only reconstruct dietary profiles of animals but to also provide information about ancient human behavioural patterns. Domestic dogs from

both Western Basin and Ontario Iroquoian sites have been successfully used to expand our understanding of the transition to maize dependency during the Late Woodland, and support interpretations recently made from isotopic work on Western Basin humans (Dewar et al. 2010; Spence et al. 2014; Watts et al. 2011). Further, differences in dog diets support archaeological data indicating that Western Basin peoples were exploiting fish to a greater degree than their Ontario Iroquoian neighbours, using their landscapes very differently despite the fact that both groups consumed similar amounts of maize.

The analysis of one the most ancient dogs in Ontario, dating to 3500BP from the Davidson site, provided invaluable data on the relationship between Archaic humans and dogs. The results suggest the dog was domesticated, as it was provisioned with high trophic level food (i.e., fresh water fish) during life, and may have been consumed (i.e., boiled) in death.

Wild species, particularly wild turkey and foxes have expanded our understanding of the similarities and differences in subsistence practices by Ontario Iroquoian and Western Basin people. For example, wild turkey data support the hypothesis that Western Basin peoples continued to use a more mobile settlement pattern, wherein they followed seasonally available resources and geographically separated cold weather hunting activities and maize cultivation. On the other hand, some Ontario Iroquoian peoples appear to have capitalized on hunting in maize fields by purposefully leaving maize in fields, thereby creating food assurance for certain species (i.e., wild turkeys) and a cold weather hunting ground.

The completely C_3 food diets of white-tailed deer from both Ontario Iroquoian and Western Basin sites reflect a behavioral shift by deer who appear to have moved further away from cleared and open-lands to escape hunting pressures created by the effect of population increase on demand for deer skins and meat.

It is hypothesized that extensive boiling of animal bone, particularly deer, as a method of Post-mortem processing caused abnormally high $\delta^{13}C_{sc}$ values and, therefore, unexpectedly large $\Delta^{13}C_{sc\text{-}col}$ values. Although commonly used tests for post-mortem alteration, such as the CI index, did not indicate alteration of structural carbonate values,

deer bone structural carbonate could not be used for reconstructing diet with validity. The prevalence of altered structural carbonate values indicates that extensive boiling, whether done for accessing grease and marrow or using brains for tanning, was a significant means of post-mortem processing for both Ontario Iroquoian and Western Basin peoples. This finding provides a new and meaningful use for altered data.

5.4 Future research considerations

Future research will continue to expand the data set by focusing on the selection of a wider temporal and geographic sample of fauna in order to fill gaps, particularly from the Middle to Late Woodland transition at Ontario Iroquoian sites, as well as the entire Western Basin temporal span in Ontario. Western Basin dog, wild canid and wild turkey data, as well as squirrel and raccoon data, are needed to more fully understand Western Basin landscape changes and subsistence strategies.

Sampling of multiple tissues (e.g. enamel, dentine and bone) needs to be a component of future faunal analyses as a means to better understand long- and short-term dietary choices, seasonal patterns, geographic movement in life, and potential Post-mortem alteration of the bone. An additional tissue, cementum, which is an annually forming dental layer (Meaers 2005; Stallibrass 1982), should be included in mammalian studies as means to provide temporal profiles across the life span of the animal, not just the first few months of life (i.e., enamel and dentine).

Finally, further work is currently being pursued to investigate the usefulness of altered structural carbonate data to reconstruct *in vivo* human behaviour, i.e. methods of post-mortem processing of animal remains and its cultural meaning.

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6 Appendices

Appendix A: Summary of Ontario sites with faunal material isotopically analyzed for this study.

PRE-MAIZE SITES:

Bruce Boyd (AdHc-4) is a burial site is located in Norfolk County, Ontario excavated in 1976 by Spence, Williamson and Dawkin. The site is composed of several Early Woodland (700 to 900B.C.) burials located on a knoll, including that of an incomplete adult male (Feature 1) associated with the remains of animals (including wild turkey). There is no evidence of habitation structures, and Spence et al. (1978) speculate it may have been used repeatedly over several seasons to inter individuals in the spring/summer. In this thesis, Bruce Boyd samples are designated BrB. Samples were obtained with permission from the Museum of Ontario Archaeology and included faunal material from Feature 1 (two wild turkeys) as well as deer and a large canid (no feature information).

References: Spence, M.W., Williamson, R.F., Dawkins, J.H., 1978. The Bruce Boyd Site: An early Woodland component in southwestern Ontario. Ontario Archaeology, 29,33–46.

Cranberry Creek (AfGv-62), a Middle Woodland site in Hadlimand-Norfolk county, was excavated by Stothers and Lennox in 1974. The site is estimated to be multi-component with two occupation dates of 200 to 300 B.C. and A.D. 700 to 900. Because Cranberry Creek was occupied during both the Middle and Late Woodland, only a limited number of samples were selected for analysis from site, including a deer, canid (probable dog), and woodchuck. Samples analysed from Cranberry Creek are designated as CrC in this thesis. Samples were obtained with permission from the Anthropology Department at McMaster University.

Reference: Lennox, P.A. (n.d) The Cranberry Creek Site: An Early Middle and Late Woodland Component in Haldimand Country.

Davidson (AjGw-4) is an unusually large Archaic site situated on the Ausable River near Grand Bend and is currently being excavated by Dr. Chris Ellis. Excavations began at the site by Kenyon in the late 1970s. The site is complex, multicomponent site occupied during the Archaic through Middle and Late Woodland. Investigations at the site have included test pitting, surface survey, and excavation but also gradiometer/magnetometer survey. Site features include houses and large pits. An Archaic Broadpoint component (radiocarbon dated to ca. 2400 to 2030 B.C.) included the remains of a dog and deer. A dog and three deer were analyzed for this study, courtesy of Dr. Chris Ellis. Davidson samples are designated Dav.

References: Ellis, C., 2006. A Preliminary Report on the 2006 Test Excavations at the Davidson Site: An Archaic "Broad Point" Component. Kewa 06(7), 1-16.

Kenyon, I.T., 1980. The George Davidson Site: An Archaic 'Broad Point' Component in Southwestern Ontario. Archaeology of Eastern North America 8, 11-28.

ONTARIO IROQUOIAN TRANSITIONAL AND LATE WOODLAND SITES:

Bogle II (AiHa-11) is a Neutral hamlet located in the Hamilton-Wentworth region, part of the Bronte Creek site cluster (along with Hood, Christianson, Bogle I and Hamilton). The site was excavated in 1979 by Paul Lennox and is estimated to be relatively small, at approximately 50 x 50 m with a faunal assemblage of 1468. Bogle II dates to A.D. 1638 to 1651, roughly contemporaneous with the larger Hamilton village site. Lennox suggested that Bogle I and II represent hamlets (or satellite villages) based on their small size, though it is believed to been occupied year round based on the faunal data and the presence of at least four houses. Because there were an unusually high number of invertebrates (shell) at Bogle II, the site is hypothesized Bogle II was used by Hamilton site inhabitants for the collection and processing of shell for pottery production.

Designated as Bog for this thesis, samples analyzed include black bear, beaver, raccoon, deer and dog. Samples were obtained with permission from the Anthropology Department at McMaster University.

Reference: Lennox, P.A., 1984. The Bogle I and Bogle II Sites: Historic Neutral Hamlets of the Northern Tier. National Museum of Man Mercury Series Paper 121. Canadian Museum of Civilization.

Stewart, F. L., 2000. Variability in Neutral Iroquoian Subsistence, AD 1540–1651. Ontario Archaeology, 69, 92–117.

Cleveland (AhHb-7) is located in Brant County, Ontario along a Grand River tributary and is a pre-contact Neutral village excavated by Noble in 1971. Cleveland was excavated by Noble in the early 1970s and is dated to A.D. 1540. A set of three near complete dog burials were found at Cleveland, including the skeleton of a diseased dog, investigated by Rhonda Bathurst and found to have tuberculosis.

Designated Clv in this thesis and include several deer and a wild turkey. The Cleveland dog was analyzed by Laura Booth. Samples were obtained with permission from the Anthropology Department at McMaster University.

Reference: Bathurst, R. R., Barta, J. L., 2004. Molecular evidence of tuberculosis induced hypertrophic osteopathy in a 16th-century Iroquoian dog. Journal of Archaeological Science, 31(7), 917-925.

Prevec, R., Noble, W. C., 1983. Historic Neutral Iroquois faunal utilization. Ontario Archaeology, 39, 41–56.

Stewart, F. L., 2000. Variability in Neutral Iroquoian Subsistence, AD 1540–1651. Ontario Archaeology, 69, 92–117.

Crawford Lake (AiGx-6) village site is located on Crawford Lake on the Niagara Escarpment, West of Toronto, Ontario. The site was dated to the Middle Ontario Iroquoian stage (A.D. 1435 to 1459) using stratified pollen layers in the lake sediment .

The site was excavated by Finlayson and Byrne starting in 1973, and six long houses were discovered. The use of flotation screening was used and provided evidence of not only maize cultivation (as was expected based on the pollen data) but also bean cultivation.

Crawford Lake samples are designated Crf and include a number of turkey, deer, dog and raccoon. Samples were obtained with permission from the Museum of Ontario Archaeology.

References: Finlayson, W. D., Bryne, R., 1975. Investigations of Iroquoian settlement and subsistence patterns at Crawford Lake, Ontario-a preliminary report. Ontario Archaeology, 25, 31-36.

Fonger (AhHb-8) is a Neutral village site excavated by Gary Warrick in 1978 and 1979 near Brantford, Ontario. Fonger is a smaller village (0.8 ha) dating to A.D. 1580 to 1620. A large number of invertebrates (shell) at the site is believed to be related to pottery production (Holterman2007). The site is composed of six middens and eighteen longhouses, encircled by palisades. The Fonger site yielded 1621 faunal remains.

Fonger samples are designated as Fon and include black bear, dog, squirrel, deer and wild turkey. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Holterman, C., 2007. So Many Decisions! The Fonger Site: A Case Study of Neutral Iroquoian Ceramic Technology. [Unpublished M.A. thesis]. McMaster University, Hamilton, ON.

Prevec, R., Noble, W. C., 1983. Historic Neutral Iroquois faunal utilization. Ontario Archaeology, 39, 41–56.

Warrick, G., 1984. The Fonger Site: A Protohistoric Neutral community, Monograph, Ontario Heritage Foundation, Toronto.

Hamilton (AiHa-5) site is a large Neutral (A.d. 1638 to 1651) village located In West Flamborough township, Ontario. The site was first investigated by Noble in 1970 and further excavated by Lennox in 1972. The 3 ha site is surrounded by a double palisade and includes at least 8 middens (most at the periphery of the village, though midden B was within the village itself) and 5 houses. Lennox argues that, based on its size and location, Hamilton may represent a “capital” for the site clusters of the region. The site yielded 20481 faunal samples, with emphasis on wild turkeys (and de-emphases on passenger pigeons) including a number of juveniles hunted in the fall.

Hamilton samples are identified in this thesis as Ham and include bear, dog, deer and wild turkey. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Lennox, P., 1977. The Hamilton Site: A Late historic Neutral Town. [Unpublished Ph.D. Thesis] McMaster University, Hamilton, ON.

Lightfoot (AjGw-5), located in Mississauga Ontario, is an Early Ontario Iroquoian site excavated by Mayer, Poulton and Associates Inc. in 1988 and 1989. The Lightfoot camp is composed of 5 long houses and several middens and yielded 402 faunal remains.

Bear and woodchuck were analyzed from the Lightfoot site, designated as Lig samples in this thesis. Samples were obtained with permission from D.R. Poulton & Associates Inc.

References: Prevec, R. 1989. The Lightfoot Site AjGw-5: Faunal Report submitted to Mayer, Poulton and Associates Inc., Burlington, Ontario.

Pipeline (AiGx-12) site is a late Middle Ontario Iroquoian village (or early pre-contact Neutral) dating to A.D. 1400 and estimated to be over 2 ha. The site was first excavated in 1975 and 1977 and again in 2006 by D.R. Poulton & Associates Inc. Pipeline includes at least six long houses, though no evidence of a palisade. Over 19,000 faunal samples were recovered in the excavations

Pipeline samples are labelled as Pip and include a number of dog and deer as well as fox, rabbit, raccoon, and wild turkey. Samples were obtained with permission from D.R. Poulton & Associates Inc. and the Museum of Ontario Archaeology.

References: Dodd, C.F., Poulton, D.R., Lennox, P.A., Smith, D.G., Warrick, G.A., 1990. The middle Ontario Iroquoian stage. In: Ellis, C.J., Ferris, N., (Eds.), The archaeology of southern Ontario to A.D. 1650. Occasional Publications of the London Chapter, OAS Number 5, pp. 321–360.

Neill, C.G., 2008. The Faunal Specimens from Pipeline Site (AiGx-12). Report on file with D.R. Poulton & Associates Inc.

Porteous (AgHb-1) is a village (43 x 160 m) near Brantford, Ontario dating to the Princess Point/Transitional Woodland (A.D. 700 to 900). The site was first excavated in 1969 by Noble. The site has two longhouses (and probable third) and 17 distinct pit features. The longhouses are noted by Noble and Kenyon to be unusually "refined" for the date of the site. There is no evidence of palisades and shallow middens. 2753 faunal remains were recovered from Porteous.

A small canid and deer were isotopically analyzed from Porteous, designated Por in this thesis. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Crawford, G. W., Smith, D. G., 1996. Migration in prehistory: Princess Point and the Northern Iroquoian case. American Antiquity, 782-790.

Noble, W.C., Kenyon, I.T., 1972. Porteous (AgHb-1): A Probable Early Glen Meyer Village in Brant County, Ontario. Ontario Archaeology, 19, 11-38.

The **Princess Point (AhGx-1)** site (near Hamilton, Ontario) is part of the Princess Point complex (n = ~80 sites) of sites originally identified by Stothers as Transitional period

between the Middle and Late Woodland dating to A.D. 500 to 900/1000 (extended by Smith and Crawford). The Princess Point site is believed to be a larger site within the complex, located in a wetland area. The site has evidence of maize, but does have a later Early Ontario Iroquoian component that could be intrusive. There is some debate as to whether site was occupied year-round or seasonally in warmer months as a macro-band site.

A black bear, wild turkey and several deer were analyzed from the Princess Point site, identified as Pri. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Crawford, G. W., Smith, D. G., 1996. Migration in prehistory: Princess Point and the Northern Iroquoian case. American Antiquity, 782-790.

Smith, D.G., Crawford, G., 1997. Recent Developments in the Archaeology of the Princess Point complex in Southern Ontario, Canadian Journal of Archaeology 21(1): 9–32.

Stothers, P. M., 1977. The Princess Point Complex. Musée National de l'Homme. Collection Mercure. Commission Archéologique du Canada. Publications d'Archéologie. Dossier Ottawa, (58), 1-403.

Old Lilac Garden (AhGx-6) is a small Princess Point site located on a peninsula, elevated from the water. The site was excavated in1984. There is some debate as to whether site was occupied year-round or seasonally in warmer months as a macro-band site.

Deer, rabbit, and a dog were analyzed isotopically and are designated as OLG. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Smith, D.G., Crawford, G., 1997. Recent Developments in the Archaeology of the Princess Point complex in Southern Ontario, Canadian Journal of Archaeology 21(1), 9–32.

Rife (AiGx-7) is a Middle Ontario Iroquoian, 1.4 ha village site occupied between A.D. 1474 and 1504. The original small village site, excavated first in the 1980s and later again by Finlayson in 1998, was expanded twice to form a much larger village. Finlayson undertook careful excavations (i.e., half meter vs. 1 meter squares), particularly of House 2, an undisturbed longhouse, producing *in situ* took kits.

Canids, deer and turkey were analyzed from Rife, designated Rif. Samples were obtained with permission from the Museum of Ontario Archaeology.

References: Dodd, C.F., Poulton, D.R., Lennox, P.A., Smith, D.G., Warrick, G.A., 1990. The middle Ontario Iroquoian stage. In: Ellis, C.J., Ferris, N., (Eds.), The archaeology of southern Ontario to A.D. 1650. Occasional Publications of the London Chapter, OAS Number 5, pp. 321–360.

Finlayson, W. D., 2004. Archaeological Research in the Crawford Lake Area 1997-2003. Report for the Niagara Escarpment Commission. Leading Edge, March 3-5.

Slack-Caswell (AfHa-1) is a multicomponent site, intensively used as hamlet site dated to A.D. 1300 to 1380 (Middle Ontario Iroquoian stage). The site located in Townsend Township, Ontario was excavated over two seasons. The hamlet is composed of a very large longhouse (90m), four middens, and possible additional structure. No palisade was identified. Eight-four faunal elements were identified from the site.

Slack-Caswell samples, designated Sla, included a duck, squirrel, canid, turtle and deer. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Dodd, C.F., Poulton, D.R., Lennox, P.A., Smith, D.G., Warrick, G.A., 1990. The middle Ontario Iroquoian stage. In: Ellis, C.J., Ferris, N., (Eds.), The archaeology of southern Ontario to A.D. 1650. Occasional Publications of the London Chapter, OAS Number 5, pp. 321–360.

Jamieson, S.M., 1986. Late Middleport Catchment Areas and the Slack-Caswell example. Ontario Archaeology, 45, 27-38.

Thorold (AgGt-1) is a large, Historic Neutral (A.D. 1615-1630) town located in the Niagara Peninsula. The site was excavated by Noble in 1979 and estimated to be 4 ha, composed of at least five longhouses and several middens, enclosed within palisades. Noble suggest the site may have served as a regional capitol.

The site faunal assemblage is notable in its relatively low numbers of deer. Samples analyzed from Thorold, abbreviated to Tho, include deer, turkey, a woodchuck, fox and dog. Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Prevec, R., Noble, W. C., 1983. Historic Neutral Iroquois faunal utilization. Ontario Archaeology, 39, 41–56.

Stewart, F. L., 2000. Variability in Neutral Iroquoian Subsistence, AD 1540–1651. Ontario Archaeology, 69, 92–117.

Van Besien (AfHd-2) is an Early Ontario Iroquoian site dated to A.D 940 located in Oxford county, Ontario. During its occupation, Van Besien expanded twice from 0.4 to 0.6, finally, to 1.2 ha, and was palisaded during some of the time. Noble began excavations at the site 1971 continuing for another season in 1972. Despite the expansions at the site, Noble identified three long houses. Middens were excavated on the three, sloping hills of the sites sides.

The remains of 4967 fauna, indicating year-round subsistence economy, were found at the site. Bear, fox, dog, squirrel, porcupine, rabbit, raccoon, deer, wild turkey and ground hog were all isotopically anlayzed from Van Besien, designated Van in this thesis.

Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Noble, W.C., 1975 Van Besien (AfHd -2): A Study in Glen Meyer Development. Ontario Archaeology 24, 3-95.

Walker (AgHa-9) is located in Brant County and is identified as a large, 4 ha Neutral town excavated by Walker in the mid-1970s. Despite its size and date, no palisades could be identified at the Walker site.

Seven middens were excavated, along with twelve houses (including House 8 identified as a winter house). Over 10,500 faunal elements were recovered from the site. Noble interpreted the site as a regional capital. Black bear, passenger pigeon, beaver, dog, mink, squirrel, skunk, muskrat, porcupine, rabbit, raccoon, turtle, deer, wild turkey and woodchuck were all isotopically analyzed from the Walker site (Wal). Samples were obtained with permission from the Anthropology Department at McMaster University.

References: Wright, J.W. 1977. The Walker Site. [Unpublished M.A. thesis] McMaster University, Hamilton, ON.

Winking Bull (AiHa-20) is 0.8 ha Middle Ontario Iroquoian village from the Crawford Lake region dating to A.D. 1280. The site was excavated by Finlayson in the early 1980s. 1704 faunal samples were identified at Winking Bull, including a large number that had modified bone (bone beads).

Canids, raccoons, deer and wild turkey were isotopically analyzed from Winking Bull (designated Win). Samples were obtained with permission from the Museum of Ontario Archaeology.

References: Dodd, C.F., Poulton, D.R., Lennox, P.A., Smith, D.G., Warrick, G.A., 1990. The middle Ontario Iroquoian stage. In: Ellis, C.J., Ferris, N., (Eds.), The archaeology of southern Ontario to A.D. 1650. Occasional Publications of the London Chapter, OAS Number 5, pp. 321–360.

WESTERN BASIN TRANSITIONAL AND LATE WOODLAND SITES:

Dobbelaar (no borden) is a Wolf Phase site dated to A.D. 1400-1550 located near the St. Clair river. The faunal material (n=5187) was analyzed by Lindsay Foreman, who interprets the sites emphasis on muskrat procurement as a warm weather settlement. A fox and dog were analyzed from the Dobbelaar site. Samples from Dobbelaar (Dob) were accessed courtesy of the London Office of the Ministry of Tourism, Culture and Sport.

References: Foreman, L., 2011. Seasonal subsistence in Late Woodland southwestern Ontario: An examination of the relationship between resource availability, maize agriculture, and faunal procurement and processing strategies. [Unpublished Ph.D. thesis]. The University of Western Ontario, London, ON.

Figura (AgHk-52), also known as Inland Aggregate or Inland West Pit No. 1, is part of an aggregation of sites near Arkona, ON, excavated by Golder and Associates. The site was excavated in 2007 and 2008 along with **Inland Aggregate locations 3 (AgHk-54), 9 (AgHk-58) and 12 (AgHk-60)** by Golder and Associates and were sampled courtesy of Sustainable Archaeology.

The Stage 4 excavation at the Figura site (88 x 105 m) revealed 303 features (including two large middens), as well as six small house structures. Five houses and one midden are surrounded by a palisade. Over 11,200 faunal remains were recovered at the site, but at the time of the 2008 excavation a detailed faunal report was still forthcoming. The site is dated to the Yonge Phase (A.D. 800 to 1200). In this thesis Figura samples are identified as IWP(01) and include deer, wild turkey, and raccoon.

