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Reconstructing childhood and adulthood diets from a Caribbean population using stable carbon and nitrogen isotope analysis of dentin and bone collagen

By

Hillary Sparkes

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Abstract

The purpose of this study was to establish stable carbon (C) and nitrogen (N) isotope signatures for the 43 individuals in this study population using bone and dentin collagen, and extrapolate the isotopic data to dietary regimes using historical and archaeological evidence as indirect baseline data. This research used stable isotope analysis to reconstruct the diets of 43 individuals recovered from the archaeological site of Sainte-Marguerite on the island of Guadeloupe in the West Indies. This site was excavated in response to severe erosion that threatened it. The site has been dated to the colonial era (circa A.D. 1800) and has been identified as a possible slave burial ground. This study continues previous research conducted in the region by Varney (2003). The bone collagen from 16 individuals and dentin samples from all 43 individuals were isolated in this study and analysed. Isotopic data for bone collagen from 27 of the 43 individuals taken from the study by Varney (2003). C and N isotope signatures were analyzed to compare changes in diet over the course of an individual's life. There was a substantial change in diet from childhood to adulthood for 20 of the 43 individuals. This shift in diet was reflected in an increase in $\delta^{15}N$ values and a positive shift in $\delta^{13}C$ values compared to the dentin isotope signatures. No significant differences based on age or sex could be identified. The majority of individuals were consuming a mixed C_3 and C_4 diet. This is consistent with historic accounts that indicate staple grains like maize and millet were consumed in large proportions along with root crops such as cassava. The individuals in this population are thought to be slaves from the region because of their isotopic values that correspond with predicted dietary ranges for

slaves in that region. The dentin dietary signatures reflect a variety of dietary ranges that reflect multiple regions of origin. The observed dietary changes in 20 of the 43 individuals may reflect geographic movement related to their enslaved status.

There were also four individuals with dental modification, a practice common in Africa during colonial times, who show significant dietary difference between childhood and adult signatures reflecting a probable geographic movement during life from Africa to the West Indies.

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Chapter 1: Introduction

1.1 Introduction

Dietary reconstruction has become a common tool in bio-archaeology to trace life histories and residential movements of past peoples (Katzenberg, 2001; Schwarcz and Schoeninger, 1991). Tracing residential movements or mobility patterns focuses on both free and forced movements of people and populations. Large geographic movements are often the cause of major dietary shifts that can influence the composition of an individual's skeletal tissues. Stable isotope analyses of skeletal tissues can be used to reconstruct dietary signatures and then to extrapolate potential movements of past peoples. Dietary reconstruction through the use of stable isotopes can also be used as an indicator of social status because differential access to foodstuffs can be a sign of separation of socio-economic class.

This thesis focuses on a skeletal population from a historic cemetery at the site of L'Anse Sainte Marguerite located on the North East coast of the island of Guadeloupe in the West Indies. It is a cemetery of considerable size with 210 burials excavated to date and is one of the largest sites to have been excavated in the area. The human remains were recovered from this site as part of a salvage excavation program that was developed in response to its exposure to inclement weather. Previous study of the site and of the human remains (Courtaud and Romon, 2003) has determined that the individuals from L'Anse Sainte Marguerite were most likely enslaved Africans and African descendants living during colonial times (approx. A.D. 1750-1800). Relatively little archaeological work in cemeteries had been done in the West Indies until recently when the influx of hurricanes and

ever encroaching development made it necessary. The application of stable isotopic analysis of human remains to archaeological questions has only recently been employed in this geographic area.

Researchers have used stable isotope analysis extensively to address archaeological questions in many parts of the world, however, Varney (2003) was the first to use such techniques to reconstruct the diet of a historical skeletal population in the West Indies. This study will build on the above-mentioned work by Varney (2003) by further exploring the application of stable isotopes to trace changes in diet at different life stages using various skeletal tissues for comparison.

Bone and teeth are used for stable isotope analysis because each tissue provides a reflection of diet during different phases of an individual's life. Bone is a dynamic tissue that can repair itself, and remodel over time. As a person's bone remodels it will take the necessary dietary elements and incorporate them into the new bone tissue. The rate at which a bone turns over will govern what time period of a person's life is reflected in these tissues. Bone samples in dietary reconstruction studies can be separated into two different components: an organic portion of type I collagen protein and an inorganic mineral phase made of hydroxyapatite (Gage *et al.*, 1989). Collagen, when formed, utilizes the dietary protein portion of the diet while hydroxyapatite is formed using elements from the whole diet. Different methods applied to the bone samples can separate each component of the tissue to isolate the desired portion. Stable isotope analysis of the two portions allows reconstruction of different aspects of an individual's diet thereby revealing larger picture of that person's life history.

In comparison, teeth are unique structures in the body because they do not remodel in the same way as bones after they have been completely formed. Enamel and primary dentin (see Chapter 3 for further explanation) do not change throughout life. Secondary dentin is produced later in life in response to damage and stress experienced by the teeth, but it does not affect or change the composition of primary dentin.

At birth the deciduous tooth crowns have begun to form and are contained in the alveolar crypts of the mandible and maxilla. The permanent teeth begin forming shortly after birth (Hillson, 1996). The majority of the samples in this study were taken from permanent molars and premolars. The crown of the first permanent molar is complete by three years of age in most individuals. The roots of the first molar do not finish their development until year 12. The first and second premolars begin forming late in the second year of life but can be postponed into the third year. By year six the premolar crowns are complete (Hillson, 1996). Teeth are primarily made up of two tissues: enamel and dentin. Enamel is a highly mineralized substance much like the hydroxyapatite found in bones. Conveniently, dentin and bone share a similar composition; the organic portion of dentin consists mainly of type I collagen and is present in approximately the same proportion in both tissues (Hillson, 1996:). Dentin and bone collagen are formed using similar portions of the diet; all collagen in the body being primarily formed from dietary protein (Ambrose and Norr, 1992). The similar compositions between dentin and bone collagen make them ideal for comparison in stable isotope analysis and dietary reconstruction studies. Because teeth do not turn over once they have been

formed they maintain the dietary signature of a very young age whereas bone will reflect diet consumed in adulthood.

Early stable isotope studies began investigating diet using bone tissues from adult and juvenile skeletal material (Schoeninger, 1989; Katzenberg, 1991). An issue that developed from this method was that a mortality bias was introduced to the sample population because of the juvenile material (Wood *et al.*, 1992). These young individuals entered the archaeological record at a young age because of unknown factors affecting their health; the cause of death may influence their isotopic signature and not reflect a 'normal' diet. To avoid this bias, researchers began using enamel from permanent dentition (DeNiro, 1987; Dupras and Tocheri, 2007; Katzenberg, 1993). As mentioned above teeth maintain a juvenile signature, so by accessing enamel from adult individuals, researchers are able to isolate a healthy juvenile diet. Sealy *et al.* (1993; 1995) conducted pioneering studies using dentin tissue as an alternative method to dental enamel. Dentin isotope data produce results that return information about the dietary habits of individuals at a young age. In a study by Cox and Sealy (1997), the authors chose to use primary dentin because it is laid down in childhood, does not remodel during an individual's life and it has high collagen content. It is possible to identify a shift in diet using collagen from bone and teeth because although each tissue represents a different stage of an individual's life, they both have similar compositions.

1.2 Purpose and Hypothesis of the Study

This study aims to reconstruct the childhood diets of a West Indies skeletal population using stable isotope analysis of dentin collagen. Once a childhood dietary signature has been established, this study will compare the data to adulthood dietary signatures obtained from the bone collagen of the same individuals. The reconstruction of the diets in different stages of life, and the comparison of those diets will reveal details of both group and individual life histories and mobility patterns.

Very little is known about the individuals recovered from the site of L'Anse Sainte Marguerite. One objective in this study is to learn about the childhood diets of the slave population in the West Indies who lived during colonial times. A second objective is to examine whether there were changes in diet between childhood and adulthood and extrapolate that information to possible geographic movements. It is the aim of this study to present new information about these individuals and contribute to our understanding of where they may have originated.

The West Indies had a large enslaved population in the colonial era. This study will attempt to determine, by using stable isotope methods, whether these individuals were born in Africa and brought to the West Indies or if they were born and raised in the West Indies. Based on the results from previous research conducted by Varney (2003) using stable isotope analysis on bone collagen, bone apatite and enamel apatite from the Sainte Marguerite population it is hypothesized that many of the individuals in this study will have a childhood diet that reflects an isotopic signature from West Africa and an adult diet from the West Indies.

Secondly, it is hypothesized that certain individuals will have isotopic signatures from both dentin and bone collagen that reflect a consistent diet throughout life. One possible interpretation would be a consistent West Indies diet from childhood to adulthood indicating that the West Indies was a place of origin. An alternate interpretation is the individual did not survive long enough in the West Indies for the bones to remodel and incorporate the isotopic values from the new environment.

Chapter 2: Stable Isotopes

2.1 What are Isotopes?

Isotopes are variations of an element that have different numbers of neutrons but the same number of protons in their nuclei. Isotopes maintain the same number of electrons, which does not affect the charge or mass of the atom. The loss or addition of a neutron alters the atomic weight of the atom creating isotopes of the same element without changing the atoms charge (Hoefs, 1987). An atom's charge is important in how it responds during chemical reactions and the number of protons also defines what the element is. Isotopes of a single element will behave in a similar way during a chemical reaction; however, the rate at which a reaction occurs is altered and is one way the isotopes can be distinguished. The change in reaction speed is caused by the difference in atomic weight; the smaller, lighter isotopes will react faster compared to the heavier slower version of the element (Schoeninger and Moore, 1992). While there are approximately 300 identified elements that have isotopes, the most common isotopes used in archaeological research are: carbon, nitrogen, oxygen, strontium, sulphur and hydrogen (Schoeninger and Moore, 1992). Carbon and nitrogen are well established in the reconstruction of diet and were used in this study.

Carbon has three isotopes; ^{14}C, ^{13}C and ^{12}C. ^{13}C and ^{12}C are the stable forms of carbon isotopes used for dietary reconstruction and ^{14}C is a radioactive form that is not used for this type of research (Sealy, 1986). Nitrogen has two stable isotope forms: ^{14}N and ^{15}N.

2.2 Assessment Techniques for Sample Quality

Dietary reconstruction studies that use stable isotope analysis are possible because our body tissues are manufactured from the foods we eat. There are many processes and metabolic pathways that function to maintain a constant chemical composition in our tissues (Sealy *et al.*, 1993). Isotopic studies aim to identify many aspects of a past population such as types of food consumed, what proportion of the diet is represented by each food element and how the food being consumed changes over time or throughout an individual's life (Chisholm, 1989; Schoninger and Moore, 1992).

Before assessing isotopic values it is important to verify that the collagen extracted from samples is of good quality. Collagen is a strong fibrous molecule that when well preserved holds its shape. A good bone model is expected to maintain its original shape, be rubbery and translucent. Adequate bone models are produced when collagen is not well preserved causing small portions to break away from the main body of the sample. Poorly preserved models will break apart and appear frayed because the collagen fibers have degraded. When preparing a sample it is important that all biogenic signals be intact and reliable to produce quality data. Good quality collagen is free of contaminants that may develop postmortem in the burial environment; organic material that invades the bone can affect the collagen signal. It is important to determine the quality of collagen in a sample because a poor sample is not likely to contain proteinaceous material suitable for isotopic analysis (see Ambrose, 1990, 1993; Schoeninger *et al.*, 1989).

The chemical composition of each sample can be verified to assess the condition; checking the carbon to nitrogen (C/N) ratio will identify if a sample is of good or poor quality. The specific and unique composition of collagen produces a C/N ratio that is different from other types of proteins found in the body. Collagen has approximately 1000 amino acids that make up the collagen chain. Of these 1000 amino acids approximately every third is glycine. Glycine makes up almost 30% of the amino acids in collagen; this glycine content produces a C/N ratio of 3:1 in collagen. Other proteins in the body do not contain such high glycine levels and tend to have a C/N ratio of 5:1. The differences in C/N ratios allow researchers to establish the presence of collagen in a sample (Schoeninger and Moore, 1992).

Modern bone samples have C/N ratios ranging from 2.84 – 3.52 (DeNiro, 1985; Ambrose, 1990). A range between 2.90 and 3.54 for prehistoric samples is considered well preserved. Above or below this range indicates that a sample is of poor quality and should be treated with caution because potential diagenetic modification may have occurred (Ambrose, 1990). Schoeninger and Moore (1992) caution that C/N ratios should not be relied upon to indicate a good sample, however a poor C/N ratio should indicate rejecting a sample for analysis.

Often studies will use the collagen yield in conjunction with the C/N ratio to assess sample quality. The collagen yield describes the amount of organic material that can be isolated from an archaeological bone and is then expressed in terms of percent of the dry weight of the initial whole bone sample. Low collagen yields indicate that a sample has experienced a large degree of protein loss and/or degradation resulting in little or no collagen present. A low collagen yield could also

indicate that the little amount of collagen present has been contaminated and broken down, which would alter the isotopic signature (Ambrose, 1990, 1993; DeNiro and Weiner, 1988). Bones with low collagen yields of less than 5% have been rejected in previous studies while other researchers use a cut off of 1-2% (Ambrose, 1990). Values lower than the suggested cut offs mentioned above have been found to differ isotopically from fresh bone (Ambrose and DeNiro, 1989; Schoeninger *et al.*, 1989). Samples with very high collagen yields (>25%) may indicate incomplete demineralization which can alter the actual isotopic values if residual carbon remains in the sample (DeNiro and Weiner, 1988).

2.3 Isotopes Used in This Study

2.3.1 Carbon Isotopes

Changes in a person's diet can be identified with stable isotope research when the proper chemical elements from skeletal tissues are isolated and analyzed. Using two or more chemical elements together in a study is beneficial because the elements in an individual's diet are broken down and used as the body synthesizes many different types of tissues. The elements that are incorporated into a body's tissue from the diet are used in different proportions and to create different aspects of the tissue. For example, carbon found in collagen is mainly derived from the protein of the entire diet but can also be synthesized from fats and carbohydrates. In contrast, nitrogen is integrated into an individual's tissue directly from primary

dietary protein sources and only reflects the protein portion of the diet (Sillen *et al.*, 1989; van der Merwe *et al.*, 1987).

Carbon isotopes can be used to distinguish between the type(s) of plant matter consumed by an animal; similarly nitrogen isotopes can be used to identify animal protein in the diet based on trophic levels. For more information about the dietary resources available to the sample population in this study refer to Chapter 5. Stable carbon and nitrogen isotopes will be used in this study to reconstruct the diets of the individuals in the sample population. Carbon is an effective element for use in paleodietary research because of the two stable forms that occur naturally in the environment. ^{13}C comprises approximately 1.1% of the naturally occurring carbon while ^{12}C is more abundant making up roughly 98.9% of the naturally occurring carbon (Schoeninger and Moore, 1992; Chisholm, 1989).

Plants, depending on their adaptations to their environments, will use an appropriate photosynthetic pathway to incorporate carbon into their tissues (Schoeninger and Moore, 1992). As explained below, the photosynthetic pathways use carbon isotopes differently and produce different carbon ratios in the plant tissues. The differential use and incorporation of the isotopes during photosynthesis allows researchers to identify the different types of plants being consumed. Certain plants use the Calvin pathway, a photosynthetic process that favours the lighter ^{12}C isotope and they are called C_3 plants. C_4 plants that use the Hatch-Slack photosynthetic pathway favour the heavier ^{13}C isotope (Schoeninger and Moore, 1992; Chisholm, 1989; Sealy, 1986). Generally C_3 plants are found in temperate areas and include trees, shrubs, grains and most vegetables, while C_4

plants are found in tropical environments and include maize, millets and other tropical grasses (Schwarcz *et al*, 1985). There are plants that do have the ability to incorporate both carbon isotopes freely; they are called Crassulacean acid metabolism (CAM) plants (Sealy *et al.*, 1986).

C_3 plants commonly have an average δ^{13} C value of -26‰ and a range between -22‰ to -38‰ while C_4 plants are less negative with a δ^{13} C range between -9‰ and -21‰ with an average value of -13‰ (Tieszen, 1991; Chisholm, 1989; Katzenberg *et al.*, 1995). The CAM plants produce an intermediate δ^{13} C range between C_3 and C_4 plant δ^{13} C values (Francey and Farquhar, 1982; Tieszen, 1991). Carbon moves through the foodweb beginning with primary consumers that eat plant foods and continues up the chain as secondary and tertiary consumers eat species lower in the food web. Carbon becomes incorporated into a consumer's system, such as humans, mainly through the consumption of plant foods and by consuming lower level animals. The higher consumers' isotopic signature can then be evaluated and the types of carbon sources they were consuming can be identified (Sealy, 1986).

A second process that needs to be mentioned is the fractionation that occurs within an animal's tissues. As an animal consumes plant foods the chemical signature of those plants will be recombined into the consumer's tissue. The enrichment between diet and bone of an animal is approximately 5‰. This means that a diet based on C_3 plants will return a value of -21.5‰ (-26.5 + 5‰) and a C_4 diet will have a value of -7.5‰ (-12.5 + 5‰) (Chisholm, 1989). Carbon isotopes are very effective in identifying types of plants consumed.

As humans consume a diet that consists of a variety of plants and animals, the individual's tissues will incorporate the δ^{13}C signature of their foods. Isotopic values for individuals with specific diets have been determined and are used to evaluate isotopic signatures in unknown samples. An individual that eats a diet entirely of marine resources should have an average δ^{13}C value of -11.4‰, while someone who consumes a terrestrial C_3 diet will have a bone collagen δ^{13}C of -18.9‰. If an individual were to consume a diet equal in terrestrial C_3 and marine food stuffs their δ^{13}C for bone collagen would be -15.2‰ (Ambrose, 1993; Chisholm, 1989; Sealy, 1986). Using values such as the ones above, from a similar area to the sample population being studied can offer baseline data to assess the diet of unknown persons. The δ^{13}C values for each sample is compared to an international standard called PeeDee Belemnite (PDB) a marine carbonate. The PDB is a way to calculate the δ^{13}C values. The values are negative because most biological samples have less ^{13}C relative to ^{12}C than the PDB standard.