The Stage 4 excavation of Location 3 resulted in the recovery of 87 features and 3862 faunal pieces, which have not been analyzed at this time. The site is, approximately 65 x 45 m, and its features do not indicate the presence of house or palisade structures. The site is dated to the Yonge Phase (A.D. 800 to 1200). A detailed faunal report for the site has not yet been completed. Thesis samples from Location 3 are identified as IWP(03) and include the isotopic analysis of deer and wild turkey.

The Stage 4 excavation of Location 9 led to the recovery of over 23,000 faunal remains from 129 features (many were pits) with a partial palisade. The excavation is interpreted as a portion of a large, Yonge Phase village. A detailed faunal report for the site has not yet been completed. Faunal material (identified as IWP(09)) was analyzed from pits 2, 18, 21, 38, 46, 56, 59, 61, 72, 102 and 107 and includes black bear, ruffed grouse, domestic dogs, raccoon, deer and wild turkey.

The Stage 4 excavation of Location 12 identified 21 features and a partial palisade or fence. The remains of 4810 fauna were found at site, for which an assessment has been completed by Lindsay Foreman for two features (Feature 14 located within the palisade/fence and Feature 19 outside the palisade fence). The initial report suggests the site was used during the Yonge Phase from A.D. 1050 to 1150, with an emphasis on cervid hunting and heavy processing of the remains on site. Based on the faunal data, the

site has been interpreted as a cold weather site. Fauna analyzed for this study are labelled IWP(12) and include a dog and several deer.

References: Golder and Associates (2012) Stage 4 Archaeological Assessment: Inland West Pit Locations 1, 3, 6, 9 and 12. Part of Lots 28 and 29, Concession 5 N.E.R. Township of Warwick, Lambton County, Ontario. Ontario. Manuscript on file, Ontario Ministry of Tourism, Culture and Sport, Toronto, Ontario.

Foreman, L., 2011. Seasonal subsistence in Late Woodland southwestern Ontario: An examination of the relationship between resource availability, maize agriculture, and faunal procurement and processing strategies. [Unpublished Ph.D. thesis]. The University of Western Ontario, London, ON.

Spence, M.W., White, C.D., Ferris, N., Longstaffe, F.J., 2010. Treponemal Infection in a Western Basin Community. Kewa 10(3), 1-10.

Liahn I (AcHo-1), located near the St. Clair River, was excavated in 1977 by Ian Kenyon. The site is estimated to be 1.6 ha, but occupied intensively in a 0.6 ha area. The site, dated to the Springwells Phase (A.D. 1300 and 1600), includes large a long house and a large number of pit features. The emphasis on lake resource exploitation is suggested by Kenyon to indicate warm weather site use. Faunal samples analyzed in this thesis are designated as Lia and include a bowfin, muskrat, porcupine, raccoons and deer. Samples from Lianh I (designated Lia) were accessed courtesy of the London Office of the Ministry of Tourism, Culture and Sport.

References: Kenyon, I. 1988. Late Woodland Occupations at the Liahn I Site, Kent Co. Kewa. 88(2), 2-22.

Montoya (AfHi-243) is a Riviere au Vase (possibly used into the Yonge phase) site, dated to A.D. 800 to 1000. The site, located near Strathroy, ON, is believed to have been inhabited during the colder weather for cervid hunting, based on the faunal and artifact assemblages. The site was approximately 1.5 ha in size with over 6000 faunal remains recovered by Archaeologix Inc., who excavated the site in the early 2000s.

In this thesis, Montoya samples are designated Mon and include the analysis of several deer and a raccoon. Permission to sample Montoya site faunal material was granted courtesy of Golder and Associates Inc,

References: Archaeologix Inc., 2004 Archaeological Assessment (Stage 4): The Montoya Site (AfHi-243), Saxonville Estates Subdivision, Phase 2, Part of Lot 9, Concession 10, Geographic Township of Caradoc, Town of Strathroy, Middlesex County, Ontario. Manuscript on file, Ontario Ministry of Tourism and Culture, Toronto,

Foreman, L., 2011. Seasonal subsistence in Late Woodland southwestern Ontario: An examination of the relationship between resource availability, maize agriculture, and faunal procurement and processing strategies. [Unpublished Ph.D. thesis]. The University of Western Ontario, London, ON.

The Roffelsen (AcHn-33) site is a Yonge phase (A.D. 900 to 1000) burial site located near Chatham on the Thames River. The site was excavated by Archaeologix and analyzed by Adria Grant. Michael Spence analyzed the burial features (7 individuals). The site is approximately 50 by 45m and is mostly encompassed within a palisade. No house structures were identified, however a number of pit features were present within and outside the palisade. Feature 54, just outside the palisade, consisted of a dog burial, analyzed isotopically in this study. Permission to sample Roffelsen (designated Rof) site faunal material was granted courtesy of Golder and Associates Inc.

References: Spence, M., Williams, L., Wheeler, S., 2014. Death and Disability in a Younge Phase Community. American Antiquity, 79(1), 108-126.

Silverman (AbHr-5) site, located near Lake St. Clair beach, was first excavated in 1994 by Mayer Heritage Consultants, and went to Stage 4 excavation in 1995. The site covers an area of approximately 1.53 ha and is a multi-component relatively large campsite, occupied seasonal (spring through fall) between A.D. 700 and 1200. The features include a number of small houses and storage pit clusters. Silverman samples analyzed for this study are designated Sil and include a black bear, dog, raccoon, and deer. Samples from Silverman, (designated Sil) were accessed courtesy of the London Office of the Ministry of Tourism, Culture and Sport.

References: Mayer Heritage Consultants, 1996. Archaeological Mitigative Excavation (Stage 4) Silverman Site (AbHr-5), Registered Plan 12R-13025 Town of St. Clair Beach, Essex County, Ontario. Manuscript on file, Ontario Ministry of Tourism, Culture and Sport, Toronto, Ontario.

Appendix B: Bone collagen isotopic composition and sample description (archaeological)

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Beaver (*genus Castor*)							
Bog-038	mandible			–21.37	4.79	3.22	17.0
Wal-040	mandible, right			–19.48	1.40	3.25	15.3
Wal-041	mandible, right			–22.34	6.12	3.25	10.9
Black bear (*Ursus americanus*)							
Bog-033	phalanx			–20.00	5.97	3.32	7.5
Bog-043	phalanx			–20.46	4.75	3.28	9.3
Fon-067	phalanx, proximal			–20.89	4.98	3.02	17.1
Fon-072	phalanx, proximal			–22.32	5.78	3.02	23.0
Ham-024	mandible			–19.92	4.90	3.40	13.6
IWP(01)-052	metatarsal			–22.20	5.71	3.27	6.8
IWP(01)-052 DUP	Duplicate			–22.04	5.72	3.40	-
IWP(09)-058	mandible			–21.12	4.35	3.30	5.7
IWP(09)-058 mDUP	Method duplicate			–21.07	4.44	3.24	5.2
Lig-012	metapodial, left distal			–19.98	4.47	3.31	8.7
Lig-012 DUP	metapodial, left distal			–20.04	4.27	3.31	8.7
Pri-018	scaphoid, right			–20.86	4.92	3.13	8.0
Pri-018 DUP	scaphoid, right			–20.80	4.93	3.11	-
Sil-018	innominate, fragments			–21.10	6.24	3.24	9.1
Sil-020	metatarsals			–20.71	6.21	3.35	2.6
Van-039	phalanx, II			–20.15	5.62	3.23	19.9
Van-067	phalanx, II			–22.90	6.59	3.12	9.0
Van-067 DUP	Duplicate			–22.93	6.56	3.10	-
Van-071	phalanx, II			–21.45	6.19	3.27	12.3

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Black bear (*Ursus americanus*) continued							
Van-071 DUP	Duplicate			–21.47	6.19	3.27	-
Van-097	phalanx, V			–21.79	5.98	3.23	22.7
Van-114	phalanx, I	Juvenile		–21.38	4.69	3.30	5.8
Wal-045	phalanx, II			–20.23	4.76	3.22	22.5
Wal-046	phalanx, II			–21.85	5.87	3.21	23.0
Wal-047	phalanx, II			–20.48	5.89	3.18	22.2
Bird (Aves)							
Wal-033	ulna, left			–22.15	6.63	3.19	18.9
Sla-035	femur, right			–17.63	6.56	3.27	11.7
Aves cf. duck (*Anas*)							
Sla-011	phalanx			–18.25	8.22	3.37	15.4
Passenger pigeon (*Ectopistes migratorius*)							
Wal-031	ulna, left			–21.01	4.16	3.28	18.9
Ruffed grouse (*Bonasa umbellus*)							
IWP(09)-019	tibiotarsus			–20.80	3.77	3.28	14.7
Canid cf fox							
Crf-077 DUP	Duplicate			–19.62	10.40	3.32	-
Crf-077 mDUP	Method Duplicate			–19.59	10.21	3.35	5.4
Crf-077	mandible			–19.67	10.30	3.32	6.3
Pip(2)-016	left metapodial			–18.59	8.51	3.07	19.8
Tho-011	mandible, right			–17.95	7.57	3.23	7.1
Van-070	atlas			–19.53	8.90	3.28	4.1
Win-154	humerus, distal			–18.37	9.08	3.31	5.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
***Canid cf fox* continued**							
Win-229	mandible, right			–18.77	8.50	3.25	18.5
Dob-002	right humerus			–19.34	8.74	3.23	10.1
Canid cf. fox or small C. familiaris							
Pip(2)-010	right humerus, shaft			-11.46	10.17	3.28	15.6
Pip(2)-010B mDUP	Method Duplicate			-11.33	10.12	3.25	15.8
Pip(2)-103	left humerus (cutmarks)			-11.19	9.13	3.27	16.0
Por-012	right humerus, distal			-19.53	7.88	3.25	11.7
Por-012B mDUP	Method Duplicate			-19.55	7.95	3.26	11.9
Van-075	left zygomatic/partial skull			-21.22	9.45	3.25	18.3
IWP(09)-016				-13.90	11.41	3.52	-
Canis sp.							
Bog-030	phalanx			–13.91	9.73	3.26	20.5
Bog-042	tarsal			–14.78	9.98	3.24	9.1
IWP(09)-005	right femur, complete	Juvenile		–14.68	11.13	3.06	6.8
IWP(09)-005B DUP	Duplicate	Juvenile		–14.64	11.11	3.06	-
IWP(09)-034	humerus	Juvenile		–18.56	8.93	3.26	11.1
IWP(09)-034 DUP	humerus	Juvenile		–18.51	8.95	3.35	-
IWP(09)-066	mandible, right	Fetal		–11.12	12.02	3.26	LB
IWP(09)-068a	mandible, right	Fetal		–12.96	12.17	3.16	LB
IWP(09)-068b	mandible, right	Fetal		–14.69	10.97	3.29	LB
OLG-14	left distal tibia			–10.51	9.61	3.46	10.2

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
***Canis sp.* continued**							
Pip(1)-175	mandible	10-12 weeks		–19.15	9.46	3.40	15.1
Pip(2)-028	right tibia	Juvenile		–21.60	6.04	3.50	11.2
Pip(2)-049	right calcaneous			–11.15	9.29	3.40	8.5
Pip(2)-049B DUP	Duplicate			–11.19	9.06	3.39	-
Pip(2)-110~	atlas			–10.62	9.92	3.18	3.83
Pip(2)-110B DUP	Duplicate			–9.95	9.74	3.21	-
Rif-097	mandible, right, no teeth			–11.79	9.75	3.40	7.9
Sil-07	left tibia	Fetal		–17.11	13.99	3.23	LB
Wal-034	left calcaneous			–14.19	8.13	3.30	6.1
Win-182	cervical vertebrae			–10.14	9.61	3.28	18.3
Win-249	ulna	Juvenile		–10.30	8.30	3.35	16.5
Win-249B DUP	Duplicate	Juvenile		–10.28	9.03	3.33	-
Win-249B DUP	Duplicate	Juvenile		–10.19	8.86	3.34	-
Rif-020^^	left and right calcaneous			–11.62	9.72	3.40	1.9
Canis sp. cf. C. familiaris							
Bog-016	mandible			–13.65	9.40	3.31	8.2
Cra-010	right ulna, proximal			–21.81	6.38	5.12	0.6
Crf-054	axis			–11.89	9.49	3.27	21.1
Crf-054 mDUP	Method Duplicate			–11.88	9.46	3.29	21.3
Dav-005	maxilla, fragment			–20.75	10.38	2.97	1.7
Dav-005 mDUP	maxilla, fragment			–20.82	10.24	2.59	
Dob-001	mandible			–12.00	10.06		6.4

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
***Canis sp. cf. C. familiaris* continued**							
Fon-061	mandible, left			–12.78	8.35	3.80	7.3
Fon-117	mandible, right			–12.59	8.79	3.38	2.3
Fon-121	mandible, left			–14.76	8.97	3.05	19.6
Ham-026	mandible, right			–13.21	9.53	3.37	22.2
Ham-027	mandible, right			–15.14	9.33	3.39	16.9
Ham-028	mandible, right			–13.82	9.65	3.39	9.1
Ham-029	mandible, right			–15.82	9.18	3.38	17.8
IWP(01)-027	mandible, right			–14.57	9.40	3.13	5.1
IWP(01)-027B mDUP	Method Duplicate			–15.01	9.38	3.52	5.6
IWP(01)-035	mandible, right			–15.58	10.05	3.50	2.2
IWP(09)-091	mandible, left			–14.30	10.87	3.42	LB
IWP(09)-091B mDUP	mandible, left			–14.04	10.44	3.32	LB
IWP(12)-01	tibia, complete			–16.29	8.99	3.24	5.0
Pip-(1)-138	radius, left complete			–10.55	9.81	3.35	12.4
Pip-(1)-138B DUP	Duplicate			–10.51	9.79	3.36	-
Pip(1)-180+	ulna, left complete			–11.40	10.87	3.31	17.0
Pip(2)-018	atlas			–12.54	9.10	3.20	
Pip(2)-018B mDUP	atlas			–12.54	9.07	3.22	
Pip(2)-044	scapula, left			–10.93	10.32	3.33	19.2
Pip(2)-087	ulna, right proximal			–12.15	10.13	3.32	3.1
Rif-008	Femur, left			–10.46	9.22	3.30	19.0
Rif-019	mandible, left			–10.82	9.47	3.37	16.0

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
***Canis sp. cf. C. familiaris* continued**							
Rof-001	tibia			–12.87	10.14	3.21	2.6
Rof-001 mDUP	mandible			–12.27	10.48	3.25	4.1
Sla-018				–10.57	9.72	3.33	
Sla-018 DUP	Duplicate			–10.53	9.76	3.35	-
Sla-019	phalanx			–11.40	9.44	3.19	17.8
Tho-006	mandible			–12.80	8.85	3.24	9.1
Tho-010	ulna, proximal			–12.74	8.52	3.19	19.1
Tho-053	calcaneus, left			–13.12	7.87	3.40	13.2
Van-120	humerus, right complete			–13.13	9.13	3.32	5.4
Van-124	mandible, right			–13.09	9.62	3.43	8.8
Wal-032	right maxilla			–14.01	8.68	3.21	13.7
Wal-057	mandible, left			–12.94	9.40	3.41	7.1
Wal-058	mandible, left			–13.81	9.06	3.38	19.1
Wal-058B DUP	Duplicate			–13.76	9.10	3.37	-
Wal-059	mandible, left			–12.19	9.17	3.38	21.3
Wal-060	mandible, left			–13.19	8.78	3.41	7.6
Win-002	calcaneous			–13.38	11.34	3.25	16.5
Win-084	vertebrae lumbar			–11.66	9.86	3.25	19.2
Win-084B mDUP	Method Duplicate			–11.68	10.01	3.20	16.2
Win-150	radius			–10.81	10.28	3.29	19.9
Win-150B DUP	radius			–10.85	9.65	3.33	-
Win-161	cranial, fragment			–11.10	10.97	3.15	
Ham-025^^	mandible, right			–13.44	9.95	3.37	21.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Canis sp. cf. C. lupus or lg. C. familaris							
BrB-004	tibia, left distal			–21.86	8.38	3.53	6.5
Van-111	phalanx I			–22.13	8.87	3.29	10.8
Win-183	maxilla, right fragment			–20.88	5.48	3.34	6.4
Win-183B DUP	duplicate			–20.37	5.29	3.39	-
IWP(09)-067	tibia			–14.40	11.05	3.19	LB
IWP(09)-067B DUP	tibia			–14.35	11.04	3.19	-
Carnivora skunk (*Mephitidae*)							
IWP(01)-023	mandible			–20.02	9.04	3.47	2.6
Wal-030	maxilla, right			–19.48	9.17	3.25	18.2
Carnivora American mink (*Neovison vison)*							
Wal-023	mandible			–23.30	8.53	3.22	16.0
Eastern gray/black squirrel (*Sciurus carolinensis*)							
Fon-030	femur			–18.53	5.54	3.07	16.7
Fon-064	femur			–20.45	4.64	3.09	14.2
Fon-091	femur			–19.83	5.04	3.01	18.4
Fon-113	femur			–20.02	5.15	3.04	13.3
Fon-113 DUP	femur			–19.92	5.41	3.22	-
Fon-113 DUP	femur			–19.91	5.09	3.23	-
Sla-032	innominate			–19.38	4.34	3.16	19.4
Sla-032 DUP	innominate			–19.25	4.38	3.17	-
Tho-005	humerus			–19.20	5.03	3.24	8.8
Van-041	femur, right			–20.42	4.52	3.05	15.2
Van-042	tibia, right			–20.28	4.09	3.01	16.5
Van-052	humerus, right			–18.50	6.66	3.25	16.2
Van-085	mandible, left			–19.49	4.97	3.23	14.6

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Eastern gray/black squirrel (*Sciurus carolinensis*) continued							
Van-090	innominate, right			–19.76	6.39	3.22	19.8
Van-091	femur, right	Juvenile		–19.60	4.86	3.24	17.3
Van-091 DUP	Duplicate	Juvenile		–19.60	4.85	3.23	-
Wal-048	mandible			–19.32	4.54	3.22	17.2
Wal-048 DUP	Duplicate			–19.42	4.56	3.23	-
Wal-049	mandible			–19.47	3.84	3.25	19.1
Fish, Bowfins (*Amia calva*)							
Lia-003	post-orbitals			–20.14	8.46	3.19	4.5
Mammal, large							
Lig-008	long bone, fragment			–23.27	3.97	3.33	7.8
Mammal, medium							
Sla-025	radius			–25.84	1.05	3.21	13.3
Muskrat (*Ondatra zibethicus*)							
Lia-014	mandible			–20.43	4.71	3.26	11.2
Wal-025	maxilla			–23.00	7.28	3.25	12.0
Wal-052	mandible, left			–20.55	6.79	3.30	13.6
Porcupine (*Hystricomorph Hystricidae*)							
Lia-007	mandible			–19.86	4.93	3.25	2.9
Lia-007 DUP	Duplicate			–20.00	4.92	3.26	-
Van-102	maxilla			–21.41	5.60	3.12	4.4
Wal-054	mandible, right			–20.21	4.42	3.28	9.8
Rabbit or hare (Leporidae)							
OLG-015	femur, right			–19.74	4.66	3.08	12.8
Pip(2)-017	innominate, left			–19.49	4.11	3.07	19.6
Tho-019	humerus			–22.12	3.44	3.20	17.4

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Rabbit or hare (Leporidae) continued							
Tho-019 DUP	Duplicate			–22.16	3.48	3.17	-
Tho-023	femur, left			–22.08	3.46	3.20	17.9
Van-068	femur, right			–27.35	3.96	3.33	4.1
Van-118	femur, right			–23.10	4.14	3.05	8.4
Wal-024	humerus, right			–22.05	4.08	3.22	12.9
Wal-053	femur, right			–27.08	2.09	3.25	14.1
Raccoon (*Procyon lotor*)							
Bog-002	calcaneous			–20.96	8.09	3.26	13.9
Crf-039	mandible			–13.98	6.76	3.07	12.4
Crf-039 DUP	Duplicate			–13.99	6.64	3.07	-
Crf-039 DUP	Duplicate			–13.93	6.65	3.21	-
Crf-040	mandible			–15.52	7.51	3.20	12.8
Crf-040 DUP	Duplicate			–15.52	7.46	3.20	-
Fon-109	mandible, right			–20.96	8.95	3.07	13.8
IWP(01)-017	radius			–20.36	9.47	3.14	6.1
IWP(09)-001	mandible			–19.88	7.84	3.08	6.0
IWP(09)-004	ulna, left			–21.28	9.65	3.07	8.9
IWP(09)-010	ulna, right			–20.66	9.72	3.33	5.1
IWP(09)-014	mandible			–20.07	9.03	3.15	5.7
IWP(09)-018	humerus, right			–21.56	9.45	3.28	6.9
IWP(09)-040	fibula			–21.27	10.35	3.13	19.0
IWP(09)-078	maxilla			–20.13	7.68	3.03	7.9
IWP(09)-078 DUP	Duplicate			–19.98	8.38	3.21	-
IWP(09)-111	calcaneous, right			–20.82	9.13	3.15	9.2
IWP(09)-116	humerus, distal			–20.77	5.83	3.13	7.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Raccoon (*Procyon lotor*) continued							
IWP(09)-118	ulna			–20.93	8.49	3.14	7.5
IWP(09)-131	ulna, proximal			–20.48	9.64	3.09	5.4
Lia-001	radius			–23.48	9.84	3.26	3.4
Lia-012	maxilla			–21.36	4.62	3.25	2.2
Lia-013	mandible, right			–23.61	9.11	3.25	12.9
Lia-013 DUP	Duplicate			–23.72	9.09	3.25	12.9
Mon-001	ulna, proximal			–21.29	9.25	3.37	4.1
Pip(1)-151	mandible			–22.87	9.58	3.14	6.4
Sil-006	mandible, left			–20.46	9.08	3.25	2.4
Van-103	mandible, right			–20.50	9.59	3.29	9.7
Van-106	mandible, left			–20.94	8.87	3.30	5.0
Wal-042	mandible, right			–21.27	7.44	3.26	8.6
Wal-055	mandible, right			–22.25	8.30	3.20	19.3
Wal-056	ulna, shaft			–21.27	8.81	3.20	18.4
Win-218	mandible			–19.73	7.46	3.07	19.1
Win-218 DUP	Duplicate			–19.73	7.44	3.07	-
Win-233	mandible			–21.67	9.56	3.21	17.8
Sla-007	carapace			–23.18	5.04	3.21	16.1
Sla-034	carapace			–22.96	5.08	3.23	16.7
Wal-026	femur			–25.05	7.23	3.22	13.0
White-tailed deer (*Odocoileus virginianus*)							
BrB-010	mandible, right			–23.46	4.75	3.10	4.8
BrB-011	manidle, right			–23.63	4.88	3.14	3.3
BrB-012	mandible, left			–21.60	4.35	3.11	5.4