2.3.2 Nitrogen Isotopes

Nitrogen, the second element used in this study, has two stable isotopes ^{15}N and ^{14}N with a natural abundance ratio of 0.36 to 99.64% (Schoeninger and Moore, 1992). Similar to carbon, nitrogen is also compared to an internal standard. The ambient inhalable reservoir (AIR) is used because the isotope ratio of N_2 in the atmosphere does not vary across the globe (Schoeninger and Moore, 1992).

Nitrogen fixation can occur when nitrogen fixing organisms (bacteria) found in bacterial nodules on their roots break down organic material and makes nitrogen available to the surrounding plants. This bacterial process functions as a plant's

tissues are synthesized and result in δ^{15} N values with an isotopic signature similar to atmospheric N_2. Legumes use this process and rely on the nitrogen fixing bacteria around their roots. There is very little fractionation that occurs causing legumes to have δ^{15} N values of approximately 0 ‰ with a range of -3‰ to 5‰ (DeNiro, 1987).

Secondly, non-legume plants obtain their nitrogen found in the soils surrounding them derived from the decay of organic material. Plants using this process will have slightly more positive δ^{15} N values compared to the first example of legumes with an average of 9‰ (DeNiro, 1987).

Nitrogen reflects dietary protein by trophic level changes in a diet (Schurr, 1997). The trophic levels correspond with animals in the foodweb. Animals higher in the food web will have higher trophic levels as well as increased δ^{15} N values. The trophic levels can indicate what types of protein an individual was consuming. Nitrogen can also indicate a change between marine and terrestrial protein sources if skeletal tissues like bone and teeth are available for comparison (Schoeninger, 1989).

While δ^{15}N values are useful for tracing trophic levels, δ^{13} C values in a trophic system are only increased by 1‰, an increase that is not noticeable when the overall variation of a population is taken into consideration. Dupras and Tocheri (2007) noticed an approximate 5‰ increase in nitrogen values from plants to human collagen. They also observed an approximately 3 ‰ increase in nitrogen values from one level of the food chain to the next (Dupras and Tocheri, 2007). Researchers are able to identify what types of protein animals or individuals were

eating because of the regular average increase of nitrogen in trophic levels. Stable nitrogen isotope ratios of a species reflect their trophic position in the food chain.

Generally, carnivores have higher trophic levels than animals lower on the food chain because the carnivores are consuming other animal tissues. Humans generally consume a large amount of animal protein, therefore their $\delta^{15}N$ levels are expected to be high as well (Katzenberg, 2001). Nitrogen can be distinguished between the flesh of terrestrial animals and fish. Studies have shown that freshwater fish have an average δ^{15} N value of 10.4‰ and terrestrial herbivores have an enriched value of 3‰ giving a mean δ^{15} N value of 6.0‰ because of the trophic effect (Morton and Schwarcz, 2004). When herbivores eat plants, the $^{15}N/^{14}N$ ratio becomes higher in the herbivores' tissues compared to the ratio seen in plants and this trophic increase continues up the food wed from herbivores to carnivores and humans (Katzenberg *et al.*, 1995; Schoeninger and Moore, 1992). See Figure 2.2 for a detailed illustration of nitrogen traveling through the foodweb.

The trophic effect seen in nitrogen isotopes makes it useful when comparing terrestrial and marine diets. Marine food webs are much more complex than terrestrial environments because there are more levels to cause a nitrogen enrichment in the tissues.

Figure 2.1 is a representation of the dietary ranges produced from different plants and animals in various food webs. While figure 2.2 illustrates how the isotopic values for the different food types would be arranged when the δ^{13} C and δ^{15} N values are compared. It also illustrates the expected values from specific foodstuffs.

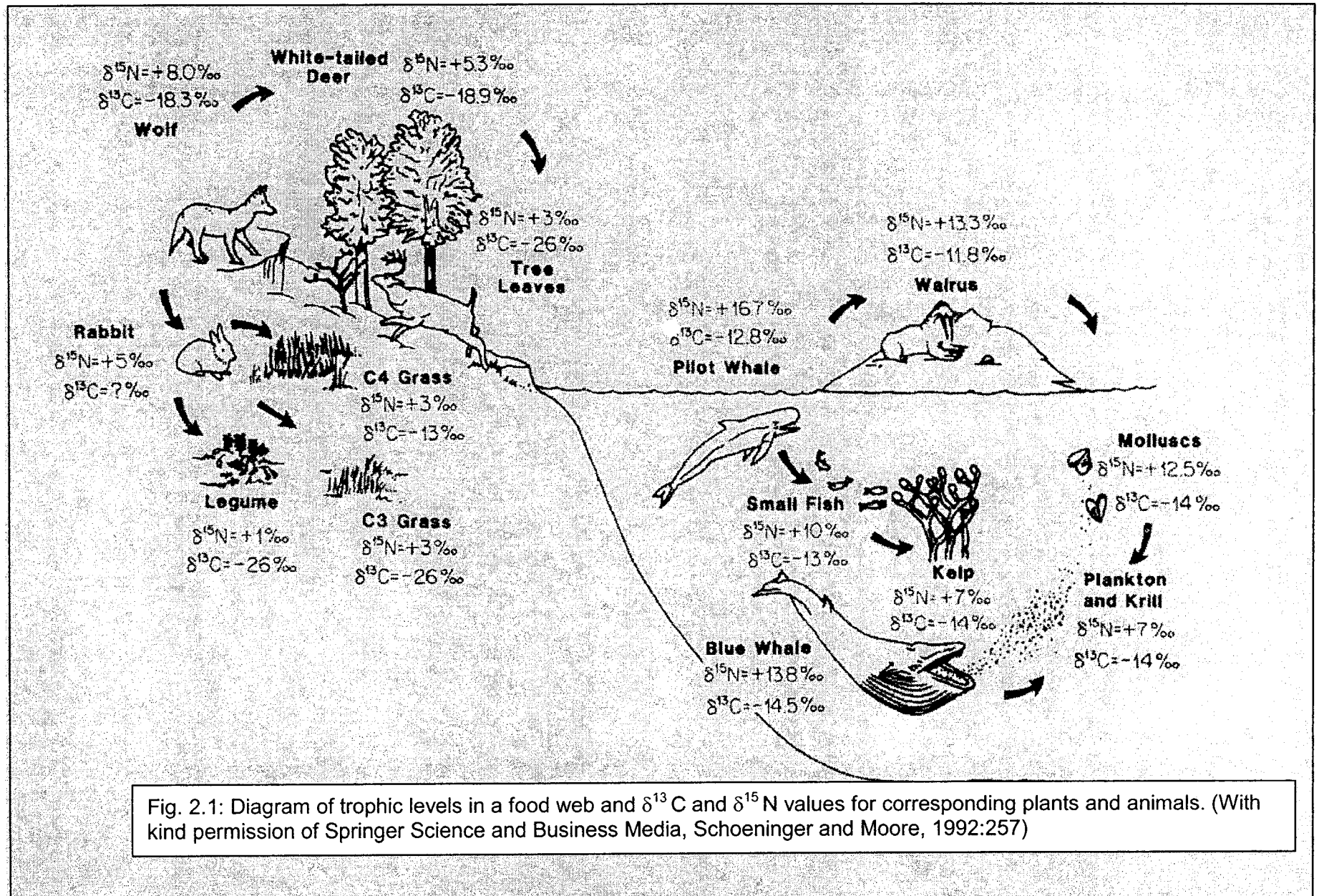

Fig. 2.1: Diagram of trophic levels in a food web and $\delta^{13}C$ and $\delta^{15}N$ values for corresponding plants and animals. (With kind permission of Springer Science and Business Media, Schoeninger and Moore, 1992:257)