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
BrB-013	mandible, left			–23.60	4.99	3.17	2.7
Bog-054	mandible, right			–23.02	5.03	3.37	8.0
Bog-054 mDUP	Method Duplicate			–23.01	4.87	3.36	8.0
Clv-015	mandible, right			–22.05	6.12	3.34	8.1
Clv-016	mandible, right			–22.38	5.68	3.43	-
Clv-017	mandible, right			–21.19	8.16	3.44	8.3
Clv-017 DUP	Duplicate			–21.20	7.65	3.44	-
Clv-019	mandible, right			–22.65	5.13	3.40	-
Cra-001	astragulus			–23.33	4.58	3.26	16.3
Cra-001 mDUP	Method Duplicate			–23.26	4.76	3.32	15.2
Crf-002	phalanx			–23.45	4.15	3.24	9.7
Crf-095	mandible			–21.85	5.17	3.38	6.3
Crf-095 DUP	Duplicate			–21.86	5.39	3.32	6.0
Dav-001	long bone, fragment			–23.92	3.90	3.38	3.7
Dav-003	long bone, fragment			–23.16	4.27	3.43	2.6
Dav-004	fkull, fragment			–22.01	6.16	3.30	9.5
Fon-001	phalanx			–22.80	4.98	3.07	18.1
Fon-001 DUP	Duplicate			–22.79	4.97	3.06	-
Fon-001 mDUP	Method Duplicate			–22.82	5.03	3.28	17.6
Fon-001 mDUP DUP	Method Duplicate			–22.82	5.05	3.28	-
Fon-009	mandible			–22.79	6.14	3.31	15.8
Fon-009 mDUP	Method Duplicate			–22.78	6.10	3.31	14.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Fon-014	mandible			–22.19	5.81	3.04	15.7
Fon-019				–22.79	5.46	2.97	21.9
Fon-019 mDUP	Method Duplicate			–22.64	5.61	3.25	23.4
Fon-047				–22.91	5.12	3.06	16.2
Fon-047 DUP	Duplicate			–24.88	2.83	3.25	-
Ham-004	mandible			–22.02	4.98	3.36	6.1
IWP(01)-001	mandible, right			–23.34	5.29	3.36	6.1
IWP(01)-001 mDUP	Method Duplicate			–23.38	5.31	3.32	6.3
IWP(01)-009	mandible, left			–23.36	5.68	3.41	4.7
IWP(01)-025	mandible			–24.07	5.65	3.07	6.2
IWP(01)-025 DUP	Duplicate			–23.85	5.34	3.29	-
IWP(01)-036 DUP	Duplicate			–23.64	5.47	3.18	12.9
IWP(01)-036 mDUP	Method Duplicate			–23.68	4.96	3.31	16.7
IWP(03)-23	phalanx			–23.49	4.85	3.47	6.8
IWP(09)-002	mandible			–23.84	4.92	3.08	5.0
IWP(09)-047	maxilla			–22.95	4.78	3.04	6.0
IWP(09)-047 DUP	Duplicate			–23.32	4.80	3.49	-
IWP(09)-047 DUP	Duplicate			–22.79	4.91	3.36	-
IWP(09)-054	mandible			–23.31	5.07	3.33	18.7
IWP(09)-054 mDUP	Method Duplicate			–23.54	5.25	3.26	19.9
IWP(09)-134	mandible			–23.43	5.19	3.42	2.6
IWP(09)-134 mDUP	Method Duplicate			–23.40	5.13	3.37	2.9
IWP(12)-003	metatarsal			–22.54	4.70	3.28	3.2
IWP(12)-004	navicular			–22.14	5.35	3.27	5.3

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
IWP(12)-005				–22.94	5.14	3.24	4.2
Lia-006	bulla			–23.82	6.82	3.45	4.0
Lia-006 mDUP	Method Duplicate			–23.69	7.08	3.52	5.2
Lia-010	mandible			–20.72	8.62	3.24	6.0
Mon-004	innominate, right			–22.48	5.96	3.43	6.6
Mon-005	mandible			–21.79	4.40	3.46	3.3
Mon-005 DUP	Duplicate			–21.72	4.47	3.44	-
Mon-006	mandible			–22.66	4.78	3.32	2.3
Mon-006 mDUP	Method Duplicate			–22.54	5.08	3.46	1.3
Mon-007	mandible			–23.05	5.33	3.38	2.3
Mon-008	mandible			–23.10	5.41	3.38	3.9
OLG-001	mandible, right			–22.12	7.00	3.32	18.3
OLG-001 mDUP	Method Duplicate			–22.19	7.00	3.29	18.3
OLG-002	phalanx			–21.70	6.07	3.05	22.6
OLG-013	ulna, proximal left			–23.22	5.08	3.12	2.9
OLG-013 mDUP	Method Duplicate			–23.32	5.57	3.35	3.0
Pip(1)-103	mandible, left			–22.06	3.73	2.98	14.7
Pip(1)-103 mDUP	Method Duplicate			–22.03	3.79	3.26	15.5
Pip(1)-157	phalanx, II			–22.43	4.54	3.15	19.1
Por-009	phalanx II			–22.09	6.12	3.27	5.8
Por-009 DUP	Duplicate			–22.08	6.06	3.09	-
Por-009 mDUP	Method Duplicate			–22.19	6.05	3.36	-

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Por-017	carpal, left radial			–22.13	5.01	3.12	6.3
Por-017 mDUP	Method Duplicate			–21.99	5.04	3.31	6.5
Pri-008	astragulus, right			–23.05	4.95	3.16	9.6
Pri-017	vertebrae, cervical			–22.35	4.91	3.19	8.4
Pri-017 DUP	Duplicate			–20.24	5.85	3.01	-
Pri-019	tibia, distal, left			–22.54	4.41	3.16	8.1
Pri-019 DUP	Duplicate			–22.46	2.99	3.19	-
Rif-007	mandible			–21.25	8.23	3.92	4.0
Rif-007 mDUP	Method Duplicate			–21.32	8.05	3.27	3.9
Rif-077	mandible			–22.65	6.80	3.40	6.3
Sil-019				–22.65	5.54	3.34	2.4
Sil-019 DUP	Duplicate			–23.25	5.48	3.29	-
Sil-026				–23.81	6.09	3.34	4.0
Sil-026 DUP	Duplicate			–23.95	6.17	3.24	-
Sla-017	carpal			–24.18	5.82	3.06	19.3
Tho-002	humerus, distal			–22.07	5.73	3.30	4.9
Tho-012	phalanx			–22.08	5.75	3.08	12.7
Tho-012 mDUP	Method Duplicate			–22.00	5.87	3.31	13.2
Tho-018	ulna, proximal			–22.07	5.69	3.30	10.2
Van-001	astragulus, right			–23.00	5.52	3.09	5.3
Van-001 mDUP	Method Duplicate			–23.03	5.82	3.35	4.7
Van-003	astragulus, right			–21.82	4.49	3.06	3.1
Van003 mDUP	Method Duplicate			–21.82	4.47	3.44	1.6
Van-018	maxilla, left			–21.45	6.33	3.33	4.7

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Van-019	maxilla, left			–22.20	5.56	3.25	12.2
Van-020	mandible, right			–23.84	5.35	3.15	5.2
Van-022	mandible, right			–24.06	4.92	3.33	5.4
Van-108	skull			–23.10	5.45	3.15	5.2
Wal-003	radius, left			–23.79	4.18	3.19	14.2
Wal-005	phalanx, proximal			–23.29	4.29	3.17	19.7
Wal-008	phalanx, middle			–23.71	6.11	3.17	15.0
Wal-009	calcaneous, right			–24.32	5.86	3.24	17.3
Wal-010	phalanx, proximal			–23.65	5.54	3.25	12.5
Wal-010 DUP	Duplicate			–23.63	5.60	3.24	-
Wal-011	mandible			–22.56	4.77	3.36	3.7
Wal-013	phalanx, proximal			–23.54	4.49	3.31	6.8
Wal-014	phalanx, proximal			–24.06	5.61	3.21	-
Wal-014	phalanx, proximal			–23.56	4.26	3.24	16.4
Wal-014 DUP	Duplicate			–23.53	4.24	3.25	-
Wal-016	phalanx, proximal			–23.84	4.26	3.36	5.0
Wal-018	phalanx, proximal			–22.37	5.08	3.19	21.5
Wal-021	phalanx, distal			–24.66	5.35	3.20	19.3
Wal-036	phalanx, proximal			–22.40	6.13	3.25	7.3
Wal-037	maxilla, right			–23.36	4.76	3.20	20.6
Wal-037 DUP	Duplicate			–23.33	4.88	3.21	-
Wal-038	maxilla, left			–21.91	5.54	3.22	18.2
Win-157				–21.19	8.17	3.79	3.3
Win-157 mDUP	Method Duplicate			–21.25	8.25	3.95	-

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Win-159	mandible			–21.93	7.29	3.30	3.3
Win-159 DUP	Duplicate			–21.86	7.33	3.35	3.3
BrB-02	tibiotarsus, right			–20.89	5.50	3.12	4.5
BrB-03	humerus, right			–20.68	5.28	3.10	5.5
Clv-033 +	scapula, right	Juvenile, large		–20.77	6.25	3.45	14.4
Clv-033 DUP	Duplicate	Juvenile, large		–20.77	6.26	3.47	14.4
Crf-043~	tarsosmetatarsus, left		Possible female	–20.61	6.04	3.04	24.7
Crf-044~	tarsosmetatarsus, left		Possible female	–20.16	5.77	3.04	8.5
Crf-045~	tarsosmetatarsus, proximal, left			–17.75	6.74	3.06	16.3
Crf-046~	tarsosmetatarus, left	Juvenile, large		–18.53	6.60	3.05	16.3
Crf-047 mDUP	Method Duplicate	Juvenile, large		–17.45	7.33	3.32	19.3
Crf-047~	tarsosmetatarus, left	Juvenile, large		–17.44	7.24	3.04	19.2
Crf-048 DUP	Duplicate		Possible female	–18.77	6.48	3.03	-
Crf-048~	tarsosmetatarsus, right		Possible female	–18.78	6.56	3.04	15.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Crf-051~	tarsosmetatarsus, right	4 + years	Probable male	–20.92	6.17	3.09	6.7
Fon-020	carpometacarpus, left			–21.59	6.31	3.09	7.0
Fon-020 mDUP	Method Duplicate			–21.65	6.80	3.41	7.0
Fon-020 mDUP DUP	Duplicate			–21.63	6.67	3.41	-
Fon-033	foot phalanx			–21.01	6.90	3.23	23.3
Fon-033 DUP	foot phalanx			–21.01	6.94	3.22	-
Fon-104	foot phalanx			–21.29	5.39	3.10	9.0
Ham-05	humerus, right distal			–9.93	8.17	3.32	16.5
Ham-05 DUP	Duplicate			–9.83	7.89	3.36	-
Ham-05 mDUP	Method Duplicate			–10.23	7.91	3.29	15.3
Ham-06	coracoid			–19.80	6.25	3.42	12.9
Ham-07	long bone frag (id'd by McMaster)			–20.64	6.13	3.34	15.1
Ham-07 mDUP	Method Duplicate			–20.72	6.17	3.32	14.5
Ham-08	coracoid, left	Juvenile, large		–17.08	6.75	3.39	18.1
Ham-09~	coracoid, distal, left		Possible female	–19.59	6.39	3.44	12.4
Ham-10~	humerus, right	Juvenile, large		–22.83	4.88	3.47	13.0
Ham-11~	coracoid, left	Juvenile, large		–19.13	5.55	3.37	16.9

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
IWP(01)-30	coracoid, left proximal			–22.37	6.75	3.07	8.3
IWP(01)-30 DUP	Duplicate			–22.31	6.76	3.08	-
IWP(03)-02	ulna, right shaft			–21.88	6.76	3.01	17.2
IWP(03)-06	sternal rib			–21.45	6.58	3.00	21.9
IWP(03)-07	carpometacarpus, left			–23.48	5.79	3.00	18.7
IWP(03)-08	phalanx			–23.18	5.47	3.03	18.9
IWP(03)-15	coracoid, left		Possible female	–21.85	6.14	2.96	18.9
IWP(09)-009	radius, left distal			–21.49	5.67	3.31	5.0
IWP(09)-012	phalanx, third			–23.56	5.75	3.14	11.9
IWP(09)-012 DUP	Duplicate			–23.28	6.60	3.31	-
IWP(09)-032	carpometacarpus, left			–22.07	6.78	3.11	7.2
IWP(09)-048	carpometacarpus, right			–20.21	4.72	3.03	9.1
IWP(09)-079	scapula, right			–23.24	6.67	3.24	8.1
IWP(09)-083	humerus, left			–23.67	5.96	3.07	5.7
IWP(09)-083 mDUP	Method Duplicate			–23.75	6.29	3.42	5.2
IWP(09)-088	phalanx, third			–22.45	8.49	3.09	5.3
IWP(09)-119	vertebrae			–23.17	5.71	3.08	8.1
IWP(09)-122	phalanx, first			–21.30	7.64	3.24	19.9
Pip(1)-010^	femur, left			–20.52	6.18	3.05	17.1
Pip(1)-023 +	coracoid, right+		Possible male	–20.76	6.39	3.05	18.9

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Pip(1)-024 +	coracoid, right		Possible male	–21.05	6.03	3.04	12.6
Pip(1)-024 mDUP	Method Duplicate		Possible male	–20.83	6.15	3.43	18.9
Pip(1)-024 mDUP DUP	Duplicate		Possible male	–20.77	5.21	3.39	-
Pip(1)-025	coracoid, right		Possible male	–21.52	6.03	3.10	19.3
Pip(1)-048	phalanx, third			–19.88	6.84	3.09	21.9
Pip(1)-075	skull, complete			–20.62	8.49	3.03	25.2
Pip(1)-179	vertebrae, axis			–20.40	5.97	3.06	20.5
Pip(1)-184	scapula, left			–22.50	5.44	3.04	20.6
Pip(2)-070	scapula, left	Juvenile, medium		–20.07	6.86	3.05	16.1
Pri-007	vertebrae, cervical	Juvenile		–18.33	5.24	3.16	10.9
Rif-062	scapula			–20.63	7.12	3.06	13.5
Rif-080	coracoid, left	Immature	Possible male	–22.34	6.81	3.07	16.6
Rif-092	vertebrae			–19.80	6.78	3.29	19.5
Rif-092 mDUP	Method Duplicate			–19.74	6.72	3.30	18.9
Rif-107	phalanx, second wing, right			–22.96	5.18	3.03	22.4
Rif-107 DUP	Duplicate			–23.07	5.05	3.03	-
Tho-035	carpometacarpus, left			–22.36	5.03	3.42	7.5

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Tho-046	humerus			–22.31	5.86	3.40	5.6
Tho-054	humerus, right			–21.78	4.00	3.40	12.9
Tho-054 DUP	Duplicate			–21.80	4.81	3.45	12.9
Tho-058	ulna, shaft			–22.22	4.87	3.40	11.7
Tho-065	synsacrum			–22.16	6.60	3.41	10.2
Van-011	tibiotarsus, left distal			–21.33	5.56	3.34	5.9
Van-012	tarsometarsus, left distal			–21.32	6.76	3.32	5.6
Van-017	synsacrum			–20.93	6.31	3.30	6.7
Wal-050	ulna, shaft			–20.19	5.46	3.25	17.1
Wal-050 mDUP	Method Duplicate			–20.20	5.61	3.48	18.4
Wal-051	vertebrae, cervical			–21.95	5.63	3.22	22.1
Win-047	coracoid, left			–19.55	6.92	3.09	19.0
Win-047 DUP	Duplicate			–19.58	6.85	3.08	19.0
Win-221	humerus, right (very large)		Possible male	–19.02	6.11	3.04	5.6
Woodchuck/groundhog *(Marmota monax)*							
Cra-015	skull			–23.30	4.25	3.22	19.9
Fon-025	innominate			–24.22	2.53	3.01	21.5
Fon-049	mandible			–19.40	3.94	3.04	11.6
Lig-004	mandible			–23.21	2.27	3.30	17.2
Lig-009	ulna, left			–23.05	2.79	3.13	2.0
Lig-014	mandible			–23.30	2.67	3.27	6.2
Tho-007	radius			–23.76	2.27	3.19	19.3
Van-044	femur, left			–25.60	3.09	3.02	15.1
Van-056	humerus, left	Juvenile		–23.66	3.11	3.08	13.8
Van-069	humerus, left			–25.49	3.05	3.07	7.4

Appendix B continued

Sample ID (Genus and/or species)	Sample Description	Age**	Sex	$\delta^{13}C_{col}$ (‰,VPDB)	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Van-072	tibia, right	Juvenile		–26.39	3.13	3.24	15.6
Van-080	mandible, left			–25.75	2.73	3.24	16.1
Van-093	mandible, left			–25.67	3.20	3.11	5.7
Van-095	mandible, left			–26.45	2.95	3.07	14.9
Van-113	femur, left	Juvenile		–22.89	4.86	3.16	2.9
Van-119	mandible, left			–25.76	3.01	3.16	4.7
Wal-017	mandible			–23.17	2.13	3.21	20.0
Wal-020	mandible, left			–25.05	3.34	3.25	14.9

Sex = unknown, unless noted

Age = probable or definite adult, unless noted
^ = carnivore puncture marks
^^=partially burnt
~ possible purposeful burial (complete individual or special circumstance)
+ cut marks

Appendix C: Bone collagen isotopic composition and sample description (modern)

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{13}C_{col}$ +1.65‰	δ^{15N}_{col} (‰, AIR)	C:N	Collagen Yield (%)
White-tailed deer *(Odocoileus virginianus)*									
Mod-Deer-01	mandible, left	adult	male	London, Middlesex County	–20.17	–18.52	4.58	3.37	21.2
Mod-Deer-01 DUP	Duplicate			-	–20.22	–18.57	5.85	3.36	
Mod-Deer-01 mDUP	Method Duplicate			-	–20.20	–18.55	5.29	3.27	21.2
Mod-Deer-01 mDUP DUP	Duplicate			-	–20.21	–18.56	5.42	3.37	
Mod-Deer-02^	mandible	adult	male	outside Strathroy, Middlesex County	–19.42	–17.77	3.62	3.36	19.0
Mod-Deer-03^	mandible, right	adult	male	outside Strathroy, Middlesex County	–20.22	–18.57	5.26	3.36	21.3
Mod-Deer-03 DUP	Duplicate			-	–20.27	–18.62	5.26	3.35	
Mod-Deer-04^				outside Strathroy, Middlesex County	–20.38	–18.73	4.02	3.31	21.13
Mod-Deer-04 DUP	Duplicate			-	–20.46	–18.81	3.47	3.35	
Mod-Deer-05				Renfrew County	–24.61	–22.96	2.07	3.41	21.7
Mod-Deer-05 DUP	Duplicate			-	–24.61	–22.96	1.76	3.42	
Mod-Deer-06	mandible	adult	male	Haldimand-Norfolk County	–22.05	–20.40	7.78	3.31	21.1
Mod-Deer-06 DUP	Duplicate			-	–22.02	–20.37	7.27	3.32	
Mod-Deer-07	mandible	adult	male	Kitchener-Waterloo	–20.82	–19.17	5.65	3.39	22.5
Mod-Deer-07 DUP	Duplicate			-	–20.87	–19.22	5.25	3.36	
Mod-Deer-08	mandible	adult	male	Haldimand-Norfolk County	–22.25	–20.60	4.23	3.31	22.2

Appendix C continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{13}C_{col}$ +1.65‰	δ^{15N}_{col} (‰, AIR)	C:N	Collagen Yield (%)
Mod-Deer-09	mandible	adult	male	Haldimand-Norfolk County	–23.38	–21.73	2.80	3.31	23.5
Mod-Deer-09 DUP	Duplicate				–23.37	–21.72	2.78	3.31	
Mod-Deer-10	mandible	adult	male	Haldimand-Norfolk County	–23.67	–22.02	5.17	3.49	17.9
Mod-Deer-11	mandible	adult	male	Haldimand-Norfolk County	–22.89	–21.24	4.56	3.37	17.7
Mod-Deer-12	mandible	adult	unknown	south London, Middlesex County	–20.93	–19.28	5.70	3.37	25.2
Mod-Deer-12 DUP	Duplicate				–20.49	–18.84	5.41	3.38	
Mod-Deer-13	mandible	juvenile	unknown	Peel County	–21.22	–19.57	5.32	3.38	5.5
Mod-Deer-14	mandible	adult	male	Middlesex County	–18.94	–17.29	4.52	3.44	14.9
Mod-Deer-15	mandible	adult	male	Haldimand-Norfolk County	–18.66	–17.01	4.21	3.18	-
Mod-Deer -15 mDUP	Method Duplicate			-	–19.33	–17.68	4.23	3.12	-
Mod-Deer -16	mandible	adult	male	Haldimand-Norfolk County	–18.44	–16.79	6.44	3.11	-
Mod-Deer -16 mDUP	Method Duplicate			-	–18.66	–17.01	6.36	3.13	-
Wild turkey *(Meleagris gallopavo)*									
Mod-turk-01B	ulna, left	3	male	Elgin County	–14.07	–12.42	6.03	3.28	22.1
Mod-turk-01B DUP	Duplicate			Duplicate	–14.04	–12.39	6.10	3.27	
Mod-turk-02B	ulna, left	5+	male	Haldimand-Norfolk County	–17.65	–16.00	4.45	3.23	21.0

Appendix C continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{13}C_{col}$ +1.65‰	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Mod-turk-03B	ulna, left	1	male	Haldimand-Norfolk County	–20.08	–18.43	5.11	3.29	23.0
Mod-turk-04B	ulna, right	2	male	Elgin County	–16.35	–14.70	5.10	3.23	22.4
Mod-turk-05B	ulna, left	2	male	Haldimand-Norfolk County	–17.31	–15.66	6.21	3.25	24.7
Mod-turk-06B	ulna, right	4	male	Norfolk County	–18.48	–16.83	6.63	3.24	12.8
Mod-turk-06B DUP	Duplicate			-	–18.54	–16.89	6.67	3.23	
Mod-turk-07B	ulna, left	2+	male	near London, Middlesex County	–17.82	–16.17	6.57	3.22	24.8
Mod-turk-07B mDUP	Method Duplicate			-	–17.95	–16.30	6.53	3.25	24.0
Mod-turk-08B	ulna, right	2+	male	near London, Middlesex County	–19.36	–17.71	6.11	3.30	22.3
Mod-turk-09B	ulna, left	1	male	near London, Middlesex County	–19.17	–17.52	5.93	3.24	22.5
Mod-turk-10B	ulna, left	1	male	near London, Middlesex County	–17.59	–15.94	5.41	3.23	22.9
Mod-turk-11B	ulna, left	adult	male	near London, Middlesex County	–17.39	–15.74	4.92	3.24	21.3
Mod-turk-11B mDUP	Method Duplicate	adult	male	-	–17.75	–16.10	5.00	3.24	20.8
Mod-turk-12B	ulna, right	adult	male	near London, Middlesex County	–16.60	–14.95	4.37	3.27	21.3
Mod-turk-13B	ulna, right	adult	male	near London, Middlesex County	–17.02	–15.37	4.55	3.24	31.4

Appendix C continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{13}C_{col}$ +1.65‰	δ^{15N}_{col} (‰,AIR)	C:N	Collagen Yield (%)
Mod-turk-14B	ulna, left	adult	male	unknown	–17.86	–16.21	4.35	3.30	20.2
Mod-turk-14B mDUP	Method Duplicate				–17.88	–16.23	4.37	3.29	19.7
Mod-turk-15B	phalanx	adult	male	near London, Middlesex County	–18.43	–16.78	4.90	3.62	21.2
Mod-turk-16B	phalanx	adult	male	near London, Middlesex County	–20.85	–19.20	6.81	3.64	9.6
Mod-turk-17B	femur	adult		unknown	–14.23	–12.58	7.63	3.44	15.3
Mod-turk-17B mDUP	Method Duplicate				–14.22	–12.57	7.53	3.29	16.8
Mod-turk-18B	ulna	adult		London City Centre, Middlesex County	–17.61	–15.96	6.33	3.45	19.2
Mod-turk-19B	tarsometarsus	juvenile	unknown	Walsingham Township, Norfolk County	–17.74	–16.09	6.21	3.37	10.3
Mod-turk-19B DUP	Duplicate				–17.85	–16.20	6.03	3.22	

^ hunted in maize field

Appendix D: Bone structural carbonate isotopic composition and sample description (archaeological)

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc-col}$
American black bear (*Ursus americanus*)										
Bog-043			phalanx	–11.29	22.22	66.6	7.1	2.85	0.42	9.16
Fon-072			phalanx, proximal	–14.87	22.01	75.6	6.6	2.54	0.84	7.45
Ham-024			mandible	–11.56	22.45	70.7	n/a	2.75	0.44	8.36
IWP(01)-052			metatarsal	–11.55	18.93	55.7	5.7	2.86	0.40	10.65
Pri-018			scaphoid, right	–12.51	22.70	66.3	n/a	2.86	0.42	8.35
Sil-020			metatarsals	–13.79	22.19	71.6	5.2	3.19	0.25	6.92
Van-071			phalanx, II	–11.58	21.46	71.0	6.5	2.75*	0.39*	9.87
Canid cf fox										
Crf-077			mandible	–8.58	19.39	68.5	6.7	2.71*	0.52*	11.09
Crf-077 DUP			mandible, no teeth	–8.01	19.30	-	7.1	-	-	11.61
Tho-011			mandible, right	–9.92	21.19	79.1	6.7	2.77	0.39	8.03
Van-070			atlas	–10.97	22.39	75.3	5.3	2.66	0.40	8.57
Win-154			humerus, distal	–9.17	19.21	71.2	6.8	2.72	0.48	9.20
Win-154B mDUP			humerus, distal	–8.41	20.97	68.7	6.9	-	-	-
Win-229			mandible, right	–13.03	21.49	68.4	6.1	2.60	0.72	5.74
Dob-002			right humerus	–10.37	20.61	77.3	5.4	2.96	0.35	8.97
Dob-002B DUP			right humerus	–12.27	21.59	-	5.2	-	-	-
Canid cf. fox or small C. familiaris										
Pip(2)-010			right humerus, shaft	–5.66	20.43	66.1	5.5	2.73	0.49	5.81
Pip(2)-010B DUP			right humerus, shaft	–5.51	20.44	-	5.4	-	-	-

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Pip(2)-010B mDUP			right humerus, shaft	–5.59	20.47	66.8	5.4	-	-	5.74
Pip(2)-103			left humerus (cutmarks)	–4.83	19.85	63.0	5.8	2.71	0.73	6.35
Pip(2)-103B DUP			left humerus (cutmarks)	–4.54	19.85	-	5.7	-	-	-
Por-012			right humerus, distal	–13.05	21.50	64.5	5.4	2.84	0.71	6.48
Por-012B mDUP			right humerus, distal	–12.81	22.03	75.0	4.7	-	-	6.74
Van-075			left zygomatic/partial skull	–15.79	21.30	72.4	7.8	2.65	0.73	5.43
Van-075B DUP			left zygomatic/partial skull	–15.89	21.24	-	7.2	-	-	-
IWP(09)-016				–6.09	19.54	80.4	3.7	3.03	0.27	7.80
Canis sp.										
Bog-030			phalanx	–7.49	21.45	67.4	5.2	2.68	0.75	6.42
Bog-042			tarsal	–7.47	21.29	65.7	6.0	2.80	0.45	7.32
IWP(09)-066	Fetal		mandible, right	–3.47	20.41					7.65
OLG-14			left distal tibia	–4.31	24.06	75.6	4.7	2.90*	0.36*	6.20
OLG-14B mDUP			left distal tibia	–4.12	23.57		5.3	-	-	-
Pip(1)-175	10-12 weeks		mandible	–11.48	22.77	74.6	6.6	2.64	0.71	7.67
Pip(2)-028	juvenile		right tibia	–11.38	21.90	76.3	5.5	2.82*	0.57*	10.23

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Pip(2)-049			right calcaneous	–3.19	21.64	66.1	-	2.69	0.51	7.96
Pip(2)-110			atlas	–3.81	20.81					6.81
Sla-026			metacarpal	–4.74	20.52	70.5	6.6	2.61	0.73	-
Wal-034			left calcaneous	–6.73	20.95	73.4	-	2.49	0.53	7.45
Win-249	juvenile		ulna	–4.63	20.14	70.7	7.0	2.75	0.68	5.67
Rif-020			left and right calcaneous (burnt)	–5.30	19.81	65.2	7.4	2.81*	0.40*	6.32
Canis sp. cf. C. familiaris										
Bog-016			mandible	–7.52	22.03	76.5	6.5	2.85	0.38	6.13
Cra-010			right ulna, proximal	–7.72	22.32	88.0	7.7	2.93	0.32	14.09
Crf-054			axis	–4.87	18.71	69.7	4.4	2.59*	0.63*	7.02
Crf-054 mDUP			axis	–4.70	18.34	68.2	5.2	-	-	7.18
Dav-005			maxilla, fragment	–9.80	18.42	88.8	6.9	2.73	0.36	10.95
Dav-006			maxilla, fragment	–9.38	20.16	60.7	2.5	3.24	0.28	11.44
Dob-001			mandible	–4.92	22.30	100.3	4.8	2.99*	0.36*	7.08
Dob-001B mDUP			mandible	–5.01	22.37	81.1	7.6	-	-	-
Dob-001B mDUP DUP			mandible	–5.02	22.01	-	7.1	-	-	-
Fon-061			mandible, left	–7.71	22.32	75.9	7.3	2.68	0.53	5.07
Fon-117			mandible, right	–6.59	19.99	63.0	6.1	2.46	0.61	6.00

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Fon-121			mandible, left	–8.35	20.93	75.8	7.6	2.63	0.88	6.41
Ham-026			mandible, right	–7.01	20.25	75.0	5.7	2.61*	0.82*	6.20
Ham-027			mandible, right	–9.32	19.83	75.5	4.4	2.63	0.51	5.82
IWP(01)-027			left & mandible, right	–5.89	21.83	61.6	7.6	2.75	0.46	8.67
IWP(01)-035			mandible, right	–7.51	21.66	84.7	4.4	3.00	0.29	8.07
IWP(12)-01			tibia, complete	–6.06	20.49	80.5	7.6	2.78*	0.42*	10.23
Pip-(1)-138			left radius, complete	–4.42	20.32	75.0	7.0	2.59	0.21	6.13
Pip(1)-180			left ulna, complete (cutmarks)	–5.30	20.40	75.1	5.7	2.64	0.71	6.10
Pip(2)-044			left scapula	–5.65	20.79	72.7		2.61	0.71	5.28
Pip(2)-087			right ulna, proximal	–6.47	21.70	46.3	5.4	2.88	0.38	5.68
Rif-008			left femur	–5.13	21.95	73.4	4.9	2.56	0.63	5.33
Rif-008B repeat			left femur	–5.18	21.61	-	5.8	-	-	-
Rif-019			left and mandible, right	–5.33	20.02	74.9	7.8	2.69	0.54	5.48
Rof-002			mandible	–7.37	22.35		4.8	-	-	4.90
Rof-2B mDUP			mandible	–7.54	21.57	100.9	7.5	3.26	0.35	-
Sla-019			phalanx	–4.77	20.16	72.2	6.2	2.63	0.60	6.63
Tho-006			mandible	–5.38	21.65	75.9	7.5	3.00	0.33	7.42
Tho-010			ulna, proximal	–7.11	21.93	69.0	6.3	2.73	0.82	5.64

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Tho-053			left calcaneus,	–7.59	21.60	77.5	7.9	2.66	0.68	5.53
Van-124			mandible, right	–7.05	22.08	82.3	5.0	2.85*	0.40*	6.04
Van-124B mDUP			mandible, right	–7.01	21.23	76.5	5.6	-	-	-
Wal-032			right maxilla	–7.79	21.96	77.4	7.4	2.57	0.48	6.22
Wal-057			mandible, left	–7.31	23.40	69.3	3.5	3.11	0.27	5.63
Wal-058			mandible, left	–7.91	22.71	66.8	6.7	2.61	0.62	5.90
Wal-059			mandible, left	–6.51	21.82	69.9	5.5	2.63	0.57	5.68
Wal-060			mandible, left	–7.05	22.24	71.4	5.9	2.69	0.36	6.14
Win-002			calcaneous	–5.93	18.96	64.8	5.4	2.78	0.51	7.45
Win-084			lumbar vertebrae	–5.00	19.48	65.3	5.9	2.69*	0.60*	6.66
Win-084B mDUP			lumbar vertebrae	–5.03	19.68	68.8	6.0	-	-	6.65
Win-150			radius	–4.42	20.80	75.0	5.7	2.47	0.85	6.39
Ham-025			mandible, right (burnt)	–9.46	21.38	72.5	4.9	2.79	0.78	3.98
Ham-025 DUP			mandible, right (burnt)	–9.20	21.40	-	5.1	-	-	-
Canis sp. cf. C. lupus or lg. C. familaris										
BrB-004			left tibia, distal	–13.31	22.57	82.6	5.5	3.01*	0.37*	8.54
Van-111			phalanx I	–10.95	23.15	53.7	6.1	2.74	0.43	11.18
Win-183			right maxilla, fragment	–13.61	21.64	76.0	7.1	2.60	0.49	7.27

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Win-183B DUP			right maxilla, fragment	–13.09	21.15	-	7.1	-	-	7.28
Eastern gray/black squirrel (*Sciurus carolinensis*)										
Van-085			mandible, left	–13.64	20.53	69.5	n/a	2.47	0.79	5.85
Mammal, medium										
Sla-025			radius	–17.03	20.98	70.5	6.8	2.61	0.73	8.81
Raccoon (*Procyon lotor*)										
Crf-039			mandible	–8.67	22.45	69.6	n/a	3.14	0.24	5.31
Crf-040			mandible	–8.60	22.66	85.1	6.2	3.20	0.24	6.93
Sil-006			mandible, left	–11.94	21.30		n/a	2.83	0.38	8.52
Win-233			mandible	–15.83	19.44	71.2	6.2	2.61*	0.75*	5.84
White-tailed deer (*Odocoileus virginianus*)										
Bog-054			mandible, right	–11.12	22.41	73.9	6.1	2.61	0.47	11.89
BrB-011			manidle, right	–12.29	21.93	70.0	4.9	3.06	0.34	11.34
BrB-011 DUP			mandible, right	–12.28	21.24	-		-	-	-
BrB-013			mandible, left	–12.94	21.75	63.5	5.5	2.99	0.31	10.66
Clv-015			mandible, right	–11.35	22.55	66.3	5.0	2.99	0.36	10.70
Clv-016			mandible, right	–11.71	21.69	75.5	7.7	2.20	0.44	10.68
Clv-017			mandible, right	–10.72	20.99	82.4	7.5	2.61	0.57	9.81
Clv-017 DUP			mandible, right	–11.39	20.64	-	7.7	-	-	-
Clv-019			mandible, right	–10.59	21.96	80.0	8.6	2.62	0.55	12.06
Cra-001			astragulus	–12.50	20.66	64.6	4.6	2.57	0.63	10.83
Crf-002			phalanx	–8.84	23.00	78.0	6.1	2.80	0.41	14.61

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Crf-002 mDUP			phalanx	–8.67	22.92	79.6	6.7	-	-	-
Crf-095			mandible	–6.72	20.10	79.9	7.2	2.96	0.32	15.13
Crf-095 DUP			mandible	–6.61	20.03	-	7.4	-	-	15.25
Dav-001			long bone frag	–11.01	22.01	83.4	3.5	3.03	0.35	12.91
Dav-003			long bone frag	–11.26	21.23	84.1	7.3	3.10	0.34	11.90
Dav-004			skull frag	–11.51	20.96	82.4	5.8	2.92	0.38	10.50
Dav-04 DUP			skull frag	–11.56	21.04	-	5.3	-	-	-
Fon-001			phalanx	–13.04	20.05	69.8	7.3	2.09	0.67	9.77
Fon-019				–14.15	20.34	69.6	4.8	3.06	0.31	8.64
IWP(01)-001			mandible, right	–8.03	19.33	61.6	5.8	2.87	0.37	15.30
IWP(01)-001 mdup			mandible, right	–8.13	20.21	59.9	5.6	-	-	15.25
IWP(01)-036 mDUP			mandible	–14.02	21.07	63.9	8.4	2.68	0.63	9.66
IWP(01)-036 rerun			mandible	–13.95	21.12	64.7	7.9	-	-	9.69
IWP(09)-054			mandible	–13.66	20.06	65.9	7.8	2.68	0.63	9.65
IWP(09)-054 mDUP			mandible	–13.72	19.98	66.8	7.8	2.60	0.74	9.81
IWP(09)-054 mdup DUP			mandible	–13.72	19.84	-	7.1	-	-	-
IWP(09)-134			mandible	–8.29	18.94	54.7	5.8	2.82	0.37	15.14
IWP(12)-003			metatarsal	–8.40	21.06	68.5	5.7	2.87	0.33	14.14
IWP-(03)-023				–8.16	20.09		8.0	-	-	15.33
IWP-(03)-023 DUP				–8.33	20.45		7.3	-	-	-
IWP-(03)-023 mDUP				–8.01	19.85		7.8	-	-	-
Lia-006			bulla	–13.69	22.68	72.6	6.4	2.78	0.46	10.13

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Lia-006 mDUP			bulla	–13.68	22.44	75.0	5.5	-	-	10.01
Mon-004			innominate, right	–8.90	21.90	n/a	5.1	3.07	0.37	13.59
Mon-006			mandible	–9.87	21.14	59.5	5.6	2.93	0.35	12.79
Mon-006 mDUP			mandible	–9.89	21.63	-	4.7	-	-	12.64
Mon-008			mandible	–9.73	21.78	76.9	5.7	3.28	0.27	13.36
Mon-008 mDUP			mandible	–9.99	22.01	87.0	4.5	-	-	-
OLG-001			mandible, right	–14.20	21.44	72.2	5.5	2.57	0.63	7.92
OLG-013			ulna, proximal left	–8.91	21.35	71.7	7.3	2.68	0.33	14.31
Pip(1)-103			mandible, left	–8.74	21.82	83.0	8.9	2.73	0.64	13.32
Pip(1)-103 mDUP			mandible, left	–9.17	21.99	77.9	8.5			12.86
Por-017			carpal, left radial	–5.97	22.28	82.1	5.3	2.83	0.40	16.16
Rif-007			mandible	–7.95	23.76	83.0	5.5	3.00	0.30	13.30
Rif-007 mDUP			mandible	–8.52	22.62	82.7	5.1	-	-	12.80
Rif-077			mandible	–11.11	22.88	-	6.3	2.94	0.32	11.54
Tho-012			phalanx	–11.03	21.74	58.2	5.7	2.75	0.46	11.04
Van-001			astragulus, right	–11.32	20.57	66.5	6.3	2.81	0.40	11.68
Van-003			astragulus, right	–10.12	21.78	74.6	4.2	2.97	0.29	11.70
Van-003 mDUP			astraguls, right	–10.12	21.96		4.6	3.11	0.26	11.70
Van-020			mandible, right	–8.80	22.05	87.1	7.8	2.78	0.42	15.04
Van-020 DUP			mandible, right	–8.52	21.88	-	8.1	-	-	-

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Van-020 mDUP rerun			mandible, right	–8.48	21.43	63.3	8.8	2.79	0.42	-
Win-157				–8.59	22.77	83.6	4.9	3.21	0.24	12.60
Win-157 mDUP				–8.62	22.41	81.5	4.7	-	-	12.63
Win-159			mandible	–8.98	23.27	79.6	6.2	2.96	0.37	12.95
Win-159 DUP			mandible	–9.08	23.18	-	5.8	-	-	12.78
Wild turkey (*Meleagris gallopavo*)										
Crf-045~			tarsosmetatarsus, proximal, left	–11.10	21.09	76.0	2.0	3.39	0.18	6.65
Crf-048~		Possible female	tarsosmetatarsus, right	–11.21	19.59	78.2	3.4	2.93*	0.33*	7.57
Ham-005			humerus, right distal	–5.41	19.98	76.6	6.1	2.57	0.52	4.52
Ham-005 DUP			humerus, right distal	–5.53	19.92		6.7			4.30
Ham-005 mDUP			humerus, right distal	–5.42	19.94	76.6	7.0			4.82
Ham-008	Juvenile, large		coracoid, left	–8.92	22.16	76.6	5.0	2.97	0.46	8.16
IWP(03)-002			ulna, right shaft	–12.67	20.23	84.8	5.9	3.07	0.30	9.21
Pip(2)-070	Juvenile, medium		scapula, left	–11.13	22.11	78.1	4.5	2.65	0.61	8.94
Pip(2)-070 DUP	Juvenile, medium		scapula, left	–11.63	22.15	-	5.7	-	-	-

Appendix D continued

Sample Name	Age**	Sex	Element	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P*	$\delta^{13}C_{sc\text{-}col}$
Pri-007	Juvenile, undetermined		vertebrae, cervical	–9.48	20.48	83.4	3.8	2.86	0.44	8.86
Rif-062			scapula	–13.43	21.19	76.4	5.2	2.55	0.68	7.20
Rif-080	Immature	Possible male	coracoid, left	–12.19	20.49	79.1	6.1	2.68*	0.66*	10.15
Rif-080 DUP	Immature	Possible male	coracoid, left	–12.13	20.67	-	9.1	-	-	-
Rif-092			vertebrae	–10.22	20.60	80.1	6.8	2.71	0.74	9.58
Rif-107			phalanx, second wing, right	–11.87	21.54	80.8	5.9	2.67	0.77	11.09
Rif-107 DUP			phalanx, second wing, right	–12.28	22.18	-	9.7	-	-	10.79
Tho-035			carpometacarpus, left	–10.19	21.52	84.7	7.9	2.60	0.53	12.17
Tho-035 DUP			carpometacarpus, left	–10.68	20.67	-	8.2	-	-	-
Win-047			coracoid, left	–12.01	18.06	76.6	6.7	2.58	0.79	7.54

Sex = unknown, unless noted

Age = probable or definite adult, unless noted

+ cut marks

~ possible purposeful burial (complete individual or special circumstance)

^ = carnivore puncture marks

^^= partially burnt

* CI or C/P value based on mDuplicate

Appendix E: Bone structural carbonate isotopic composition and sample description (modern)

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P *	$\delta^{13}C_{sc-col}$
White-tailed deer (*Odocoileus virginianus*)												
Mod-Deer-01	mandible, left	adult		London, Middlesex	–12.81	–11.16	22.51	81.5	5.4	2.54		
Mod-Deer-02^	mandible	adult		outside Strathroy, Middlesex	–11.91	–10.26	22.56	59.3	4.7	2.39	0.89	
Mod-Deer-02 mDUP	Method Duplicate	adult			–12.05	–10.40	22.62	54.9	4.2			
Mod-Deer-03^	mandible, right	adult		outside Strathroy, Middlesex	–12.89	–11.24	22.10	79.7	8.8	2.50	0.74	
Mod-Deer-03 DUP	Duplicate	adult			–12.97	–11.32	21.86		8.4			
Mod-Deer-04^	mandible	adult		outside Strathroy, Middlesex	–13.59	–11.94	22.73	70.0	5.4	2.47	0.67	
Mod-Deer-04 DUP	Duplicate	adult			–13.95	–12.30	22.54		5.3			
Mod-Deer-05	mandible	adult		Combermere Renfrew County	–19.47	–17.82	22.27	92.7	4.8	2.57	0.72	
Mod-Deer-06	mandible	adult		Norfolk	–16.11	–14.46	20.16	26.1	5.8	2.57	0.81	
Mod-Deer-06 DUP	Duplicate	adult				1.65						
Mod-Deer-07	mandible	adult		Kitchener-Waterloo	–14.10	–12.45	23.93	66.5	4.8	2.58	0.57	