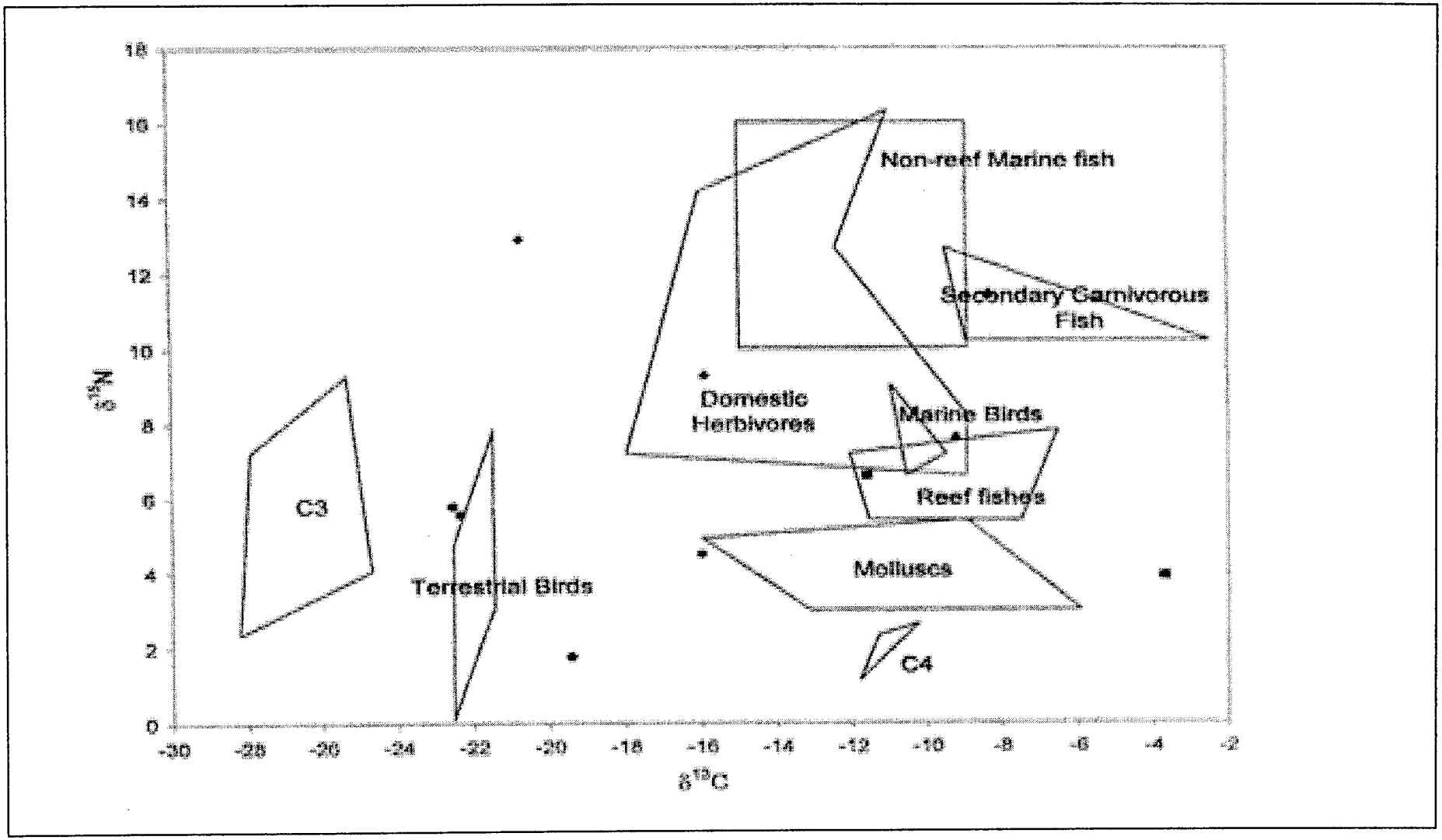

Figure 9.1: $\delta^{13}C$ and $\delta^{15}N$ values for possible foodstuffs in colonial age diet. Data compiled from Ambrose 1993; Schoeninger and DeNiro 1984; Keegan and DeNiro 1988; Varney 2003. Shapes were drawn for data groups of more than 4 individuals. Data points were assigned to groups of less than 4 individuals.

2.3.3 Limitations to Stable Isotope Analysis

A major limitation to stable isotope analysis and dietary reconstruction is post depositional contamination of collagen found in bone. The burial context around a skeleton can influence its chemical composition and alter the isotopic signatures of the bones. This alteration can occur by either the addition or loss of elements. resulting in isotopic changes. The recovery of an original biological signature free of diagenetic alterations is very important to the success of these studies (Price *et al.*, 2000).

Humic acids and nitrogen containing compounds are two contaminants that commonly affect collagen samples. Fungi and bacteria are potential catalysts that cause breakdown of organic material that may result in the alterations of bone collagen (Schoeninger and Moore, 1992). Studies have shown that collagen will last up to 10 000 years in tropical and sub tropical environments, however in different climates the time frame will be altered and length of preservation reduced (Sillen *et al.*, 1989).

Along with diagenesis[1], another concern about collagen use is how, during life, dietary resources were used to form bodily tissues. Biological processes involved in separating required elements and nutrients from the diet do not synthesize all elements equally or in the same manner to form tissues. Specific elements required at the time of tissue synthesis to complete the necessary tissues

[1] Diagenesis is a term borrowed from Geology that pertains to the physical, chemical and/or biological changes in sediments or sedimentary rocks. In Biological Anthropology we refer to diagenesis as the process of physical, chemical and/or biological change that occurs to bones in the burial context.

are selected based on need (Schoneneger and Moore, 1992). If certain fractions of the diet (ie. fats, carbohydrates and protein) are used instead of a full representation of the foods being consumed then it is important to know the proportion of diet that is being utilized for the production of new tissues to interpret the isotopic values. For example, all carbon necessary for tissue production is, in theory, provided by carbohydrates, protein and lipids, which are derived from the entire diet. However, nitrogen is only supplied by protein; the source of this protein may be from plants or animals. Determining the source of protein, whether it is derived from all sources or from one source is important to understand the nitrogen isotopic signals (Schoeninger and Moore, 1992). Although the notion that all diet components are represented equally during tissue synthesis has support (see Ambrose, 1993; Katzenberg, 2001; Lehninger, 1975 for reviews), it has been shown that in cases where animal protein sources are abundant, like marine rich environments, the isotopic signatures may reflect a preference to protein over other dietary elements (Kruger and Sullivan, 1984, Schoeninger and Moore, 1992).

Being aware of the limitations mentioned above, and the techniques to assess the quality of a sample, will ensure that researchers are producing and working with adequate samples and isotopic signatures. It is important to know about the burial context, environment and how these criteria may have influenced the skeletal sample to avoid poor quality samples. As will be discussed in Chapter 4, stable isotopes have been used extensively in the past for dietary reconstruction with excellent results.

Chapter 3: Tissues Used in Stable Isotope Analysis

3.1 Introduction

Stable isotope analysis of skeletal tissues has allowed researchers to explore a variety of new questions that previously could not be answered because the appropriate methods were not available. Innovative techniques of extracting material from skeletal tissues have given researchers the ability to produce evidence of past people's biographies. The type of skeletal tissue employed in dietary reconstruction studies depends on the research question being posed. Bony elements remodel at different rates while other portions of the skeleton do not change once they have been formed. The fact that the period of life each skeletal tissue represents differs allows for reconstruction of diet at different stages in the lifespan. The two main tissues used in dietary reconstruction and stable isotope studies involving an archaeological population are bone and teeth. As will be discussed later in this chapter, bone remodels over time and will represent an adult isotopic signature. Teeth on the other hand do not remodel and therefore maintain a childhood dietary signature from the time teeth are formed early in life.

This chapter provides a brief outline of the main components of the skeletal elements used in this study in terms of their composition and relevant properties. An examination of how each element is useful for isotopic studies will be made. Lastly, an analysis of why it is beneficial to use bone and dental tissues together in this study will be outlined.

3.2 Bone Tissue

The adult human skeleton is a collection of approximately 206 dynamic bone structures that can repair and reshape themselves. Bone is a composite structure made from both non organic mineral and organic protein sources. Bone consists of 30% organic material, and 70% mineral. The mineral in bone is from the apatite family (Price, 1989). Collagen proteins make up 90% of the organic component of bone, the other portion consists of non-collagenous proteins and lipids (Miller, 1984). Collagen also makes up the bulk of the organic portion of tooth dentin (Hillson, 1996). Collagen provides bones with their flexibility and the hydroxyapatite mineral is responsible for the rigidity (White and Folkens, 2005).

There are four main variants of collagen found in the body; the dominant type of collagen is Type I. Type I is found both in teeth and in bone; structurally Type I collagen is made up of three amino acid chains that all coil tightly around each other into a triple helix structure making it strong like a rope (Gage *et al.*, 1989; Hillson, 1996). This tightly coiled structure provides strength to the molecule and because of this structure it is able to withstand degradation and diagenetic factors (Hillson, 1996).

Bone is made from two types of tissue: cortical and trabecular (See Figure 3.1). On a molecular and cellular level these two types of bone are identical, differing only on the structural level. Cortical bone is a dense solid bone that is found on the walls of long bones while trabecular bone is spongy and made of thin spicules commonly found inside the shaft of long bones in the medullary cavity

(White and Folkens, 2005). Trabecular bone adds tensile strength and makes bone lighter because of its high porosity (Price, 1989).