Appendix E continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	Cl*	C/P *	$\delta^{13}C_{sc\text{-}col}$
Mod-Deer-08	mandible	adult			–15.58	–13.93	23.12	67.0	5.8	2.55	0.70	
Mod-Deer-08 DUP	Duplicate	adult			–15.54	–13.89	23.55		6.1			
Mod-Deer-09	mandible	adult		Norfolk	–17.29	–15.64	22.30	62.8	5.6	2.83	0.79	
Mod-Deer-10	mandible	adult		Norfolk	–18.27	–16.62	23.53	52.5	2.8	2.83	0.60	
Mod-Deer-11	mandible	adult		Norfolk	–15.86	–14.21	19.80	32.9	0.9	n/a		
Mod-Deer-11 DUP	Duplicate	adult			–15.10	–13.45	20.46		0.9			
Mod-Deer-11 DUP	Duplicate	adult			–11.70	–10.05	22.32		1.0			
Mod-Deer-14	mandible	adult		richard baskeyMiddlesex	–10.78	–9.13	21.83	77.7	4.5	2.70	0.46	
Mod-deer-14 DUP	Duplicate	adult			–10.41	–8.76	21.79		3.8			
Mod-Deer -15				Norfolk	–18.66	–17.01	4.21	3.18				
Mod-Deer -15 mDUP	Method Duplicate			Norfolk	–19.33	–17.68	4.23	3.12				
Mod-Deer -16				Norfolk	–18.44	–16.79	6.44	3.11				
Mod-Deer -16 mDUP	Method Duplicate			Norfolk	–18.66	–17.01	6.36	3.13				

Appendix E continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P *	$\delta^{13}C_{sc\text{-}col}$
Wild turkey (Meleagris gallopavo)												
Mod-turk-01B	ulna, left	3	male	Elgin County	–5.53	–3.98	21.40	59.5		2.56	0.81	8.53
Mod-turk-02B	ulna, left	5+	male	Norfolk County	–9.79	–8.24	20.92	65.5		2.61	0.65	7.85
Mod-turk-03B	ulna, left	1	male	Norfolk County	–12.16	–10.61	19.57	47.6		2.56	0.84	7.92
Mod-turk-04B	ulna, right	2	male	Elgin County	–8.93	–7.38	20.80	70.1		2.55	0.74	7.42
Mod-turk-04B DUP	Duplicate	2	male	Elgin County	–9.16	–7.61	20.85	-		-	-	-
Mod-turk-06B	ulna, right	4	male	Norfolk County	–10.69	–9.14	20.81	67.7		2.56	0.74	7.79
Mod-turk-07B	ulna, left	2+	male	near London, Middlesex County	–10.35	–8.80	20.57	72.7		2.47	0.79	7.47
Mod-turk-09B	ulna, left	1	male	near London, Middlesex County	–11.35	–9.80	18.82	66.1		2.52	0.76	7.82
Mod-turk-09B mDUP	Method Duplicate	1	male	near London, Middlesex County	–11.28	–9.73	19.83					

Appendix E continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P *	$\delta^{13}C_{sc\text{-}col}$
Mod-turk-09B DUP	Duplicate	1	male	near London, Middlesex County	–10.75	–9.20	20.43					
Mod-turk-10B	ulna, left	1	male	near London, Middlesex County	–8.79	–7.24	21.27	66.1		2.61	0.64	8.80
Mod-turk-11B	ulna, left	adult	male	near London, Middlesex County	–9.92	–8.37	21.19	71.4		2.54	0.74	7.47
Mod-turk-12B	ulna, right	adult	male	near London, Middlesex County	–8.19	–6.64	20.54	71.0		2.54	0.69	8.42
Mod-turk-13B	ulna, right	adult	male	near London, Middlesex County	–8.30	–6.75	20.85	70.7		2.56	0.71	8.72
Mod-turk-13B DUP	Duplicate	adult	male	near London, Middlesex County	–8.28	–6.73	20.59					

Appendix E continued

Sample Name	Sample Description	Age	Sex	Location	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite Yield (%)	CO_3 (%)	CI*	C/P *	$\delta^{13}C_{sc\text{-}col}$
Mod-turk-14B	ulna, left	adult	male	unknown	–9.32	–7.77	19.74	57.1		2.57 *	0.64 *	8.54
Mod-turk-14B mDUP	Method Duplicate	adult	male		–9.46	–7.91	19.65	68.1		-	-	8.42
Mod-turk-17B	femur	adult	unknown	unknown	–8.60	–7.05	15.12	56.0		2.56	0.79	5.63

^Hunted in maize field

Appendix F: Whole insect isotopic composition and sample description

Sample Name	Location	Date Collected	$\delta^{13}C$ (‰,VPDB)	$\delta^{15}N$ (‰,AIR)	C:N
Cricket (Order: *Gryllidea*)					
Cricket CO july #2	Cornfield	July-11	–21.00	4.84	5.04
Cricket CO july #2 DUP	Cornfield	July-11	–20.68	4.71	4.94
Cricket FO july#1	Meadow	July-11	–27.54	2.21	5.40
cricket 1c	Cornfield	September-11	–16.81	4.70	5.36
cricket 1f	Meadow	September-11	–28.67	1.52	7.54
cricket 1f DUP	Meadow	September-11	–28.79	1.48	8.03
cricket 2c	Cornfield	September-11	–16.61	6.19	4.55
cricket 2f	Meadow	September-11	–28.16	1.53	5.21
cricket 3f	Meadow	September-11	–27.49	1.05	5.58
06CRcorn1	Cornfield	June-12	–22.22	5.94	4.87
06CRfield1	Meadow	June-12	–25.27	1.22	5.10
08CRcorn1	Cornfield	August-12	–24.28	4.57	5.70
08CRcorn1 DUP	Cornfield	August-12	–24.46	4.59	5.31
08CRfield2	Meadow	August-12	–26.88	3.41	5.06
09CRcorn1	Cornfield	September-12	–23.65	2.05	5.28
09CRcorn2	Cornfield	September-12	–23.62	3.31	6.00
09CRcorn3	Cornfield	September-12	–23.28	3.09	5.46
09CRfield1	Meadow	September-12	–26.55	1.55	4.79
09CRfield2	Meadow	September-12	–27.01	2.49	4.87
09CRfield3	Meadow	September-12	–26.55	2.09	4.51
Grasshopper (Order: *Caelifera*)					
Grasshopper FO june#2	Meadow	June-11	–27.10	1.81	5.19
Grasshopper FO june#3	Meadow	June-11	–28.65	1.30	5.13
Grasshopper FO june#3 DUP	Meadow	June-11	–28.41	1.16	5.01
Grasshopper CO july #3	Cornfield	July-11	–26.99	1.75	4.68
Grasshopper CO july #3 DUP	Cornfield	July-11	–27.16	1.81	4.80
11GHfield1	Meadow	September-11	–28.62	5.63	5.47
grasshopper 1c	Cornfield	September-11	–29.70	1.86	5.36
grasshopper 1f	Meadow	September-11	–29.53	–0.75	5.14
grasshopper 2c	Cornfield	September-11	–30.08	2.09	5.46
grasshopper 2f	Meadow	September-11	–27.81	1.65	4.44
grasshopper 3c	Cornfield	September-11	–30.56	2.22	6.18
grasshopper 3f	Meadow	September-11	–28.99	0.68	5.36
Grasshopper FO sept #1	Meadow	September-11	–26.56	1.85	4.45
05GHcorn1	Cornfield	May-12	–29.36	0.75	4.39
05GHcorn2	Cornfield	May-12	–28.72	0.16	4.78
05GHcorn3	Cornfield	May-12	–28.77	2.84	4.69
05GHcorn4 (new corn)	Cornfield	May-12	–28.31	0.65	4.36
05GHfield1	Meadow	May-12	–29.27	1.59	5.67
05GHfield2	Meadow	May-12	–27.38	1.00	3.97

Appendix F Continued

Sample Name	Location	Date Collected	$\delta^{13}C$ (‰,VPDB)	$\delta^{15}N$ (‰,AIR)	C:N
05GHfield3	Meadow	May-12	–30.36	4.19	4.41
05GHfield4	Meadow	May-12	–30.33	–0.33	4.69
05GHfield5	Meadow	May-12	–29.40	0.31	4.89
06GHcorn1	Cornfield	June-12	–30.48	1.34	6.49
06GHcorn2	Cornfield	June-12	–26.03	3.38	4.98
06GHcorn3	Cornfield	June-12	–27.88	3.10	4.68
06GHcorn3 DUP	Cornfield	June-12	–27.85	3.02	4.68
06GHcorn4	Cornfield	June-12	–27.20	2.90	5.21
06GHfield1	Meadow	June-12	–28.03	1.46	4.85
06GHfield1 DUP	Meadow	June-12	–28.05	1.38	4.84
06GHfield2	Meadow	June-12	–28.43	1.03	4.86
06GHfield4	Meadow	June-12	–29.81	–0.63	6.02
08GHcorn1	Cornfield	August-12	–27.02	3.27	5.17
08GHcorn1 DUP	Cornfield	August-12	–26.81	3.41	5.00
08GHcorn2	Cornfield	August-12	–20.95	4.49	5.15
08GHfield1	Meadow	August-12	–27.15	2.48	4.47
08GHfield2	Meadow	August-12	–28.28	0.52	5.84
08GHfield3	Meadow	August-12	–27.73	3.85	5.20
09GHcorn1	Cornfield	September-12	–19.66	3.10	5.04
09GHcorn2	Cornfield	September-12	–25.89	3.77	4.49
09GHcorn3	Cornfield	September-12	–25.89	3.21	4.38
09GHfield2	Meadow	September-12	–27.25	1.23	4.55
09Ghfield3	Meadow	September-12	–27.30	1.60	4.38

Appendix G: Whole plant isotopic composition and sample description

Specimen Name (*Genus species*)	$\delta^{13}C$ (‰,VPDB)	$\delta^{15}N$ (‰,AIR)	Wt Carbon	Wt Nitrogen	C/N ratio
"Cherry" 1 (*Prunus*)	-26.37	-6.22	42.73	0.44	113.19
"Cherry" 2 (*Prunus*)	-26.71	2.42	47.15	4.17	13.20
Acorn nut 3 (*Quercus*)	-27.74	-0.98	44.59	0.78	66.66
Acorn nut 1 (*Quercus*)	-27.83	1.76	49.60	0.84	68.79
Acorn nut 2 (*Quercus*)	-29.61	0.56	48.71	0.94	60.21
Beech (*Fagus*)	-28.20	-3.30	54.98	3.21	19.94
Blackwalnut flesh *(Juglans nigra*)	-30.69	-8.18	46.90	0.33	163.30
Blackwalnut seed (*Juglans nigra*)	-31.34	1.17	55.71	3.54	18.33
Chestnut (*Castanea*)	-27.23	-2.30	45.17	1.23	42.81
Crabapple (*Malus*)	-26.29	-5.59	45.88	0.51	105.00
Hickory (*Carya*)	-28.85	-4.04	54.56	1.18	53.88
Raspberry (*Rubus occidentalis*)	-29.11	-2.24	49.87	0.91	64.24
Raspberry DUP (*Rubus occidentalis*)	-29.20	-1.00	49.57	1.28	45.08

Appendix H: Dentinal collagen isotopic composition and sample description
Appendix Hi: Modern white-tailed deer

Tooth	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{13}C_{col}$ +1.65‰	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Mod-deer-03					
M1	–21.62	–19.97	3.87	3.27	11.49
M2	–19.32	–17.67	4.25	3.26	8.06
M3	–17.06	–15.41	4.81	3.24	8.94
PM4	–18.19	–16.54	4.64	3.22	7.81
Mod-deer-07					
M1	–20.00	–18.35	6.71	3.26	8.51
M2	–18.41	–16.76	6.17	3.25	8.45
M3	–19.27	–17.62	5.97	3.24	8.16
PM4	–21.59	–19.94	6.03	3.26	8.40

Appendix Hii: Archaeological white-tailed deer

Tooth	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
BrB-011				
M1	–23.98	7.10	3.41	3.65
M2	–23.76	6.62	3.36	
M3	–22.78	6.95	3.43	11.90
PM4	–22.98	6.33	3.44	3.01
Clv-016				
M1	–22.55	7.97	3.22	9.00
M2	–22.34	8.00	3.20	6.62
M3	–21.94	7.75	3.14	7.19
PM4	–21.51	7.56	3.24	5.99
Clv-017				
M1	–22.44	7.73	3.46	6.34
M2	–21.54	8.07	3.24	3.69
M3	–21.26	8.20	3.24	3.08
PM4	–21.32	8.15	3.26	3.94
Clv-019				
M1	–22.79	7.57	3.20	726.00
M2	–21.99	7.47	3.19	5.87
M3	–22.26	6.75	3.22	8.57
PM4	–21.73	6.31	3.14	7.47
Van-020				
M1	–22.96	6.61	3.25	5.36
M2	–24.22	7.15	3.25	2.94
M3	–23.45	7.26	3.28	3.61
PM4	–23.93	6.43	3.30	4.67
IWP(01)-036				
M1	–24.28	7.31	3.32	4.50
M2	–23.80	7.20	3.25	4.61
M3	–23.33	6.72	3.29	3.87
PM4	–23.58	6.89	3.26	11.75
IWP(09)-054				
M1	–23.90	6.55	3.30	11.08
M2	–23.09	6.57	3.24	7.73
M3	–22.02	6.05	3.25	
PM4	–23.01	5.69	3.24	6.87
Mon-008				
M2	–23.02	6.53	3.10	0.89

Appendix HiiI: Archaeological dog

Tooth	$\delta^{13}C_{col}$ (‰,VPDB)	$\delta^{15N}{}_{col}$ (‰,AIR)	C:N	Collagen Yield (%)
Van-124				
M1	–16.53	10.67	3.73	3.71
M2	–14.84	9.99	3.43	3.77

Appendix I: Enamel structural carbonate isotopic composition
Appendix Ii: Modern white-tailed deer

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI	C/P
Mod-deer-03							
Mod-Deer-03M1 tip	–18.43	–16.78	24.72	82.2	5.9		
Mod-Deer-03M1 middle	–18.77	–17.12	24.59	65.6	6.4	3.25	0.28
Mod-Deer-03M1 cervix	–17.78	–16.13	23.69	84.7	5.9		
Mod-Deer-03M2 tip	–17.26	–15.61	22.37	54.9	3.7		
Mod-Deer-03M2 tip DUP	–16.51	–14.86	22.81	54.9	3.7	3.01	0.32
Mod-Deer-03M2 middle	–13.93	–12.28	22.17	84.7	4.1		
Mod-Deer-03M2 cervix	–12.98	–11.33	20.89	78.9	4.0		
Mod-Deer-03M3 tip	–11.38	–9.73	21.17	81.0	3.7		
Mod-Deer-03M3 middle	–10.99	–9.34	20.66	80.2	4.3	3.20	0.22
Mod-Deer-03M3 middle DUP	–10.63	–8.98	20.83	-	6.3		
Mod-Deer-03M3 cervix	–10.47	–8.82	22.07	76.3	4.0		
Mod-Deer-03PM3 tip	–12.03	–10.38	22.54	21.6	5.8		
Mod-Deer-03PM3 middle	–12.41	–10.76	24.23	18.9	3.9	3.22	0.35
Mod-Deer-03PM3 cervix	–14.54	–12.89	24.61	80.8	5.4		

Appendix Ii continued

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{13}C_{sc}$ +1.65‰	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI	C/P
Mod-deer-07							
Mod-Deer-07dpm3 bulk	–17.07	–15.42	25.71	39.3	4.8		
Mod-Deer-07M1 tip	–17.95	–16.30	25.30	25.0	4.5		
Mod-Deer-07M1 middle	–17.81	–16.16	25.20	50.3	5.5		
Mod-Deer-07M1 cervix	–16.74	–15.09	23.60	27.6	4.5	3.06	0.3
Mod-Deer-07M2tip	–15.56	–13.91	23.74	43.9	3.5		
Mod-Deer-07M2 middle	–12.95	–11.30	21.98	-	4.6		
Mod-Deer-07M2 middle DUP	–12.85	–11.20	22.29	83.4	3.9		
Mod-Deer-07M2 cervix	–14.04	–12.39	22.53	109.6	4.0		
Mod-Deer-07M3 tip	–12.62	–10.97	20.32	85.0	1.8	3.45	0.2
Mod-Deer-07M3 tip DUP	–12.44	–10.79	20.42	-	3.3		
Mod-Deer-07M3 middle	–13.89	–12.24	19.24	38.4	4.6		
Mod-Deer-07M3 middle DUP	–13.69	–12.04	19.08	-	3.7		
Mod-Deer-07M3 cervix	–14.70	–13.05	20.65	65.1	3.2		
Mod-Deer-07PM3 tip	–16.23	–14.58	24.29	65.8	2.7		
Mod-Deer-07PM3 middle	–16.57	–14.92	24.23	81.6	5.3		
Mod-Deer-07PM3 middle	–16.23	–14.58	24.33	-	4.0		
Mod-Deer-07PM3 cervix	–16.61	–14.96	23.51	56.7	4.0		

Appendix Iii: Archaeological white-tailed deer

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI*	C/P*
BrB-011 (Bruce Boyd Site)						
BrB-011 M1 tip	–17.28	24.18	85.7	4.1		
BrB-011 M1 middle	–17.77	24.65	179.7	3.7		
BrB-011 M1 cervix	–17.53	24.63	85.0	3.7		
BrB-011 M2 tip	–17.77	23.35	91.1	3.8		
BrB-011 M2 middle	–17.49	23.02	91.8	4.1	3.65	0.18
BrB-011 M2 cervix	–16.25	20.78	95.9	3.7		
BrB-011 M3 tip	–15.21	21.36	86.0	1.8		
BrB-011 M3 tip DUP	–15.43	21.54	-	3.9		
BrB-011 M3 middle	–14.56	18.82	92.4	3.4	3.62	0.18
BrB-011 M3 middle DUP	–14.79	19.10	-	3.7		
BrB-011 M3 cervix	–14.84	18.99	123.5	3.5		
BrB-011PM3 tip	–14.63	21.86	93.2	3.1		
BrB-011PM3 middle	–14.31	21.87	194.4	3.7		
BrB-011PM3 cervix	–14.08	23.09	95.2	3.3		
BrB-011PM1 bulk	–13.98	23.63	-	2.5	3.65	
BrB-011PM1 bulk mDUP	–13.81	23.66	64.5		3.43	0.22
Clv-016 (Cleveland Site)						
Clv-016M1 tip	–15.94	25.06	86.6	4.9		
Clv-016M1 middle	–16.02	23.98	85.0	4.8	3.14	0.29
Clv-016M1 cervix	–15.90	24.43	81.3	4.2		
Clv-016M2 tip	–15.62	23.31	87.3	4.0		
Clv-016M2 middle	–15.39	22.32	85.5	3.8	3.32	0.21
Clv-016M2 cervix	–14.99	20.69	84.5	4.9		
Clv-016M3 tip	–14.82	20.09	93.9	3.5		
Clv-016M3 tip mdup	–13.62	19.42	-	2.4		
Clv-016M3 tip mdup DUP	–13.61	19.82	76.3	3.8	3.50	0.19
Clv-016M3 middle	–14.21	21.31	85.5	4.0		
Clv-016M3 middlemDUP	–14.88	20.59	85.3	4.0		
Clv-016M3 cervix	–13.58	22.10	131.3	4.9		
Clv-016M3 cervix DUP	–14.16	22.17	-	4.7		
Clv-016PM3 tip DUP	–14.90	21.78	-	4.5		
Clv-016PM3 tip	–14.82	21.95	85.9	4.0		
Clv-016PM3 middle	–14.68	22.46	74.6	4.0		
Clv-016PM3 cervix	–14.70	23.40	40.5	4.0		

Appendix Iii continued

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI*	C/P*
Clv-017 (Cleveland Site)						
Clv-017M1 tip	–16.36	25.96	84.3	5.4		
Clv-017M1 middle	–16.07	26.00	84.7	5.9		
Clv-017M1 cervix	–15.90	25.62	84.3	5.6		
Clv-017M2 tip	–14.60	24.03	87.2	5.5		
Clv-017M2 middle	–14.17	22.69	80.6	5.6	3.52	0.21
Clv-017M2 cervix	–14.18	22.99	89.4	6.2		
Clv-017M3 tip	–14.36	22.31	91.6	4.4	3.45	0.21
Clv-017M3 middle	–14.42	22.22	89.1	4.9	3.34	0.23
Clv-017M3 cervix	–14.59	22.86	88.6	4.5		
Clv-017PM3 tip	–14.10	23.79	83.4	5.2		
Clv-017PM3 middle DUP	–13.88	24.47	80.0	3.3		
Clv-017PM3 cervix	–13.81	23.92	84.4	5.4		
Clv-019 (Cleveland Site)						
Clv-019M1 tip	–16.53	25.84	83.7	5.0		
Clv-019M1 middle	–16.43	25.83	85.0	5.4		
Clv-019M1 cervix	–14.66	24.02	87.0	6.4	3.13	0.27
Clv-019M2 tip	–15.71	23.65	94.2	4.7		
Clv-019M2 middle						
Clv-019M2 cervix	–13.49	22.27	91.5	7.0		
Clv-019M3 tip	–14.33	20.74	87.0	3.3		
Clv-019-M3 middle	–13.99	20.16	85.3	4.6	3.39	0.22
Clv-019-M3 cervix	–13.95	21.20	85.4	4.5		
Clv-019PM3 tip	–14.94	21.78	88.2	3.7		
Clv-019PM3 middle	–14.13	23.22	87.0	3.5		
Clv-019PM3 cervix	–13.66	23.73	84.1	4.0		
Van-020 (Van Besien Site)						
Van-020M1 tip	–16.91	23.85	86.7	4.2		
Van-020M1 middle	–17.61	24.13	88.8	4.9		
Van-020M1 cervix	–17.35	23.01	77.9	4.7		
Van-020M2 tip	–16.53	22.71	90.9	5.2		
Van-020M2 middle	–16.89	22.81	81.9		2.95	0.26
Van-020M2 middle DUP	–17.21	22.60	-			
Van-020M2 cervix	–17.21	22.21	87.3	4.5		
Van-020M3 tip	–15.38	20.49	87.1	4.3		
Van-020M3 tip mDUP	–15.19	20.41	81.5		3.33	0.22