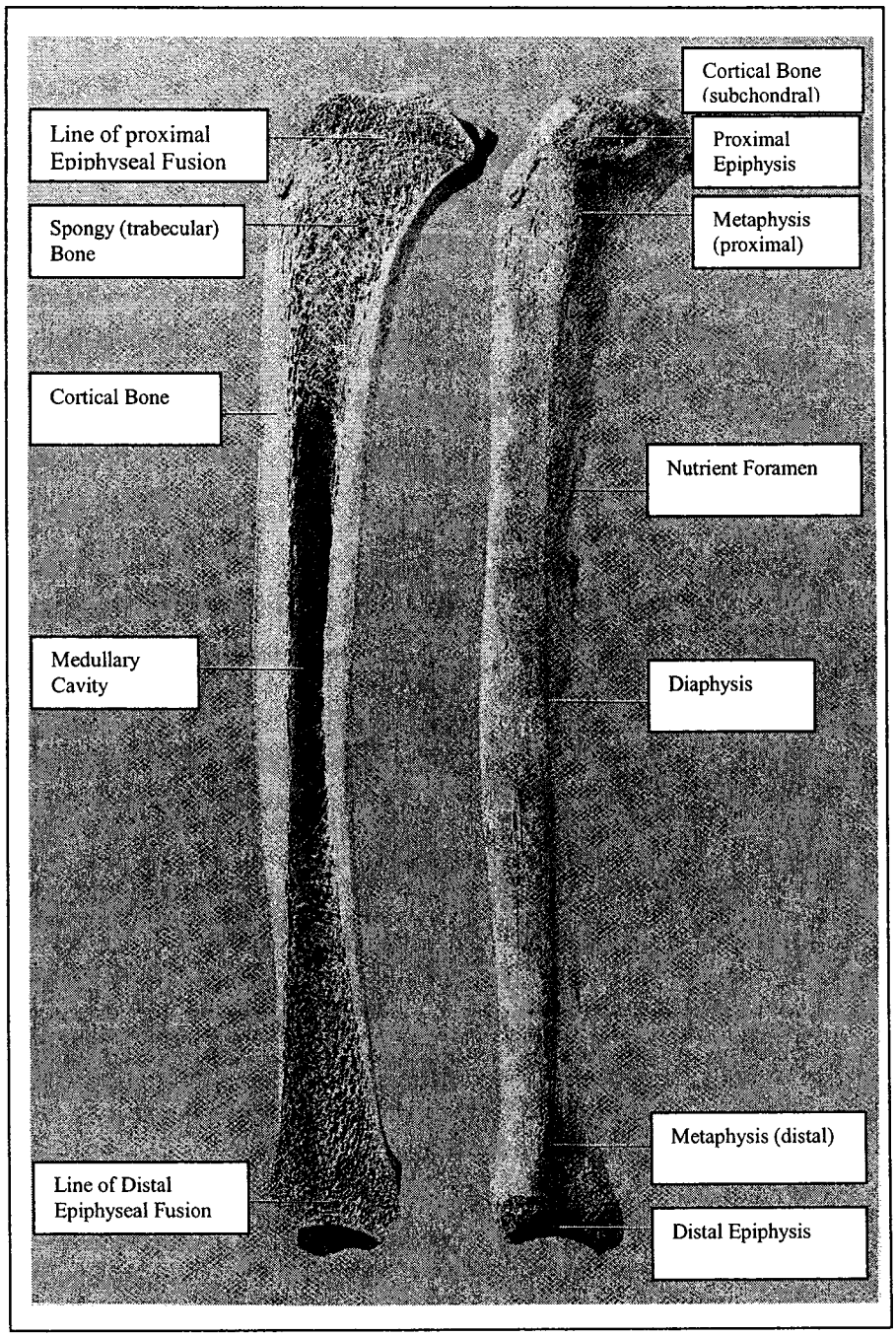

Fig. 3 1: Cross section of a Tibia shaft illustrating the components and tissues of a long bone (With kind permission of Elsevier Academic Press, White and Folkens, 2005).

Initially bone formation begins *in utero* as a cartilaginous framework that then ossifies into immature bone. Immature bone is full of osteocytes that then turn into new living bone that has been laid down by bone-producing cells called osteoblasts (White and Folkens, 2005). As immature bone turns into mature bone an orderly structure of osteocytes develop. Osteocytes do not divide; therefore, all bone growth is the result of deposition and resorption. Osteblasts are cells responsible for depositions and osteoclasts resorb bone (White and Folkens, 2005). Remodelling of bone is an ongoing process; and bone is continuously turning over as the osteoblasts and osteoclasts work together keeping bone healthy and viable. The turnover of bone is faster in trabecular bone because of its larger surface area compared to the slow rate at which cortical bone remodels (Price, 1989). Different skeletal elements will turn over at different rates depending on the amount of cortical bone present. For example, a rib that has a thin layer of cortical bone will have a much faster turnover rate compared to a thick femur shaft.

3.3 Dental Tissues

Human teeth are a very small component of the skeleton but these small structures carry within them a wealth of information. Humans have two sets of teeth that develop in their lifetime. This dentition contains 4 types of teeth: incisors, canines, premolars and molars that vary in form and function (Steele and Bramblett 1988). There are twenty deciduous teeth that are the first to develop and are later replaced by 32 permanent teeth (Hillson, 1996).

The information that can be gained from teeth for stable isotope analysis is possible because of their composition and the sequence and timing of their growth. (See

Hillson, 1996 for review). Tooth development is a continuous process that begins *in utero* within six weeks of fertilization and persists into early adult life (Hillson, 1996; Scheuer and Black, 2000). Figure 3.2 outlines the sequence of development for each deciduous and adult tooth. The deciduous anterior teeth are the first to form around 14 to 16 weeks after fertilization. The deciduous molars begin shortly after the anterior teeth (Hillson, 1996). At birth most of the deciduous teeth have been formed with the molars lagging behind slightly. Three to four months after birth the permanent dentition begins to develop. The permanent dentition follows a pattern of tooth development sequences similar to that of the deciduous teeth. The third permanent molar is the last tooth to form, and it is frequently smaller and slightly malformed because there is often not enough space to accommodate it in the jaw.

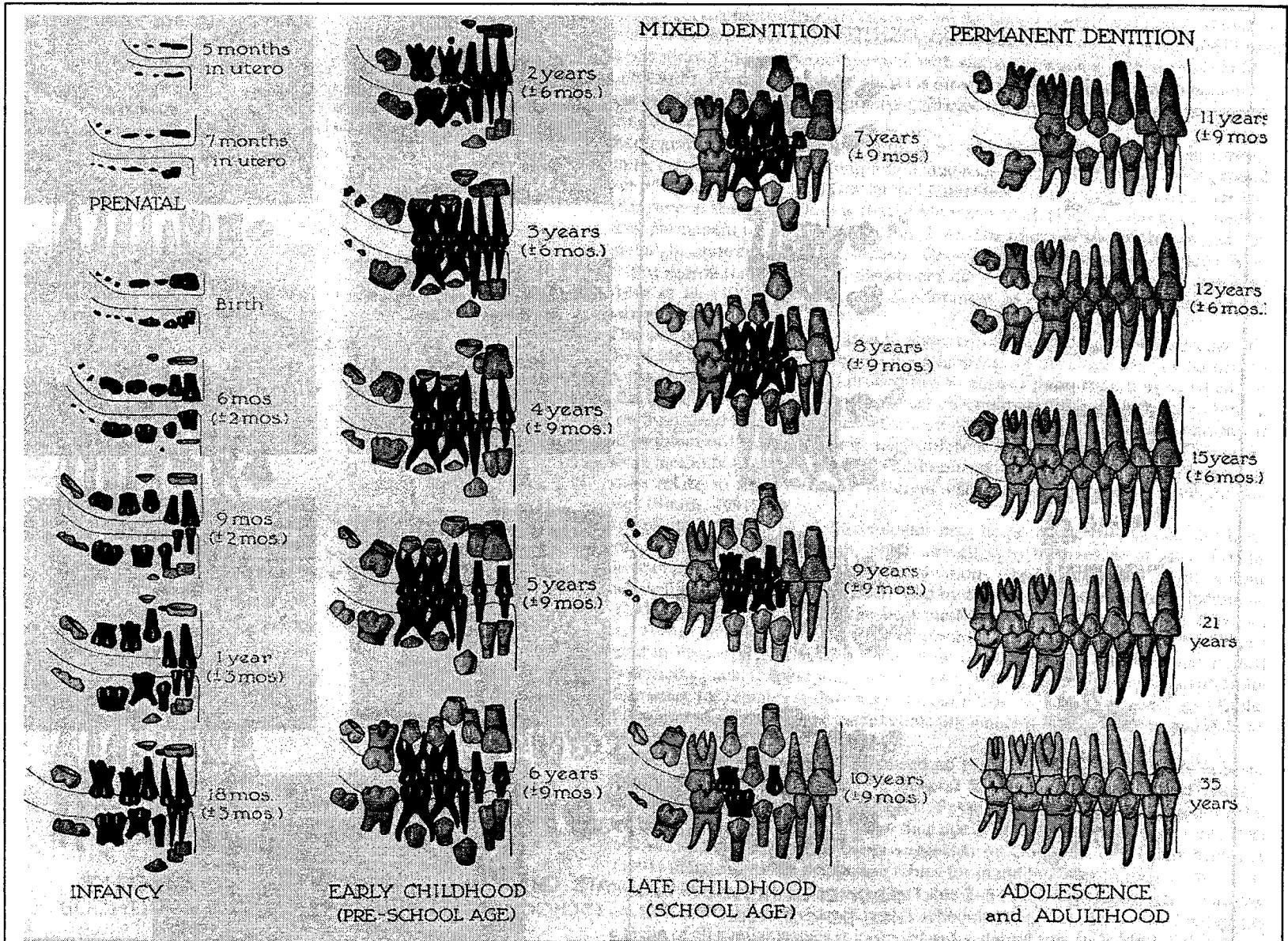

Fig. 3 2: Schour and Massler's original dental development diagram. (Massler and Schour, 1958:Plate 6). Kind Permission granted by Elsevier academic Press.

Teeth are unique because when they have finished forming and have come into occlusion they are the only part of what can be considered the skeleton to interact with the external environment (White and Folkens, 2005). Since teeth interact with the external environment they must have a distinct composition compared to bones, so they can resist the different types of forces they encounter. Their composition makes teeth more resistant to the stresses during life. However, teeth do not have the capability to remodel like bones, therefore they must be durable and strong in order to endure wear from daily use and survive throughout an individual's life. The tooth crown can only be changed by tooth wear, breakage or demineralization (White and Folkens, 2005). There are three types of tissue found in teeth: enamel, dentin and cement (See Figure 3.3). These tissues all have specific functions and interact in specific ways to make teeth the hardest elements in the body. For this study enamel and dentin will be discussed in greater detail because they are relevant to this research.

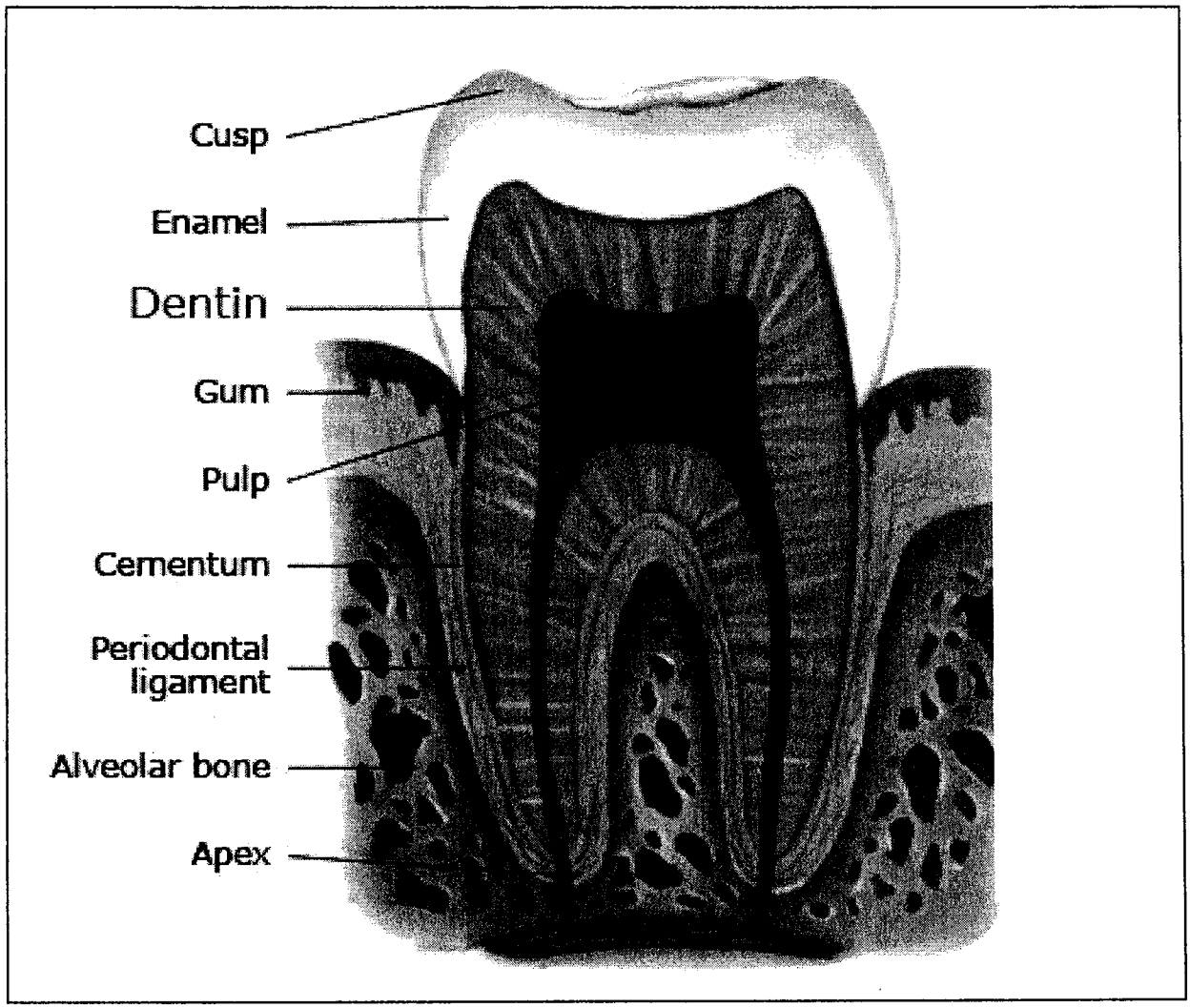

Fig. 3 3: cross section of a mandibular molar illustrating the various elements of a tooth. (Modified from http://www.studiodentaire.com/en/glossary/dentin.php).

3.3.1 Enamel Composition

Enamel tissue forms the tooth crown, the visible portion of the tooth that erupts into the mouth. Mature enamel is composed of 95% mineral, 4% water and 1% organic matrix (Garant, 2003; Schroeder, 1991). Once formed enamel tissue is non-cellular. Enamel formation is closely regulated in a controlled manner where time sequences are very important to the proper growth of each tooth crown (Lyngstadaas, 1995). Enamel does not remodel or have the ability to repair itself. The mineral component, mainly hydroyapatite, of enamel is what gives the tissue its strength (Alt *et al.*, 1998; Hillson, 1996), but without the organic matrix the enamel would be brittle and unable to withstand the pressures teeth encounter daily. Enamel is the surface that interacts with the outside world and must resist chemical and physical breakdown. The prismatic nature of its mineralization forms a very strong rigid structure that is impermeable to outside influences; the outer layers of enamel are arranged aprismatically to prevent foreign elements attaching themselves to the crown (Garant, 2003). Enamel is a very strong tissue that is resistant to change even after death.

3.3.2 Dentin Composition

Dentin tissue makes up the majority of the tooth; the tooth's size and shape is largely dependant on the amount of dentin produced (Gage, *et al.*, 1989). It is found right below the enamel layer filling in the crown and composes the tooth root.

There are three types of dentin: primary dentin that is initially laid down as the tooth is formed, secondary dentin that is laid down during life along the enamel-dentin junction in response to stresses and tertiary dentin that is able to perform small repairs. Secondary dentin does not interact with primary dentin but is laid down and lines the pulp chamber (Hillson, 1996) Tertiary dentin is produced as a reparative response when a tooth becomes worn or when primary or secondary dentin becomes exposed (Hillson, 1996). Tertiary dentin is commonly found at the enamel dentin junction and can be identified easily because it is a darker colour than primary dentin and there is a change in direction of the dentinal tubules (Moss-Salentijn and Kulvert, 1980).

Like enamel, dentin is also a mineralized tissue, although it has a slightly different composition. Dentin is composed of 70% inorganic material, 20% organic matrix and 10% water (Alt *et al.*, 1998). The inorganic substance is hydroxyapatite, the same material found in the inorganic component of enamel. The collagen found in dentin is the same type found in bone, type I. This makes dentin an ideal comparison to bone for stable isotope analysis because the collagen in both tissues is derived from similar parts of the diet. Dentin and bone, being formed from the same components of the diet allows researchers to conduct a longitudinal study that compares different periods of time locked in the tissues of an individual that are both represented by the same portion of the diet.

3.4 Skeletal Tissues for Stable Isotope Analysis

As mentioned previously in this chapter, bone and teeth share similarities based on their composition; both contain hydroxyapatite minerals and collagen.

Teeth and bone are excellent materials to use for comparison in stable isotope analysis because of these similarities and because they isolate a different period of an individual's life. Teeth are composed of static tissues that do not remodel. They are formed at a young age and maintain the dietary signature from that period of time. Bone on the other hand is a dynamic tissue that is in a continuous process of remodelling resulting in a more recent dietary signature. Having access to both of these tissues gives researchers the ability to compare dietary information reflecting different time periods.

Chapter 4: Previous Isotopic Studies

4.1 Previous Isotopic Studies

This chapter was included to provide a brief review of previous important work done using stable isotope analysis for dietary reconstruction. This chapter will focus on the use of carbon and nitrogen isotopes because of their importance in this study. In addition a discussion of the introduction of dentin as a reliable tissue in stable isotope and dietary reconstruction analysis studies will be provided.

In the early 1970's and 1980's many researchers were working to establish stable isotope analysis as a relevant and promising tool for dietary reconstruction. Longin (1971) published a study which developed a new method for collagen extraction from bone. Although this method was developed for radiocarbon dating it could also be applied to stable isotope research since it also uses extracted collagen to gather dietary signatures. Longin's (1971) method produces collagen samples with little protein degradation during the extraction process. Subsequent researchers have built on Longin's (1971) method and it remains at the base of many collagen extraction techniques still used in isotopic studies today. These techniques that have introduced modifications to the basic Longin method use a less harsh acid treatment and use various means of removing contaminants from samples.

According to Katzenberg *et al.* (1995) the first use of stable carbon isotopes for dietary reconstruction was in the late 1970's (Vogel 1978; Vogel and van der

Merwe 1977). To begin, researchers began looking at identifying dietary shifts using isotope analysis. Once standards had been developed more complex uses for isotope analysis could be researched. Since then isotopic studies have been routinely used to reconstruct past diets, identify dietary shifts and answer related questions about past populations.

Through the late 1970s and early 1980s, many pioneering studies were conducted illustrating the potential of the field of isotopic research and dietary reconstruction. DeNiro and Epstein (1978) evaluated the carbon distribution within an animal's body when it was fed a monotonous diet. They found that a population consuming the same diet had only a 1‰ enrichment of $\delta^{13}C$ values relative to the diet. This result was found to be consistent throughout the population studied. This study demonstrated that dietary analysis could be done using the $^{13}C/\ ^{12}C$ ratio of animal carbon.