Appendix Iii continued

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI*	C/P*
Van-020M3 middle	–14.99	20.48	90.0	4.4		
Van-020M3 middle DUP	–14.94	20.60	-	4.6		
Van-020M3 cervix	–14.86	21.92	88.6	4.9	3.44	0.22
Van-020PM3 tip	–14.49	22.83	86.0	3.9		
Van-020PM3 middle	–14.54	23.90	88.9	3.8	3.40	0.22
Van-020PM3 cervix	–14.84	24.43	87.4	4.1		
IWP(01)-036 (Figura Site)						
IWP(01)-036M1 tip	–17.30	22.97		5.8	2.67	0.63
IWP(01)-036M1 middle	–17.49	22.98		5.7		
IWP(01)-036M1 cervix	–16.63	21.88		5.4		
IWP(01)-036M1 cervix DUP	–16.67	21.55		5.2		
IWP(01)-036M2 tip	–17.15	21.93		5.4		
IWP(01)-036M2 middle	–15.68	20.62		6.0		
IWP(01)-036M2 middle mdup	–16.52	20.65		4.0	3.47	0.19
IWP(01)-036M2 cervix	–15.75	19.57		6.2		
IWP(01)-036M3 tip	–15.86	19.74		4.7		
IWP(01)-036M3 middle	–15.14	21.12		5.6		
IWP(01)-036M3 cervix	–14.51	22.38		5.1		
IWP(01)-036PM3 tip	–15.10	23.64		4.8		
IWP(01)-036PM3 middle	–14.69	23.94		5.3		
IWP(01)-036PM3 cervix	–14.99	22.69		6.1	3.08	0.32
IWP(01)-036PM3 cervix DUP	–14.92	22.63		5.7		
IWP(09)-054 (Inland West Aggregate Pit, Location 9)						
IWP(09)-054 M1 tip	–16.86	24.37	85.7	7.1	3.47	0.21
IWP(09)-054 M1 middle	–16.66	23.31	79.8	6.3		
IWP(09)-054 M1 cervix	–15.98	23.56	85.7	6.8		
IWP(09)-054 M1 cervix DUP	–16.92	23.71	-	4.6		
IWP(09)-054M2 tip	–15.98	22.87	88.8	6.1		
IWP(09)-054M2 middle	–15.53	21.57	88.5	6.1		
IWP(09)-054M2 cervix	–15.37	20.85	50.7	6.5		
IWP(09)-054M3 tip	–13.90	19.68	86.4	6.4		
IWP(09)-054M3 tip mdup	–14.42	19.44	72.2	3.0		
IWP(09)-054M3 tip	–13.83	19.40	86.4			
IWP(09)-054M3 middle	–13.81	19.84	88.6	6.2		
IWP(09)-054M3 cervix	–14.32	20.85	58.9	6.4	3.47	0.21
IWP(09)-054PM3 tip	–14.33	21.81	79.2	5.8		
IWP(09)-054PM3 middle	–14.84	22.14	72.9	6.1	3.47	0.19

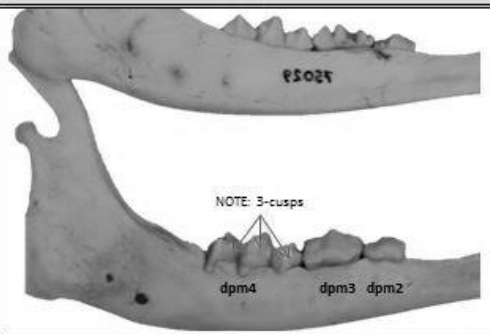
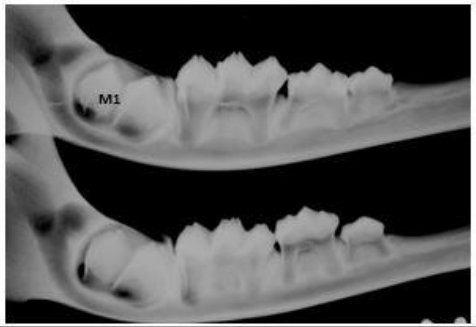
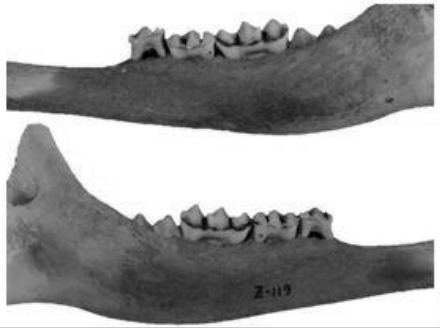
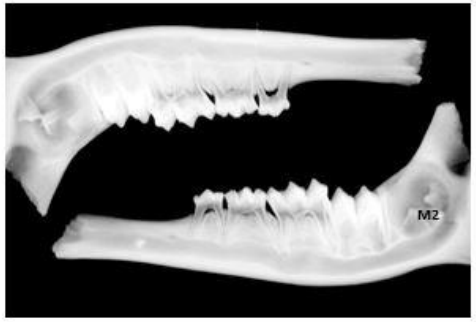
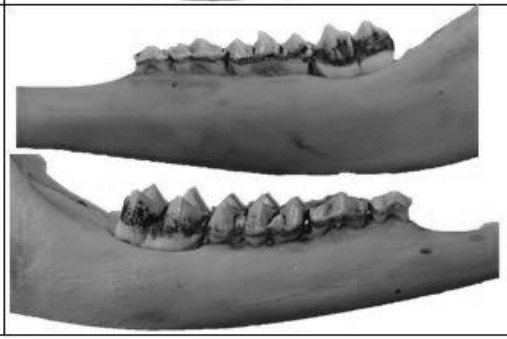
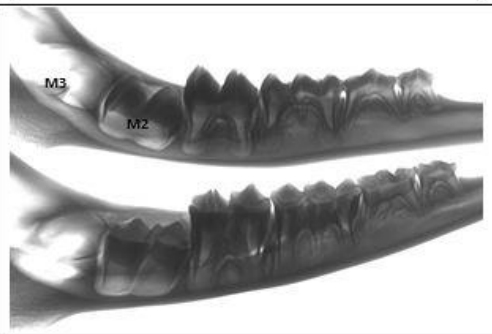
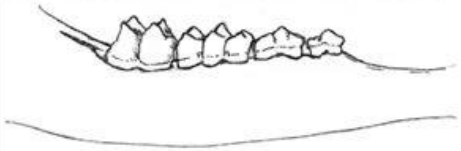
Appendix Iii continued

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI*	C/P*
IWP(09)-054PM3 cervix	–15.18	21.48	78.3	6.3		
IWP(09)-054PM3 cervix DUP	–15.71	21.65	-	5.3		
Mon-008 (Montoya Site)						
Mon-008M1 bulk	–17.94	24.75	92.2	4.2	3.36	0.19
Mon-008M2 tip	–15.71	23.21	93.9	3.4		
Mon-008M2 middle	–15.19	22.22	73.8		3.51	0.20
Mon-008M2 cervix	–14.62	21.06	90.9	3.9		
Mon-008PM2 tip	–14.70	23.78	89.0	3.7		
Mon-008PM2 middle	–13.76	23.46	96.9	3.8		
Mon-008PM2 cervix mDUP	–14.15	23.66	77.2	3.5		
Mon-008PM2 cervix	–14.66	23.81	90.9	3.5		

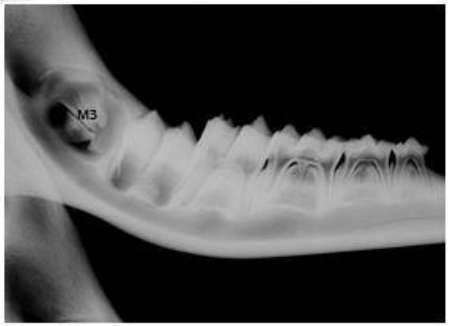
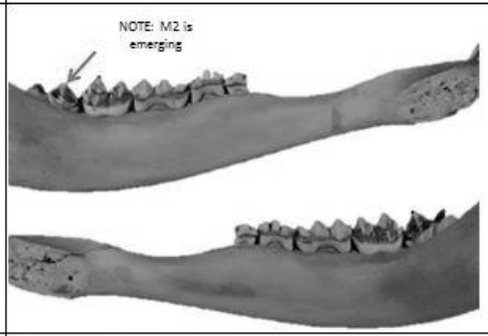
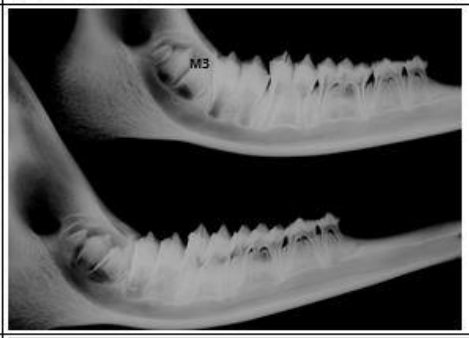
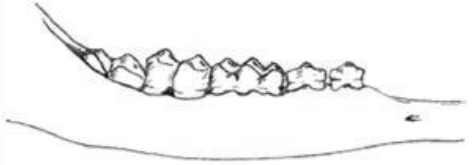
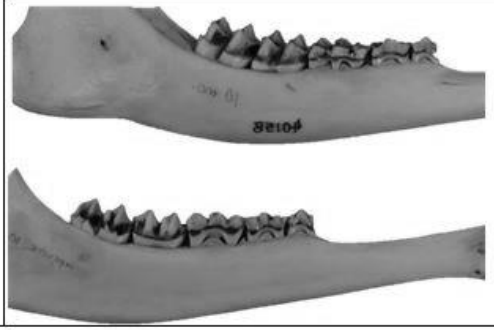
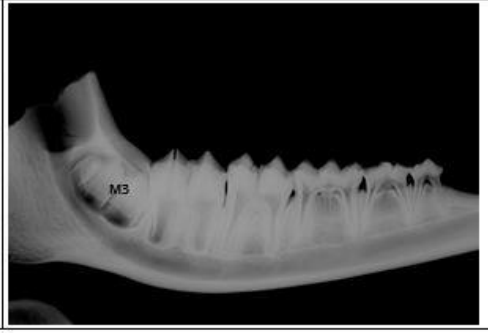
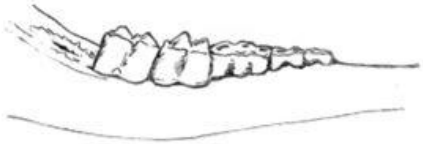
Appendix Iii: Archaeological dog

Sample	$\delta^{13}C_{sc}$ (‰,VPDB)	$\delta^{18}O_{sc}$ (‰,VSMOW)	Bioapatite (%)	CO_3 (%)	CI*	C/P*
Van-124 Van Besien Site						
Van-124 M1 tip 1.1	–6.87	24.51	82.30	5.15		
Van-124 M1 tip 1.2	–6.81	24.08	78.00	5.24		
Van-124 M1 tip 1.2 mDUP	–7.06	23.89	84.10	5.59		
Van-124 M1 tip 2	–6.50	23.92	78.90	5.14		
Van-124 M1 tip 2 DUP	–6.54	23.83	-	5.32		
Van-124 M1 middle	–6.38	23.53	84.00	5.20		
Van-124 M1 cervix	–6.07	22.84	86.50	5.94		
Van-124 M2 bulk	–5.96	23.01	88.00	5.09		

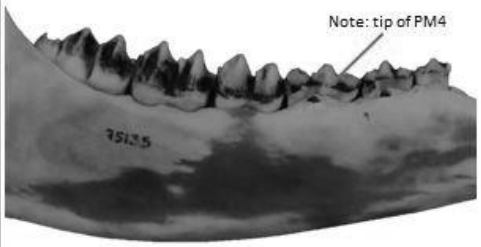
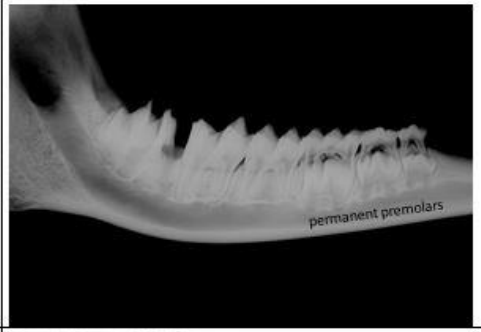
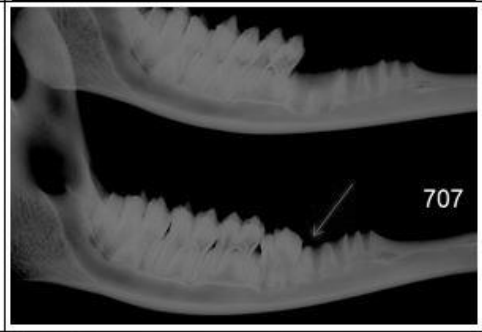
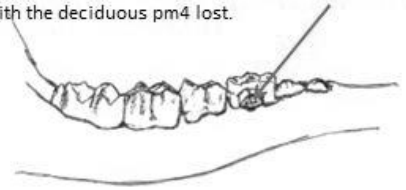
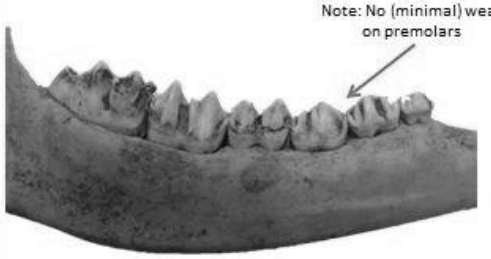
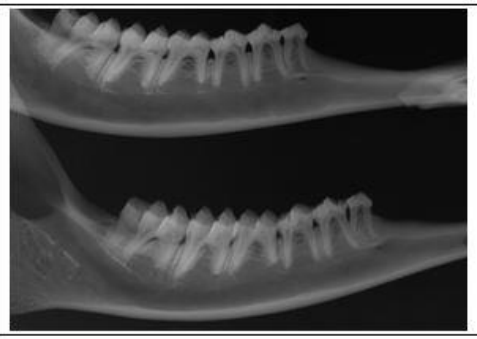
Appendix J: White-tailed deer eruption categories

Age Category	Photo	Radiograph	Comments
Birth to 1 month			White tailed deer are born with their deciduous premolars (dpm2, dpm3 and dpm4) but no permanent dentition has erupted. The first permanent molar (M1) is visible in the radiograph. NOTE the deciduous pm4 has 3 cusps. The premolars exhibit no wear.
2 to 4 months			The first permanent molar is erupting. Note that in the radiograph M2 has begun to form in its crypt. 
5 to 6 months			M1 has erupted and is in place, some wear is noticeable on the deciduous premolars. A fissue may be visible posterior to the M1 and the second permanent molar (M2) may be visible within its cyrpt but has not erupted. 

Appendix J continued

Age Category	Photo	Radiograph	Comments
6 to 7 months			M2 has just started to erupt and approximately 2 to 3 mm of cusps are visible above the alveolar bone line of 1 or 2 cusps. In the radiograph, M3 is mineralizing within its crypt.
7 to 9 months			M2 is in the process of erupting and there is increased wear on the decidulous premolars. In the radiograph, the crown of M3 has almost fully mineralized but has not begun erupting. 
10 to 13 months			The M2 has completely erupted but the third permanent molar (M3) has not begun erupted but may be visible in a fissure posterior to M2. There is increased wear on the deciduous premolars. 

Appendix J continued

Age Category	Photo	Radiograph	Comments
15 to 17 months			M3 is in the process of erupting. There is extensive wear on the deciduous premolars. The permanent premolars may be visible below the resorbing roots of the deciduous premolars but the deciduous premolars are still in place.
18 months			Deciduous premolars are lost and the permanent premolars are in the process of eruptiong. Photo at left shows deciduous pm4 with permanent premolar below. The radiograph shows the erupting permanent premolar with the deciduous pm4 lost. 
19 to 22 months			Permanent premolars are fully erupted but will exhibit no to minimal wear. There may be minimal wear on M2 and M3 and slight wear on the M1.

Appendix K: Radiograph specimen and parameters description

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814155112	**GI 051**	14-Aug-12	10secs 45kv	male 1 1/2, also labeled with a "7"
11-04 F74	**CMN 40158**	Jul-11	55-18-20	Quebec, 1973
11-04 F75	**CMN 75332**	Jul-11	60-18-20	1y ear female
I20120814144528	**GI 707**	14-Aug-12	10secs 40KV	yearling
11-04 F69	**CMN Z-119**	Jul-11	35-20-20	2 months
I20120814163917	**GI 057**	14-Aug-12	10secs 45kv	5 mo or less
I20120814145815	**GI 070**	14-Aug-12	10secs 40KV	5-6 mo fawn
11-04 F65	**CMN 75424**	Jul-11	30-17-17	fetal, whole skull
11-04 F66-4	**CMN 41065**	Jul-11	30-36-20	mislabeled as 75332
11-04 F72	**CMN 41063**	Jul-11	60-18-20	
11-04 F66-5	**CMN 75331**	Jul-11	30-36-20	fetal
11-04 F66-6	**CMN Z-676**	Jul-11	30-36-20	fetal
10-03 DF1-A	**ROM 1052**	Nov-10	Kodak digital xray	fetal, near birth
10-03 DF1-C	**ROM 1464**	Nov-10	Kodak digital xray	
10-03 DF1-D	**ROM 5625**	Nov-10	Kodak digital xray	1.1171 kg, fetal
10-03 DF1-F	**ROM 6842**	Nov-10	Kodak digital xray	3.275kg, fetal
11-04 F66-1	**CMN 75029**	Jul-11	30-36-20	fetal, near birth
11-04 F66-2	**CMN 75247**	Jul-11	30-36-20	fetal, near birth
11-04 F66-3	**CMN 75330**	Jul-11	30-36-20	fetal, near birth
I20120814163917	**GI 1004**	14-Aug-12	10secs 45kv	small male, yearling?
I20120814145815	**GI 1000**	14-Aug-12	10secs 40KV	small female
11-04 F71*	**CMN 75212**	Jul-11	50-19-20	0 to 2 months
I20120814161705^	**GI 194**	14-Aug-12	10secs 45KV	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814151009	**GI 075**	14-Aug-12	10secs 40KV	
I20120814163917	**GI 1003**	14-Aug-12	10secs 45kv	fawn mandible
I20120814161705	**GI 118**	14-Aug-12	10secs 45KV	
11-03 F1-2*	**Arch - Clv 07**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F1-3*	**Arch - Clv 08**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F2-4*	**Arch - Clv 09**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F1-1*	**Arch - Clv 11**	Jun-11	Faxitron 60 kvp, 5secs	
11-01 F3-3* max	**Arch - Van 25BT**	Mar-11	Faxitron 60 kvp, 5secs	
11-03 F2-3	**Arch - Clv 03**	Jun-11	Faxitron 60 kvp, 5secs	
10-01 F3-3	**Bio 87B**	Mar-10	Faxitron 60 kvp, 5secs	
I20120814142803	**GI 010 k**	14-Aug-12	10sec 40kv	
I201208141701019	**GI 015 e**	14-Aug-12	10secs 45kv	
I20120814160757	**GI 061**	14-Aug-12	10secs 45kv	
I20120814163917	**GI 063**	14-Aug-12	10secs 45kv	
I20120814151009	**GI 064**	14-Aug-12	10secs 40KV	
I20120814150424	**GI 066**	14-Aug-12	10secs 40KV	
I20120814162642	**GI 078**	14-Aug-12	10secs 45KV	
I20120814151009*	**GI 085**	14-Aug-12	10secs 40KV	
I20120814103616	**GI 098**	14-Aug-12	5secs 50kv	mandible only
I20120814155112	**GI 098**	14-Aug-12	10secs 45KV	skull with connected mandibles
I20120814144528	**GI 099**	14-Aug-12	10secs 40KV	
I20120814165412	**GI 1006**	14-Aug-12	10secs 45kv	small female, 1965 hunter kill
I20120814161705	**GI 117 ?**	14-Aug-12	10secs 45KV	
I20120814103616	**GI 123**	14-Aug-12	5secs 50kv	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814152015	**GI 129**	14-Aug-12	10secs 40KV	
I20120814165412	**GI 159**	14-Aug-12	10secs 45kv	
I20120814161705	**GI 184**	14-Aug-12	10secs 45KV	
I20120814160757	**GI 189 a**	14-Aug-12	10secs 45kv	
I20120814160757	**GI 189 b**	14-Aug-12	10secs 45kv	
I20120814144528	**GI D-3**	14-Aug-12	10secs 40KV	
10-03 DF2-A	**ROM 1207**	Nov-10	Kodak digital xray	
10-03 DF4-C	**ROM 5452**	Nov-10	Kodak digital xray	85lbs, males
10-03 DF1-G*	**ROM 744**	Nov-10	Kodak digital xray	
I20120814103616	**Zooarch 0001**	14-Aug-12	5secs 50kv	
I20120814141622*	**Arch - Pip(01) 001B**		10secs 40KV	archaeological deer, missing teeth
I20120814154054	**GI 008 h**	14-Aug-12	10secs 40KV	
11-03 F1-6	**Arch - Clv 01**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F3-2 DUP	**Arch - Clv 01**	Jun-11	no screen	
11-03 F2-2	**Arch - Clv 05**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F3-4 DUP	**Arch - Clv 05**	Jun-11	no screen	
11-01 F3-2	**Arch - IWP(1) 25BT**	Mar-11	Faxitron 60 kvp, 5secs	
11-01 F4-2b DUP	**Arch - IWP(1) 25BT**	Mar-11	no screen	
11-01 F4-1 DUP	**Arch - Pip(01) 001B**	Mar-11	no screen	
10-01 F4-5	**Bio T297**	Mar-10	Faxitron 60 kvp, 5secs	
I20120814154054	**GI 008 a**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 f**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 i**	14-Aug-12	10secs 40KV	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814154054	**GI 008 k**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 m**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 n**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 o**	14-Aug-12	10secs 40KV	
I20120814103616	**GI 010 m**	14-Aug-12	5secs 50kv	
I201208141701019	**GI 015 a**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 b**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 c**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 d**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 f**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 g**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 h**	14-Aug-12	10secs 45kv	
I201208141701019	**GI 015 i**	14-Aug-12	10secs 45kv	
I20120814155112	**GI 018c SAND 11**	14-Aug-12	10secs 45kv	
I20120814145815	**GI 095**	14-Aug-12	10secs 40KV	
I20120814165412	**GI 1007**	14-Aug-12	10secs 45kv	small fawn male, summer 66
I201208141701019	**GI 101**	14-Aug-12	10secs 45KV	also labelled with a "3"
I20120814103616	**GI 114**	14-Aug-12	5secs 50kv	
I20120814162642	**GI 116**	14-Aug-12	10secs 45KV	
I20120814162642	**GI 124**	14-Aug-12	10secs 45KV	
I20120814150424	**GI 132**	14-Aug-12	10secs 40KV	
I20120814161705	**GI 150**	14-Aug-12	10secs 45KV	6 mo fawn
I20120814162642	**GI 162**	14-Aug-12	10secs 45KV	bad xray, mandible tilted
I20120814165412	**GI 167**	14-Aug-12	10secs 45kv	5 to 6mo fawn, possible 107?

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814160757	**GI 169**	14-Aug-12	10secs 45kv	
I20120814150424	**GI 199**	14-Aug-12	10secs 40KV	
I20120814160757	**GI 210**	14-Aug-12	10secs 45kv	
I20120814103616	**Zooarch 0105**	14-Aug-12	5secs 50kv	
11-01 F3-5	**Zooarch 0105**	Mar-11	Faxitron 60 kvp, 5secs	adult
I20120814154054	**GI 008 g**	14-Aug-12	10secs 40KV	
10-01 F9-Mac	**Arch - Mac**	Mar-10	Faxitron 60 kvp, 5secs	
11-01 F1-1	**Arch - Pip(01) 001B**	Mar-11	Faxitron 60 kvp, 5secs	
10-03 DF3-B	**ROM 3972**	Nov-10	Kodak digital xray	
10-03 DF4-A	**ROM 598**	Nov-10	Kodak digital xray	
11-03 F1-5	**Arch - Clv 10**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F3-3 DUP	**Arch - Clv 10**	Jun-11	no screen	
11-01 F2-1	**Arch - IWP(1) 9BT**	Mar-11	Faxitron 60 kvp, 5secs	
I20120814154054	**GI 008 b**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 c**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 d**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 e**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 j**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 l**	14-Aug-12	10secs 40KV	
I20120814154054	**GI 008 p**	14-Aug-12	10secs 40KV	
I20120814141622	**GI 010 a**	14-Aug-12	10sec 40kv	
I20120814141622	**GI 010 h**	14-Aug-12	10sec 40kv	
I20120814141622	**GI 010 j**	14-Aug-12	10sec 40kv	
I20120814155112	**GI 018b SAND 14**	14-Aug-12	10secs 45kv	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814152015	**GI 1001**	14-Aug-12	10secs 40KV	juv, female, july 12, 1966, I-10
I20120814160757	**GI 1002**	14-Aug-12	10secs 45kv	small female, summer
I20120814163917	**GI 1005**	14-Aug-12	10secs 45kv	small male, july '66 (labelled 6a and 6b)
I20120814162642	**GI 151**	14-Aug-12	10secs 45KV	
I20120814163917	**GI 181**	14-Aug-12	10secs 45kv	
I20120814163917	**GI 185**	14-Aug-12	10secs 45kv	
I20120814165412	**GI 196**	14-Aug-12	10secs 45kv	
I20120814141622	**GI 228**	14-Aug-12	10secs 40KV	also labelled with "5b"
I20120814152015	**GI 233**	14-Aug-12	10secs 40KV	very small
10-03 DF2-B	**ROM 6736**	Nov-10	Kodak digital xray	
11-04 F73	**CMN 57060**	Jul-11	60-18-20	
10-01 F2-10	**Zooarch VanSas**	Mar-10	Faxitron 60 kvp, 5secs	
I20120814142803	**Arch - Clv 06**	14-Aug-12	10sec 40kv	
11-03 F1-8	**Arch - Clv 06**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F3-1 DUP	**Arch - Clv 06**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F1-4	**Arch - Clv 12**	Jun-11	Faxitron 60 kvp, 5secs	
10-01 F9-Van	**Arch - Van**	Mar-10	Faxitron 60 kvp, 5secs	
11-01 F3-4	**Arch - Van 21BT**	Mar-11	Faxitron 60 kvp, 5secs	adult
11-01 F4-4 DUP	**Arch - Van 21BT**	Mar-11	no screen	
10-01 F5-1	**Bio 211**	Mar-10	Faxitron 60 kvp, 5secs	
10-01 F5-2	**Bio 87c?**	Mar-10	Faxitron 60 kvp, 5secs	
11-04 F76	**CMN 55118**	Jul-11	60-18-20	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
I20120814142803	**GI 010 f**	14-Aug-12	10sec 40kv	
I20120814142803	**GI 010 g**	14-Aug-12	10sec 40kv	
I20120814141622	**GI 010 l**	14-Aug-12	10sec 40kv	
10-02 F1-3	**Zooarch no name**	Apr-10	Faxitron 60 kvp, 5secs	no sample ID with xray
11-03 F2-1	**Arch - Clv 02**	Jun-11	Faxitron 60 kvp, 5secs	
11-03 F3-5	**Arch - Clv 02**	Jun-11	no screen	repeat 11-03 F2-1
11-01 F1-6	**Arch - Fon 60BT**	Mar-11	Faxitron 60 kvp, 5secs	
11-03 F2-7	**Arch - Ham 1**	Jun-11	Faxitron 60 kvp, 5secs	
11-04 F70	**CMN 75135**	Jul-11	55-18-20	
I20120814152015	**GI 012 h**	14-Aug-12	10secs 40KV	also labelled with "3"
I20120814152015	**GI 012 i**	14-Aug-12	10secs 40KV	
10-03 DF2-C	**ROM 1088**	Nov-10	Kodak digital xray	
10-03 DF3-A	**ROM 451**	Nov-10	Kodak digital xray	
10-03 DF3-C	**ROM 568**	Nov-10	Kodak digital xray	
11-01 F2-4*	**Arch - IWP(1) 36BT**	Mar-11	Faxitron 60 kvp, 5secs	
10-01 F3-4 man	**Bio H**	Mar-10	Faxitron 60 kvp, 5secs	10-1 F4-4 max
I20120814142803	**GI A-1**	14-Aug-12	10sec 40kv	
11-01 F6-1	**Zooarch 0106**	Mar-11		
11-01 F2-5	**Arch - IWP(1) 47BT**	Mar-11	Faxitron 60 kvp, 5secs	
10-03 DF3-D	**ROM 3973**	Nov-10	Kodak digital xray	
11-03 F1-7	**Arch - Clv 04**	Jun-11	Faxitron 60 kvp, 5secs	fetal
11-03 F3-6 DUP	**Arch - Clv 04**	Jun-11	no screen	
10-01 F9-Fon	**Arch - Fon**	Mar-10	Faxitron 60 kvp, 5secs	
11-01 F1-7	**Arch - Fon 92BT**	Mar-11	Faxitron 60 kvp, 5secs	

Appendix K continued

X-Ray Name	Specimen Name	Date X-Rayed	X-Ray Type	Notes from Donator
10-03 DF1-B	**ROM 1050**	Nov-10	Kodak digital xray	
11-01 F1-2	**Arch - Pip(01) 017BT**	Mar-11	Faxitron 60 kvp, 5secs	
11-01 F1-3	**Arch - Pip(01) 103BT**	Mar-11	Faxitron 60 kvp, 5secs	
11-01 F1-4*	**Arch - Pip(01) 112BT**	Mar-11	Faxitron 60 kvp, 5secs	
10-01 F9-IWP	**Arch - IWP**	Mar-10	Faxitron 60 kvp, 5secs	
10-01 F7-6	**Bio T427/T429**	Mar-10	Faxitron 60 kvp, 5secs	
11-04 F68	**CMN 75330**	Jul-11	35-20-20	man and max
11-04 F67	**CMN 75331**	Jul-11	35-20-20	man and max
10-03 DF5-A	**ROM 1205**	Nov-10	Kodak digital xray	
10-03 DF4-B	**ROM 1208**	Nov-10	Kodak digital xray	
10-03 DF2-D	**ROM 744**	Nov-10	Kodak digital xray	

Specimen Name:
Arch = archaeological specimen
ROM = specimen courtesy of the Royal Ontario Museum
Bio = specimen courtesy of the Department of Biology, University of Western Ontario
CMN = specimen courtesy of from the Canadian Museum of Nature
GI = Griffith Island, specimen courtesy of the Department of Anthropology, University of Western Ontario
Zooarch = specimen courtesy of the Department of Anthropology, University of Western Ontario

*Not enough data or poor radiograph: Radiograph not used in analysis

Appendix L: Estimated age-at-death by eruption (with inter and intra obervations)

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814155112	**GI 051**	15 to 17 months	1 1/2			
11-04 F74	**CMN 40158**	10 to 13 months	1 year			
11-04 F75	**CMN 75332**	10 to 13 months	1 year			
I20120814144528	**GI 707**	18 months	1 year 6 mos			
11-04 F69	**CMN Z-119**	0 to 2 months	2 months			
I20120814163917	**GI 057**	5 to 6 months	5 mo or less			
I20120814145815	**GI 070**	5 to 6 months	5 to 6mo			
11-04 F65	**CMN 75424**	fetal	80 days old			
11-04 F66-4	**CMN 41065**	9 to 11 months	fetal			
11-04 F72	**CMN 41063**	fetal	fetal			
11-04 F66-5	**CMN 75331**	fetal	fetal			
11-04 F66-6	**CMN Z-676**	fetal	fetal			
10-03 DF1-A	**ROM 1052**	fetal	fetal			
10-03 DF1-C	**ROM 1464**	fetal	fetal			
10-03 DF1-D	**ROM 5625**	fetal	fetal			
10-03 DF1-F	**ROM 6842**	fetal	fetal			
11-04 F66-1	**CMN 75029**	fetal	near birth			
11-04 F66-2	**CMN 75247**	fetal	near birth			
11-04 F66-3	**CMN 75330**	fetal	near birth			
I20120814163917	**GI 1004**	7 to 9 months	yearling?			

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814145815	**GI 1000**	~6 months				
11-04 F71	**CMN 75212**	0 to 2 months				
I20120814161705	**GI 194**	4 months		4 months	b/w 2 to 4 and 5 to 6 months	5 to 6 months
I20120814155112	**GI 002 possibly**	4 to 5 months				
I20120814151009	**GI 075**	4 to 5 months				
I20120814163917	**GI 1003**	4 to 5 months				
I20120814161705	**GI 118**	4 to 5 months				
11-03 F1-2	**Arch - Clv 07**	5 to 13 months				
11-03 F1-3	**Arch - Clv 08**	5 to 13 months				
11-03 F2-4	**Arch - Clv 09**	5 to 13 months				
11-03 F1-1	**Arch - Clv 11**	5 to 13 months				
11-01 F3-3 max	**Arch - Van 25BT**	5 to 13 months				
11-03 F2-3	**Arch - Clv 03**	5 to 6 months				
10-01 F3-3	**Bio 87B**	5 to 6 months				
I20120814142803	**GI 010 k**	5 to 6 months		5 to 6 months	5 to 6 months	5 to 6 months
I201208141701019	**GI 015 e**	5 to 6 months				
I20120814160757	**GI 061**	5 to 6 months				
I20120814163917	**GI 063**	5 to 6 months				
I20120814151009	**GI 064**	5 to 6 months				
I20120814150424	**GI 066**	5 to 6 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814162642	**GI 078**	5 to 6 months				
I20120814151009	**GI 085**	5 to 6 months				
I20120814103616	**GI 098 ?**	5 to 6 months		5 to 6 months	5 to 6 months	5 to 6 months
I20120814155112	**GI 098 ?**	5 to 6 months				
I20120814144528	**GI 099**	5 to 6 months				
I20120814165412	**GI 1006**	5 to 6 months				
I20120814161705	**GI 117 ?**	5 to 6 months				
I20120814103616	**GI 123**	5 to 6 months		5 to 6 months	5 to 6 months	5 to 6 months
I20120814152015	**GI 129**	5 to 6 months				
I20120814165412	**GI 159**	5 to 6 months				
I20120814161705	**GI 184**	5 to 6 months				
I20120814160757	**GI 189 a**	5 to 6 months				
I20120814160757	**GI 189 b**	5 to 6 months				
I20120814144528	**GI D-3**	5 to 6 months				
10-03 DF2-A	**ROM 1207**	5 to 6 months				
10-03 DF4-C	**ROM 5452**	5 to 6 months				
10-03 DF1-G	**ROM 744**	5 to 6 months				
I20120814103616	**Zooarch 0001**	5 to 6 months		5 to 6 months	5 to 6 months	5 to 6 months
I20120814141622	**Arch - Pip(01) 001B**	5 to 7 months				
I20120814154054	**GI 008 h**	5 to 7 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
11-03 F1-6	**Arch - Clv 01**	6 to 7 months				
11-03 F3-2	**Arch - Clv 01**	6 to 7 months				
11-03 F2-2	**Arch - Clv 05**	6 to 7 months				
11-03 F3-4	**Arch - Clv 05**	6 to 7 months				
11-01 F3-2	**Arch - IWP(1) 25BT**	6 to 7 months				
11-01 F4-2b	**Arch - IWP(1) 25BT**	6 to 7 months				
11-01 F4-1	**Arch - Pip(01) 001B**	6 to 7 months		5 to 7 months		
10-01 F4-5	**Bio T297**	6 to 7 months				
I20120814154054	**GI 008 a**	6 to 7 months				
I20120814154054	**GI 008 f**	6 to 7 months				
I20120814154054	**GI 008 i**	6 to 7 months				
I20120814154054	**GI 008 k**	6 to 7 months				
I20120814154054	**GI 008 m**	6 to 7 months				
I20120814154054	**GI 008 n**	6 to 7 months				
I20120814154054	**GI 008 o**	6 to 7 months				
I20120814103616	**GI 010 m**	6 to 7 months		6 to 7 months	6 to 7 months	7 to 9 months
I201208141701019	**GI 015 a**	6 to 7 months				
I201208141701019	**GI 015 b**	6 to 7 months				
I201208141701019	**GI 015 c**	6 to 7 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I201208141701019	**GI 015 d**	6 to 7 months				
I201208141701019	**GI 015 f**	6 to 7 months				
I201208141701019	**GI 015 g**	6 to 7 months				
I201208141701019	**GI 015 h**	6 to 7 months				
I201208141701019	**GI 015 i**	6 to 7 months				
I20120814155112	**GI 018c SAND 11**	6 to 7 months				
I20120814145815	**GI 095**	6 to 7 months				
I20120814165412	**GI 1007**	6 to 7 months				
I201208141701019	**GI 101**	6 to 7 months				
I20120814103616	**GI 114**	6 to 7 months		5 to 6 months	5 to 6 months	5 to 6 months
I20120814162642	**GI 116**	6 to 7 months				
I20120814162642	**GI 124**	6 to 7 months				
I20120814150424	**GI 132**	6 to 7 months				
I20120814161705	**GI 150**	6 to 7 months				
I20120814162642	**GI 162**	6 to 7 months				
I20120814165412	**GI 167**	6 to 7 months				
I20120814160757	**GI 169**	6 to 7 months				
I20120814150424	**GI 199**	6 to 7 months				
I20120814160757	**GI 210**	6 to 7 months				
I20120814103616	**Zooarch 0105**	6 to 7 months		6 to 7 months	6 to 7 months	7 to 9 months
11-01 F3-5	**Zooarch 0105**	6 to 7 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814154054	**GI 008 g**	7 to 7 months				
10-01 F9-Mac	**Arch - Mac**	7 to 8 months				
11-01 F1-1	**Arch - Pip(01) 001B**	7 to 8 months				
10-03 DF3-B	**ROM 3972**	7 to 8 months				
10-03 DF4-A	**ROM 598**	7 to 8 months				
11-03 F1-5	**Arch - Clv 10**	7 to 9 months				
11-03 F3-3	**Arch - Clv 10**	7 to 9 months				
11-01 F2-1	**Arch - IWP(1) 9BT**	7 to 9 months				
I20120814154054	**GI 008 b**	7 to 9 months				
I20120814154054	**GI 008 c**	7 to 9 months				
I20120814154054	**GI 008 d**	7 to 9 months				
I20120814154054	**GI 008 e**	7 to 9 months				
I20120814154054	**GI 008 j**	7 to 9 months				
I20120814154054	**GI 008 l**	7 to 9 months				
I20120814154054	**GI 008 p**	7 to 9 months				
I20120814141622	**GI 010 a**	7 to 9 months		7 to 9 months	10 to 13 months	7 to 9 months
I20120814141622	**GI 010 h**	7 to 9 months		7 to 9 months	10 to 13 months	7 to 9 months
I20120814141622	**GI 010 j**	7 to 9 months		7 to 9 months	n/a	7 to 9 months
I20120814155112	**GI 018b SAND 14**	7 to 9 months				
I20120814152015	**GI 1001**	7 to 9 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814160757	**GI 1002**	7 to 9 months				
I20120814163917	**GI 1005**	7 to 9 months				
I20120814162642	**GI 151**	7 to 9 months				
I20120814163917	**GI 181**	7 to 9 months				
I20120814163917	**GI 185**	7 to 9 months				
I20120814165412	**GI 196**	7 to 9 months				
I20120814141622	**GI 228**	10 to 13 months		10 to 13 months	10 to 13 months	10 to 13 months
I20120814152015	**GI 233**	7 to 9 months				
10-03 DF2-B	**ROM 6736**	7 to 9 months				
11-04 F73	**CMN 57060**	9 to 11 months				
10-01 F2-10	**Zooarch VanSas**	10 to 11 months				
I20120814142803	**Arch - Clv 06**	10 to 13 months		10 to 13 months	10 to 13 months	10 to 13 months
11-03 F1-8	**Arch - Clv 06**	10 to 13 months				
11-03 F3-1	**Arch - Clv 06**	10 to 13 months				
11-03 F1-4	**Arch - Clv 12**	10 to 13 months				
10-01 F9-Van	**Arch - Van**	10 to 13 months				
11-01 F3-4	**Arch - Van 21BT**	10 to 13 months				
11-01 F4-4	**Arch - Van 21BT**	10 to 13 months				
10-01 F5-1	**Bio 211**	10 to 13 months				
10-01 F5-2	**Bio 87c?**	10 to 13 months				
11-04 F76	**CMN 55118**	10 to 13 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
I20120814142803	**GI 010 f**	10 to 13 months		10 to 13 months	10 to 13 months	10 to 13 months
I20120814142803	**GI 010 g**	10 to 13 months		10 to 13 months	10 to 13 months	10 to 13 months
I20120814141622	**GI 010 l**	10 to 13 months		10 to 13 months	10 to 13 months	10 to 13 months
	GI 110	10 to 13 months				
10-02 F1-3	**Zooarch no name**	10 to 13 months				
11-03 F2-1	**Arch - Clv 02**	15 to 17 months				
11-03 F3-5	**Arch - Clv 02**	15 to 17 months				
11-01 F1-6	**Arch - Fon 60BT**	15 to 17 months				
11-04 F70	**CMN 75135**	15 to 17 months				
I20120814152015	**GI 012 h**	15 to 17 months				
I20120814152015	**GI 012 i**	15 to 17 months		15 to 17 months	15 to 17 months	15 to 17 months
10-03 DF2-C	**ROM 1088**	15 to 17 months				
10-03 DF3-A	**ROM 451**	15 to 17months				
10-03 DF3-C	**ROM 568**	15 to 17months				
	C-1	17 months		17 to 18 months	18 months	18 months
11-01 F2-4	**Arch - IWP(1) 36BT**	18 months				
10-01 F3-4 man	**Bio H**	18 months				
I20120814142803	**GI A-1**	18 months		18 months	18 months	18 months
11-01 F6-1	**Zooarch 0106**	18 months				

Appendix L continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	Estimated by Donor (if provided)	Estimated by Zoe Morris (Intra)	Estimated by Faunal Expert (inter 1)	Estimated by Non-Expert (inter 2)
11-01 F2-5	**Arch - IWP(1) 47BT**	18 months +				
	D-1	18 months +		19 to 22 months	18 months	18 months
10-03 DF3-D	**ROM 3973**	19 months +				
	13 i	19 to 22 months				
11-03 F1-7	**Arch - Clv 04**	fetal				
11-03 F3-6	**Arch - Clv 04**	fetal				
10-01 F9-Fon	**Arch - Fon**	fetal				
11-01 F1-7	**Arch - Fon 92BT**	fetal		fetal		
10-03 DF1-B	**ROM 1050**	fetal				
11-01 F1-2	**Arch - Pip(01) 017BT**	less than 10 months				
11-01 F1-3	**Arch - Pip(01) 103BT**	less than 6 months				