DeNiro and Epstein continued their research to include nitrogen isotopes and their distribution through an animal's tissues (1981). Previously, the relationship between nitrogen isotopes and diet had not been established. Their study concluded that nitrogen isotopes could be used to obtain dietary information so long as the food consumed by an animal had different $\delta^{15}N$ values. DeNiro and Epstein (1981) determined that the animals in their study had $\delta^{15}N$ values that were enriched by 3‰ relative to the dietary nitrogen. They also noted that animals raised on a monotonous diet did have slightly varying $\delta^{15}N$ values. The incorporation of food into the body is a complicated process,

however there is a noticeable enrichment in nitrogen values once food has been integrated into tissue production.

DeNiro and Schoeninger (1983) evaluated both $\delta^{13}C$ and $\delta^{15}N$ nitrogen values in bone collagen. The two previously mentioned studies established how carbon and nitrogen could be used to assess diet, which allowed DeNiro and Schoeninger (1983) to build upon these findings. They were attempting to see if there would be differences between sexes, differences within a population or differences between populations. Multiple bones were sampled from different animals and they found that there was only slight variation between the bones of male and female animals being raised on a monotonous diet. DeNiro and Schoeninger (1983) suggest that in archaeological populations that are incomplete, the use of multiple skeletal elements in a study will not introduce great amounts of variation in the isotopic values as long as the population was eating similar foods because the isotopic variation within an animal's body is minimal.

Another approach to using nitrogen isotopes in dietary reconstruction is in evaluating marine and terrestrial diets. Schoeninger and DeNiro (1984) found that $\delta^{15}N$ values are different for marine and terrestrial foods. The stable nitrogen isotope ratios found in animal tissues can be traced back to the plants at the base of the foodweb that are the primary entry points for nitrogen. As animals eat plants and the nitrogen travels up the food chain there is a regular rate of fractionation that occurs. A marine system has a more complex food

chain compared to terrestrial environments, therefore marine systems will have increased nitrogen levels because of the 3‰ stepwise increase from one level in the food chain to the next. This was an important discovery because regional differences could be established with nitrogen if the carbon values were all derived from similar plants.

Although nitrogen is a useful tool for assessing a marine or terrestrial diet there are certain limitations when using this element. Sealy *et al.* (1986) evaluated nitrogen isotopes with supplemental environmental and dietary information in an arid area of southern Africa. Their results demonstrated that nitrogen should not be used as a tool to determine the difference between a marine or terrestrial diet in an arid environment without the appropriate information about the climate and dietary resources for the area. In arid environments nitrogen in an animal's body is conserved and is often concentrated because of lack of water. The concentration of nitrogen in the body's tissues will mimic an isotopic signature similar to an individual who consumed a large proportion of marine protein (Sealy *et al.,* 1987). Therefore without supplemental and appropriate information about a site the isotopic data could easily be misinterpreted.

These early studies demonstrated the usefulness of stable isotope research while the studies mentioned below use different applications of isotopic research in dietary reconstruction. Ambrose (1990) developed methods for bone and tooth collagen preparation for isotopic studies. This study outlined the proper techniques to use as well as important quality assessment tools necessary to know when to reject a poor sample (Ambrose, 1990). The

standards developed by Ambrose (1990) established a range for good and poor quality samples that is easily determined and applied to future studies.

Sealy *et al.* (1993) studied a skeleton of an older woman presumed to be a slave from a site in South Africa. Bone and dentin collagen were extracted and analyzed. Dentin was used because it was known to have a similar composition as bone and would provide a record of a childhood diet that could be used as a comparison to the bone collagen results. This research found that the dentin collagen produced excellent isotopic values and was a good tissue to use for dietary reconstruction. The childhood diet from the teeth did in fact show a different isotopic signature from the adult diet extracted from the bone collagen. Historical records were also used in this study in order to understand what types of foods were traditionally available to the enslaved population. The combination of resources and tissues used for this study made it possible for the researchers to determine the slave's origin and the researchers were able to create a more complete life history for this individual (Sealy *et al*, 1993).

Another study conducted by Sealy *et al.* (1995) used stable isotope analysis to identify mobility patterns of a number of individuals from South Africa. This study uses dentin and bone tissues to isolate $\delta^{15}N$ and $\delta^{13}C$ values for dietary analysis. This study used dentin from permanent adult teeth to isolate childhood dietary signatures in conjunction with samples from femurs and ribs from the sample population to access the adult dietary signatures (Sealy *et al.*, 1995). Their results showed that the adult diet was enriched in both ^{13}C and ^{15}N compared to the dentin results indicating a change in diet and a probable change in location throughout life.

The results are interpreted as indicating a change from a terrestrial diet to a stronger reliance on marine protein later in life typical of a slave diet (Sealy *et al.*, 1995).

Similarly van der Merwe et al. (2003) used tooth enamel and dentin and bone collagen to identify the diet of individuals recovered from an ossuary in Ontario, Canada. They compared δ^{15}N and δ^{13}C values and found that maize and fish were the staples in the diet. They were also able to determine that maize was heavily relied upon by individuals between the ages of 20-29 (van der Merwe *et al.*, 2003). The studies mentioned above helped establish isotopic research using dentin and develop the field further. Sealy *et al.* (1993, 1995) should be credited for the initial use of dentin as a tissue in human dietary reconstruction studies.

Stable isotope analysis in the West Indies has not been done extensively; in fact Varney (2003) was the first study to use isotope analysis in the region. In the study by Varney (2003) isotope analysis was performed on 100 individuals from three colonial era cemeteries in the West Indies, including 60 bone and 30 enamel apatite samples from individuals recovered from the site of L'Anse Sainte Marguerite. This study aimed to reconstruct diets and identify if there were dietary differences between different social groups namely African derived slaves and European military personnel based on isotopic signatures.

Schroeder *et al.* (2009) sampled 25 enslaved individuals from the island of Barbados. Bone and dental δ^{15}N and δ^{13}C isotopic results were used to understand where these individuals lived throughout their lives. It was found, based on their dietary signatures, that the majority of the individuals appeared to

have been born on the island of Barbados. The individuals not native to Barbados had dietary signatures that reflected various regions in Africa.

4.2 Alternate Isotopic Elements Used in Dietary Reconstruction

Isotopic analysis using different elements (e.g., oxygen and strontium) other than carbon and nitrogen are also commonly found in the literature in studies tracing population mobility (e.g., Prowse *et al.*, 2007; Tafui *et al.*, 2006) These other elements are sometimes used in conjunction with carbon and nitrogen and only those studies will be mentioned here.

Sealy *et al.* (1993) used strontium isotope analysis in conjunction with carbon and nitrogen when evaluating the skeletal remains of a female individuals believed to be a plantation slave. The strontium results from the teeth did not reflect a regional signature, while the strontium values from the femur did. These results suggested that the place of residence changed during this individual's life.

A second study by Sealy *et al.* (1995) also used strontium, carbon and nitrogen isotope analysis of human remains to evaluate life histories and mobility patterns. This study was able to show that isotope analysis does reflect the regions in which a person lives during their life and that it is a method to evaluate movements of individuals from one area to another.

Dupras and Tocheri (2007) published a study reconstructing infant weaning using carbon, nitrogen and oxygen isotopes. As weaning takes place

and breast milk is slowly replaced with drinking water and other solid foods a shift in isotopic levels occur in the tissue composition.

An infant consumes a mother's milk (tissue) which is the only source of dietary protein it receives causing an increased level of nitrogen in the tissue. As a child is weaned the protein source changes and will often have a lower δ^{15} N value compared to the mother's breast milk and increasingly similar to the adults of the population or the mother. This decline can be traced using various tissues that represent different periods of time during that phase in life (Schurr, 1997).

Dupras and Schwarcz (2001) used nitrogen and oxygen isotopes to suggest migration models from a site in the Dakhelh Oasis in Egypt. Historical records suggested that this population was isolated from neighbouring groups and were a self-contained group. However, results from this study demonstrated that trade networks and interactions with surrounding populations were very important because of the diverse isotopic values recorded from many individuals (Dupras and Schwarcz, 2001).

This section was included to demonstrate the range of possible research that can be conducted using stable isotopes. Although the present study only concentrated on carbon and nitrogen values, future research could explore other elements and learn about different aspects of these individual's lives.

4.3 Summary

This chapter includes a brief overview of how stable isotopes have been used in the past and show the range of possible research areas that can be

assessed with these techniques. It includes only a brief review of how the field developed and how each element was tested and proven to generate applicable results for dietary reconstruction.

The two studies conducted by Sealy *et al.* (1993, 1995) were the pioneering research for dentin as a tissue in stable isotope analysis. These two studies used dentin as a means of accessing a childhood diet to learn more about their life histories.

This study has built upon the studies by Sealy *et al.* (1993, 1995) and their work with dentin in an attempt to access childhood diets from the individuals in this study population.