Appendix M: Mandibular dental mineralization descriptions

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
11-04 F65	**CMN 75424**	fetal	NF	NF	NF	NF	NF	NF
11-04 F66-5	**CMN 75331**	fetal	forming	forming	forming	C.010	NF	NF
11-04 F66-6	**CMN Z-676**	fetal	decid	decid	decid	C.010	NF	NF
10-03 DF1-A	**ROM 1052**	fetal	forming	forming	forming	C.25	NF	NF
10-03 DF1-C	**ROM 1464**	fetal	forming	forming	forming	C.10	NF	NF
10-03 DF1-D	**ROM 5625**	fetal	forming	forming	forming	crypt	NF	NF
10-03 DF1-F	**ROM 6842**	fetal	decid	decid	decid	C0.1	NF	NF
11-04 F66-1	**CMN 75029**	fetal	decid	decid	decid	C0.5	NF	NF
11-04 F66-2	**CMN 75247**	fetal	decid	decid	decid	C0.5	NF	NF
11-04 F66-3	**CMN 75330**	fetal	decid	decid	decid	C0.25	NF	NF
11-03 F1-7	**Arch - Clv 04**	fetal	x	x	x	C1, RIGHT075	x	x
10-01 F9-Fon	**Arch - Fon**	fetal	x	x	decid	x	x	x
11-01 F1-7	**Arch - Fon 92BT**	fetal	x	x	decid .75	x	x	x
10-03 DF1-B	**ROM 1050**	fetal	forming	forming	fomring	crypt	NF	NF
11-04 F69	**CMN Z-119**	0 to 2 months	decid	decid	decid	C1, R0.50	C0.10	NF
11-04 F71	**CMN 75212**	0 to 2 months	decid	decid	decid	C0.75	crypt	NF
I20120814161705	**GI 194**	4 months	decid	decid	decid	C1 R0.5	C0.5	NF
I20120814155112	**GI 002 possibly**	4 to 5 months	decid	decid	decid	C1, R0.50	C0.25	NF
I20120814151009	**GI 075**	4 to 5 months	decid	decid	decid	C1, R0.75	C0.90	crypt starting

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814163917	**GI 1003**	4 to 5 months	decid	decid	decid	C1 R0.9	C0.75	NF
I20120814161705	**GI 118**	4 to 5 months	decid	decid	decid	complete	C1, RIGHT10	crypt
11-03 F1-2	**Arch - Clv 07**	5 to 13 months	decid	decid	decid	complete	x	x
11-03 F1-3	**Arch - Clv 08**	5 to 13 months	decid	decid	decid	complete	x	x
11-03 F2-4	**Arch - Clv 09**	5 to 13 months	decid	decid	decid	complete	x	x
11-03 F1-1	**Arch - Clv 11**	5 to 13 months	decid	decid	decid	complete	x	x
11-01 F3-3 max	**Arch - Van 25BT**	5 to 13 months	decid	decid	decid	complete	x	x
I20120814163917	**GI 057**	5 to 6 months	decid	decid	decid	C1, R0.50	C.050	NF
I20120814145815	**GI 070**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
11-03 F2-3	**Arch - Clv 03**	5 to 6 months	decid	decid	decid	complete	x	x
10-01 F3-3	**Bio 87B**	5 to 6 months	decid	decid	decid	complete	C1, RIGHT025	NF
I20120814142803	**GI 010 k**	5 to 6 months	x	decid	decid	complete	C1, R0.10	C0.10
I201208141701019	**GI 015 e**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814160757	**GI 061**	5 to 6 months	decid	decid	decid	C1, RIGHT90	C0.75	NF
I20120814163917	**GI 063**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	NF
I20120814151009	**GI 064**	5 to 6 months	decid	decid	decid	C1, R0.75	C0.90	crypt starting
I20120814150424	**GI 066**	5 to 6 months	decid	decid	decid	C1, R0.90	C1	crypt
I20120814162642	**GI 078**	5 to 6 months	decid	decid	decid	C1, RIGHT90	C0.75	crypt
I20120814151009	**GI 085**	5 to 6 months	decid	decid	decid	C1, R0.75	C0.90	crypt starting
I20120814103616	**GI 098**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	barely there
I20120814155112	**GI 098**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814144528	**GI 099**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814165412	**GI 1006**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814161705	**GI 117 ?**	5 to 6 months	decid	decid	decid	complete	C1, RIGHT10	crypt
I20120814103616	**GI 123**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814152015	**GI 129**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814165412	**GI 159**	5 to 6 months	decid	decid	decid	complete	C0.90	NF
I20120814161705	**GI 184**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814160757	**GI 189 a**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814160757	**GI 189 b**	5 to 6 months	decid	decid	decid	complete	C1, R0.25	C0.10
I20120814144528	**GI D-3**	5 to 6 months	decid	decid	decid	complete	C1, R0.10	C0.10
10-03 DF2-A	**ROM 1207**	5 to 6 months	decid	decid	decid	C1, R0.75	C0.75	NF
10-03 DF4-C	**ROM 5452**	5 to 6 months	decid	decid	decid	complete	C0.75	NF
10-03 DF1-G	**ROM 744**	5 to 6 months	decid	decid	decid	C1, R?	C?	forming
I20120814103616	**Zooarch 0001**	5 to 6 months	decid	decid	decid	complete	C1, R0.25	C0.10
11-01 F1-3	**Arch - Pip(01) 103BT**	less than 6 months	decid	decid	decid	C1, RIGHT90	x	x
I20120814145815	**GI 1000**	~6 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814141622	**Arch - Pip(01) 001B**	5 to 7 months	decid	decid	decid	x	C1, R0.50	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814154054	**GI 008 h**	5 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
11-03 F1-6	**Arch - Clv 01**	6 to 7 months	decid	decid	decid	complete	c1, right50	c.25
11-03 F2-2	**Arch - Clv 05**	6 to 7 months	decid	decid	decid	complete	c1, right25	c.25
11-01 F3-2	**Arch - IWP(1) 25BT**	6 to 7 months	decid	decid	decid	complete	c1, right25	cavity
10-01 F4-5	**Bio T297**	6 to 7 months	decid	decid	decid	complete	C1, R0.25	C.25
I20120814154054	**GI 008 a**	6 to 7 months	x	x	decid	complete	C1, R0.10	C0.10
I20120814154054	**GI 008 f**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	crypt
I20120814154054	**GI 008 i**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814154054	**GI 008 k**	6 to 7 months	x	decid	decid	x	C1, R0.10	C0.10
I20120814154054	**GI 008 m**	6 to 7 months	decid	decid	decid	complete	C1, RIGHT25	C0.10
I20120814154054	**GI 008 n**	6 to 7 months	decid	decid	decid	complete	C1, RIGHT25	C0.10
I20120814154054	**GI 008 o**	6 to 7 months	x	decid	decid	C1, RIGHT90	C1, R0.10	C0.10
I20120814103616	**GI 010 m**	6 to 7 months	decid	decid	decid	complete	C1, R0.50	C0.25

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I201208141701019	GI 015 a	6 to 7 months	decid	decid	decid	complete	C1, R0.25	C0.10
I201208141701019	GI 015 b	6 to 7 months	x	decid	decid	x	C1, R0.10	crypt
I201208141701019	GI 015 c	6 to 7 months	decid	decid	decid	complete	C1, R0.10	crypt
I201208141701019	GI 015 d	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I201208141701019	GI 015 f	6 to 7 months	decid	decid	decid	x	C1, R0.10	C0.10
I201208141701019	GI 015 g	6 to 7 months	decid	decid	decid	complete	C1, R0.10	crypt
I201208141701019	GI 015 h	6 to 7 months	decid	decid	decid	complete	C1, R0.10	x
I201208141701019	GI 015 i	6 to 7 months	decid	decid	decid	complete	C1, R0.25	x
I20120814155112	GI 018c SAND 11	6 to 7 months	decid	decid	decid	complete	C1, RIGHT10	crypt
I20120814145815	GI 095	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814165412	GI 1007	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I201208141701019	GI 101	6 to 7 months	decid	decid	decid	complete	C1, R0.25	C0.25
I20120814103616	GI 114	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814162642	**GI 116**	6 to 7 months	decid	decid	decid	complete	C0.75	NF
I20120814162642	**GI 124**	6 to 7 months	decid	decid	decid	complete	C1, R0.25	C0.10
I20120814150424	**GI 132**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814161705	**GI 150**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.25
I20120814162642	**GI 162**	6 to 7 months	decid	decid	decid	n/a	n/a	n/a
I20120814165412	**GI 167**	6 to 7 months	decid	decid	decid	complete	C1, R0.25	C0.25
I20120814160757	**GI 169**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814150424	**GI 199**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.25
I20120814160757	**GI 210**	6 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.25
I20120814103616	**Zooarch 0105**	6 to 7 months	decid	decid	decid	complete	C1, R0.50	C0.25
11-01 F3-5	**Zooarch 0105**	6 to 7 months	decid	decid	decid	c1, rightx	x	x
I20120814154054	**GI 008 g**	7 to 7 months	decid	decid	decid	complete	C1, R0.10	C0.10
10-01 F9-Mac	**Arch - Mac**	7 to 8 months	decid	decid	decid	complete	C1, RIGHT50	C.25

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
11-01 F1-1	**Arch - Pip(01) 001B**	7 to 8 months	decid	decid	decid	x	c1, right25	c.50
10-03 DF3-B	**ROM 3972**	7 to 8 months	decid	decid	decid	complete	C1, R0.10	crypt
10-03 DF4-A	**ROM 598**	7 to 8 months	decid	decid	decid	complete	C1, R0.10	crypt
I20120814163917	**GI 1004**	7 to 9 months	decid	decid	decid	complete	C1, R0.10	C0.10
11-03 F1-5	**Arch - Clv 10**	7 to 9 months	decid	decid	decid	complete	c1, right50	x (cavity)
11-01 F1-4	**Arch - Pip(01) 112BT**	n/a	decid	decid	x	x	x	x
11-01 F2-1	**Arch - IWP(1) 9BT**	7 to 9 months	decid	decid	decid	complete	c.1	x
I20120814154054	**GI 008 b**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C1, R0.10
I20120814154054	**GI 008 c**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.10
I20120814154054	**GI 008 d**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.25
I20120814154054	**GI 008 e**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.10
I20120814154054	**GI 008 j**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814154054	**GI 008 l**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.25
I20120814154054	**GI 008 p**	7 to 9 months	decid	decid	decid	complete	C1, R0.10	C0.10
I20120814141622	**GI 010 a**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.50
10-01 F9-IWP	**Arch - IWP**		decid	decid	decid	complete	0.5	nf
I20120814141622	**GI 010 h**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.25
I20120814141622	**GI 010 j**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.25
I20120814155112	**GI 018b SAND 14**	7 to 9 months	decid	decid	decid	complete	C1, RIGHT25	C0.10
I20120814152015	**GI 1001**	7 to 9 months	decid Ccrypt	decid C0.10	decid C0.10	complete	complete	C1,R0.90
I20120814160757	**GI 1002**	7 to 9 months	decid	decid	decid	complete	C1, R0.25	C0.10
I20120814163917	**GI 1005**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.25
I20120814162642	**GI 151**	7 to 9 months	decid	decid	decid	complete	C1, R0.25	C0.25
I20120814163917	**GI 181**	7 to 9 months	decid	decid	decid	complete	C1, R0.25	C0.25
I20120814163917	**GI 185**	7 to 9 months	decid	decid	decid	complete	C1, R0.25	C0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
I20120814165412	**GI 196**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.25
I20120814152015	**GI 233**	7 to 9 months	decid	decid	decid	complete	C1, R0.50	C0.25
10-03 DF2-B	**ROM 6736**	7 to 9 months	decid	decid	decid	complete	C1, R0.75	0.1
11-04 F66-4	**CMN 41065**	9 to 11 months	decid	decid	decid	complete	C1, R0.75	C1
11-04 F73	**CMN 57060**	9 to 11 months	decid	decid	decid	complete	C1, R0.75	C1
11-01 F1-2	**Arch - Pip(01) 017BT**	less than 10 months	decid	decid	decid	x	x	x
10-01 F2-10	**Zooarch VanSas**	10 to 11 months	decid	decid	decid	complete	C1, RIGHT75	C0.90
11-04 F74	**CMN 40158**	10 to 13 months	decid	decid	decid	complete	complete	C1, RIGHT010
11-04 F75	**CMN 75332**	10 to 13 months	decid, C0.10	decid, C0.10	decid, C0.10	complete	complete	C1, RIGHT0.1
I20120814141622	**GI 228**	10 to 13 months	decid	decid	decid	complete	complete	C1, R0.10
I20120814142803	**Arch - Clv 06**	10 to 13 months	decid	decid	decid	complete	complete	C1, R0.10
11-03 F1-8	**Arch - Clv 06**	10 to 13 months	decid	decid	decid	complete	c1, right95	c1

Appendix M continued

X-Ray #	Specimen Name	Estimated by Zoe Morris	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
11-03 F3-1	**Arch - Clv 06**	10 to 13 months						
11-03 F1-4	**Arch - Clv 12**	10 to 13 months	decid	decid	decid	complete	root socket	x
10-01 F9-Van	**Arch - Van**	10 to 13 months	decid	decid	decid	complete	c1, right75	c.5
11-01 F3-4	**Arch - Van 21BT**	10 to 13 months	decid	decid	decid	complete	c1, right75	c.75
11-01 F4-4	**Arch - Van 21BT**	10 to 13 months						
10-01 F5-1	**Bio 211**	10 to 13 months	decid	decid	decid	complete	C1, R0.25	C.25
10-01 F5-2	**Bio 87c?**	10 to 13 months	decid	decid	decid	complete	c1, right5	c.5
11-04 F76	**CMN 55118**	10 to 13 months	decid	decid	decid	complete	C1, R0.75	C1, R0.25
I20120814142803	**GI 010 f**	10 to 13 months	decid C.10	decid C.10	decid C.25	complete	complete	C1, R0.10
I20120814142803	**GI 010 g**	10 to 13 months	x C.10	decid C.10	decid C.10	complete	complete	C1
I20120814141622	**GI 010 l**	10 to 13 months	decid	decid	decid	complete	complete	C1, R0.10
10-02 F1-3	**Zooarch no name**	10 to 13 months	decid	decid	decid	complete	complete	C1, R0.25
I20120814155112	**GI 051**	15 to 17 months	decid C1, RIGHT50	decid C1, RIGHT50	decid C1, RIGHT50	complete	complete	C1,R0.10

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
11-03 F2-1	**Arch - Clv 02**	15 to 17 months	complete	complete	c1, right95	complete	complete	complete
11-01 F1-6	**Arch - Fon 60BT**	15 to 17 months	C1, R0.75	C1, R0.75	C1, R0.75	x	x	x
11-03 F2-7	**Arch - Ham 1**	15 to 17 months	c1, right5	c1, right75	c1, right75	complete	complete	x
11-04 F70	**CMN 75135**	15 to 17 months	decid, C0.75	decid, C0.75	decid, C0.75	complete	complete	C1, RIGHT0.75
I20120814152015	**GI 012 h**	15 to 17 months	decid C1, RIGHT75	decid C1, RIGHT75	decid C1, RIGHT75	complete	complete	C1,R0.90
I20120814152015	**GI 012 i**	15 to 17 months	decid C1, RIGHT75	decid C1, RIGHT75	decid C1, RIGHT75	complete	complete	C1,R0.90
10-03 DF2-C	**ROM 1088**	15 to 17 months	decid, C0.75	decid, C0.75	decid, C0.75	complete	complete	C1, RIGHT0.50
10-03 DF3-A	**ROM 451**	15 to 17months	decid, C0.75	decid, C0.75	decid, C0.75	complete	complete	C1, RIGHT0.50
10-03 DF3-C	**ROM 568**	15 to 17months	decid, C0.50	decid, C0.50	decid, C0.50	complete	complete	C1, RIGHT0.25
I20120814144528	**GI 707**	18 months	x	x	C1, RIGHT90	complete	complete	C1,R0.90
11-01 F2-4	**Arch - IWP(1) 36BT**	18 months	x	complete	complete	complete	complete	complete
10-01 F3-4 man	**Bio H**	18 months	Erupting	Erupting	Erupting	complete	complete	complete
I20120814142803	**GI A-1**	18 months	C1, R0.75	C1, R0.75	decid resorbed C1, R0.75	complete	complete	complete

Appendix M continued

X-Ray #	Specimen Name	Estimated Age	mandibular dental mineralization (x = missing, nf= not formed, crown [C] and root [R] estimate 0-1)					
			premolar 1	premolar 2	premolar 3	molar 1	molar 2	molar 3
11-01 F6-1	**Zooarch 0106**	18 months	c1, right75	x	c1, right75	complete	complete	complete
11-01 F2-5	**Arch - IWP(1) 47BT**	18 months +	x	complete	complete	complete	complete	complete
10-03 DF3-D	**ROM 3973**	19 months +	complete	complete	complete	complete	complete	complete

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Louisiana State Univesity
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2007 Ph.D.

Honours and Awards:

Province of Ontario Graduate Scholarship
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Research Western Graduate Thesis Research Award
2010, 2011

Social Science and Humanities Research Council (SSHRC)
J. Armand Bombardier Doctoral Award
2008-2011

Great Ideas for Teaching Award
Teaching Support Centre, The University of Western Ontario
2009

Graduate Student Teaching Award, Social Sciences
Teaching Support Centre, The University of Western Ontario
2008

Province of Ontario Graduate Scholarship
2008 (declined)

Western Graduate Research Doctoral Scholarship
2007-2008

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2006

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2005

Related Work Experience :

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2012-2013

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2011-2012

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2008, 2011

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2005-2006

Ethnographic Research Assistant and Interviewer
Louisiana State University
2006, 2007

Publications:
Morris, Z.H. (2011) The Value of a Four-Field Approach to Anthropology, Part II. Anthropology News. Canada, K.A. (ed.) Section News, National Association of Student Anthropologists (NASA). November Issue.

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Presentations:

2013 Ellis, L., A. Suda, A. Nelson, R. Martin, **Z.H., Morris**, E. Moffatt, J. Poulin, R. Newman, H. Sobol and I. Lefebvre
Investigating miniature masterpieces: The technical study of boxwood prayer beads in the Thomson Collection at the Art Gallery of Ontario. *Heritage Wood: Research & Conservation in the 21st Century*. Warsaw, Poland, October 28-30.

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2012 Nelson, A., Butler, J.R., Garvin, G., Gelman, G., Moran, G, Wade, A.D. and **Morris. ZH..**
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2012 **Morris, Z.H.**, White, C., Longstaffe, F. and Hodgetts, L.
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Woodland. *Ontario Archaeological Society* Annual Meeting, Windsor, ON, November 9-11.

2012 Ellis, L., Martin, R., Moffatt, E., **Morris, Z.H.**, Nelson, A. & R. Newman. Prayer Beads in the Thomson Collection at the Art Gallery of Ontario: Materials and Construction," *Proceedings from Prayer Nuts, Private Devotion and Early Modern Art Collecting*. Abegg-Stiftung, Riggisberg, Switzerland, International Colloquium, 20–21 September 2012.

2012 **Morris, Z. H.,** White, C. Longstaffe, F., Hodgetts, L. and Ferris, N. Life-stages, landscapes and human-deer interactions during the Ontario Late Woodland period: isotopic, radiographic and histological evidence. Published abstract of the 77th Annual Meeting of the *Society for American Archaeology,* Memphis TN, April 18-22.

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2011 **Morris, Z.H.**, White, C., Longstaffe, F. and Hodgetts, L. Life-stages, landscapes and human-deer interactions during the Ontario Late Woodland period: The isotopic evidence. Proceedings of *Deer and People: Past, Present and Future,* Riseholme Park, University of Lincoln, England, September 8-11.

2010 **Z.H. Morris**, C. White. L. Hodgetts, N. Ferris and F. Longstaffe. Life-stages, landscapes and human-deer interactions during the Ontario Late Woodland period: The Growing Places:Late Woodland (AD 1000-1600) Agricultural Landscapes in Southwestern Ontario. 11th *International Conference of the International Council for Archaeozoology*, Paris, August 23-28.

2009 **Z.H. Morris**, M. Manhein and G. Listi Size Matters, but So Does Location: A Consideration of Human and Nonhuman Secondary Osteon Area for Bone Fragment Identification, 37th Annual Meeting of the *Canadian Association for Physical Anthropology*, Vancouver, October 28-31.

2008 **Z.H. Morris,** M. Manhein and G. Listi Quantitative and Spatial Analysis of the Microscope Bone Structures of Deer (*Odocoileus virginianus*), Dog (*Canis familiaris*), and Pig (*Sus scrofa*

domesticus), poster presentation, 73rd Annual Meeting of the *Society of American Archaeology*, Vancouver March 26-30.

2008 **Z.H. Morris,** M. Manhein and G. Listi
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2007 **Z.H. Morris**
Visions of a Whole Community: Role of Vietnamese-American Youth Leaders in the New Orleans East Village Recovery, Annual Meetings of the *American Ethnological Society* (subsection CASCA), Toronto, May 9-12.

2007 **Z.H. Morris** and H. McKillop
The Ancient Maya and the Sea: The Cays, the Coast and Underwater in Belize, A Biological Profile of the Moho Cay and Wild Cane Burials, 72nd Annual Meeting of the *Society of American Archaeology*, Austin, April 25-29.

2006 **Z.H. Morris**
Rebuilding Community and Creating Voice: the New Orleans Vietnamese East Village, Annual Meeting Race, *Ethnicity & Place: Race Ethnicity and Katrina*, San Marcos November 3.

2006 **Z.H. Morris**
Visions of a Whole Community: Role of Vietnamese-American Young Leaders in the New Orleans East Village During and Post Katrina, Annual Meeting of the *American Folklore Society*, Milwaukee, October 18-22.

2006 **Z.H. Morris**
Creating Voice Post Katrina: Vietnamese Community of New Orleans East Village After Katrina: Rebuilding Cultures, Rebuilding Landscapes, Baton Rouge June 17.

2006 **Z.H. Morris**
Active Engagement of Identity Construction by Vietnamese American Youth Activists in Village De L'Est, New Orleans, 66th Annual Meeting of the *Society for Applied Anthropology*, Vancouver, March 28-Apr 2.

2006 **Z.H. Morris**
Bridging: Role of Vietnamese American Youth Activists from New Orleans East, 50th Annual Meeting of the Louisiana Folklore Society, Lafayette, March 25.

2005 **Z.H. Morris** and C. Crowder
Reducing Intra- and Inter-Observer Error Through Histomorphometric Variable Selection, *American Association of Forensic Sciences*, New Orleans, Feb 21-26.