Chapter 5: Colonial Diet

5.1 Introduction

The purpose of the current study is to evaluate isotopic signatures from individuals who lived in the West Indies during Colonial times in order to gain a better understanding of their life histories. This study uses isotopic data to form dietary signatures from skeletal elements in order to reconstruct these life histories. A detailed review of stable isotopes and how they are used for dietary reconstruction was given in Chapter 2. A brief description outlining the differences between C_3 and C_4 plants will be provided. The types of C_3 and C_4 plants relevant to the geographic areas mentioned in this study will be discussed as well. These plant groups are used to understand what types of foods were being included in an individual's diet based on their isotopic signature. In order for paleodietary reconstruction to be successful and produce reliable results it is important to have knowledge of what foodstuffs were available for consumption. Knowing the types of foods that were available is one step, the second step is understanding who had access to these foods and in what quantities they might have been consumed. Socio-political, socio-economic, gender and ancestry are all variables that may influence or cause differential access to food resources.

This chapter will outline dietary information for different segments of the population of Guadeloupe based on historical records and archaeological documents. The population used in this research is from the L'Anse Sainte-Marguerite cemetery on Guadeloupe, dated between A.D. 1750-1800 (Courtaud *et*

al., 2000). During this time the island was occupied and controlled as a French colony. Guadeloupe is still maintained today as an overseas department of France.

The French, in order to maintain sugar plantations, transported slaves from West Africa. Information concerning dietary habits of the French, West Africans and West Indian peoples will be discussed in this chapter.

5.2 An Introduction to C_3 and C_4 Plants

As already introduced in chapter 2, there are two types of photosynthetic pathways that can be used by plants when converting light into chemical energy. Plants can be categorized into two groups called C_3 or C_4 depending upon which photosynthetic pathway, either the Calvin or Hatch-Slack pathway respectively, that they utilize. C_3 plants are found in temperate areas and include trees, shrubs, grains and most vegetables. C_3 plants relevant to this study include wheat, rye, barley, rice, beans, tubers and most fruits and vegetables (Varney, 2003). Maize and millet are important C_4 plants that are usually found in tropical environments like the West Indies (Schwarcz *et al.*, 1985).

When discussing stable isotope studies these two groups of plants refer to different types of foods and do not have overlapping isotopic distributions (Bocherens *et al.*, 1994). C_3 plants have lower isotopic values (-38‰ to -22‰) than C_4 plants (-21‰ to -9‰) making it possible to distinguish between the two plant groups (Chisholm, 1989; O'Leary, 1981).

As individuals and animals consume plant foods the plant material is incorporated into their systems to build and maintain tissues. Therefore, an

individual whose diet is primarily based on C_3 plants or animals that consume C_3 plants, will have an isotopic ratio that reflects those foods. Thus, isotopic data is able to identify on a general level what types of plants are being consumed. Certain complications arise when a mixed diet of C_3 and C_4 plants is consumed because the isotopic ratios will reflect an intermediate value because of the combination of the two types of food sources.

Another limitation of isotopic research is when marine resources are integrated in the diet because they have a similar $\delta^{13}C$ values to C_4 plants causing confusion about the contribution of each food source to the diet (Schoeninger and Moore, 1992). Although some of the limitations can be addressed by using $\delta^{15}N$ values in the analysis, having some prior knowledge of the potential composition of the diet is essential to accurate dietary reconstruction. Historical records can be used to provide such dietary details in order to provide context for the interpretation of the isotopic data. Although historical records are not comprehensive, they do provide some essential background information on diet. Without such background information, understanding the types of foods people had access to and actually consumed is challenging and may lead to inaccurate interpretations of isotopic data. The combined use of historical information with isotopic data provides a picture of diet that cannot be obtained through the application of only one source of information.

5.3 European - French Diet

Europe is a relatively arid environment with temperate zones that has mainly C_3 plants; the tropical C_4 plants do not grow well in this part of the world (Dunn,

1972). Although C_4 plants thrive in arid climates they also require elevated temperatures that are not found in the European climate. Therefore, the European diet consists mainly of C_3 plants (Mays, 1997). There are some exceptions to the European diet because the French imported some of their foods from the tropics. Sugar cane, maize and millet, all C_4 plants, were imported to Europe to supplement the diet. However, maize was not a culturally favoured food in most of Western Europe and was thought to be only good as feed for animals (Drummond and Wilbraham, 1991). As is expected, a difference in diet existed between the socio-economic classes. Expensive items like meat, eggs and dairy products were often reserved for the wealthy. The poorer classes had access to meat only on very rare occasions (Drummond and Wilbraham, 1991).

A main staple of most peasants' diets was soup made from water; onion; garlic; vegetables such as turnips, peas, beans, cabbage or leeks; and sometimes pork fat or oil (Goubert, 1986). A variety of fruits was also available. Breads were also common dietary items that were easily made from rye, wheat, or other cereal grains. Other grains commonly eaten were oats, barley and buckwheat (Goubert, 1986).

Eating meat was a very rare occurrence for the majority of the population. Sheep, cattle, fowl and pigs were raised as food but would often be used to pay debts or eaten only for special occasions in the community (Goubert, 1986). Salted pork was the most common type of meat encountered by most commoners. It was difficult to raise animals because there was a shortage of good farmland. Perhaps this is why pigs were ideal to raise as they could be left in forested areas to

scavenge for nuts and other foods (Goubert, 1986). While raising livestock in rural areas was common, it was more difficult in urban areas. Rabbit and fish were two common sources of protein that could be acquired in urban centers. Rabbits were raised for meat in cities and could be purchased to supplement diets. Individuals who lived close to freshwater could take advantage of aquatic resources and fish became a protein source in their diets (Goubert, 1986). Dairy products and meat were difficult to find and were mostly eaten by wealthy individuals.

Water was the common beverage that was easily accessible by the entire population. Wine and beer were produced but they were expensive and therefore, were readily available only to the wealthy. A beverage made from water poured over grape stalks, leaves and fruit was made by the lower classes. This beverage was comparable to wine (Goubert, 1986).

5.4 West African Diet

West Africa was largely impacted by the slave trade for many reasons. Not only did European slave trading companies transport individuals to new countries they also influenced the types of foods available to people. Originally people in Africa depended on taro, yams and millets (Kiple, 1984). Maize, yams and sweet potatoes were introduced to many areas in Africa by the 16th century (Klein, 1999 Lewicki, 1974). Millet continued to be an important portion of the diet while the new crops replaced other older staples. Maize and millet were the primary crops grown along the North coast of Africa while the South coast relied on yams and cassava (Klein, 1999:62). Other crops that were important to Africa were peanuts, cassava,

some fruits, beans, peas, lentils, cucumbers, cabbage, onion, melon, garlic, squashes, figs, dates, lemons and oranges; many of these foods were newly introduced and quickly adopted (Lewicki, 1974).

The West African diet slaves would have been accustomed to in Africa was a combination of both C_3 and C_4 plants. Regional variation in Africa produced a wide variety of food resources for subsistence. Africa's West coast became known as the 'Rice Coast', rice being a C_3 crop. Yams and other root crops, also C_3 plants, were more common in Southern Ghana and the surrounding area. The interior of Africa is more arid where C_4 plants like sorghum are the main subsistence foods (Schroeder *et al.*, 2009).

Dietary protein sources in Africa were difficult to acquire. The elite were often the only people privileged to eat meat regularly. Sheep and cattle were the most common animals, but goats, chickens and ducks were also raised (Lewicki, 1974). Goats and cattle would be used for milk production as well as for meat. Wild game was also hunted and people along the coast fished to increase the protein levels in their diets when herd animals were not available for consumption (Lewicki, 1974).

5.5 Diet in the West Indies

5.5.1 West Indian European Colonial Diet

A brief description of West Indian-European colonial diet is included here because the skeletal population in this study was recovered from a large cemetery

on Guadeloupe. Knowledge of West Indian and European colonial diet is necessary in order to identify similar isotopic signatures and patterns should they come up.

Europeans generally maintained the "us versus them" mentality when interacting with the enslaved population in the West Indies. English settlers were more prone to continuing this type of attitude that carried over into all aspects of their lives, even with their diets. While the French did not maintain this mentality quite as strictly as the English, these trends were still noticeable.

Imported foods were common for the West Indies because agricultural lands for subsistence crops were in short supply. The Europeans also imported familiar foods from their home countries instead of consuming native plants grown in the West Indies (Dunn, 1972). Many of the smaller islands did not have the space for subsistence crops to feed the entire population and had to rely on imported goods (Dunn, 1972).

Large livestock such as cattle and horses were difficult to manage in the West Indies climate. The land for grazing was insufficient and the lack of water resulted in a poor habitat for the animals. The hot West Indies climate made it difficult to keep meat because it spoiled quickly making it an expensive purchase and it was not common fare (Debien, 1964; Dunn, 1972). Salted beef and fish were imported from Britain to appease the Europeans (Dunn, 1972). Local fish and seafood were also consumed as additions to the diet and were enjoyed by the Europeans.

Wheat flour was imported in mass quantities because, although other grains were local to the islands, the former was preferred. Lower classes relied on yams and cassavas to a greater extent but all socio-economic brackets consumed these

items regularly (Dunn, 1972). Tropical fruits were however, a favourite of the Europeans and would be purchased from the markets when available (Abrahams and Szwed, 1983). Yams, cassavas and other locally grown vegetables were consumed and rounded out the diet of the whole population (Dunn, 1972; Munford, 1991).

Guadeloupe has a relatively wet climate, which is fortunate because water was often a scarce resource in the West Indies. Rum, beer, wine and liquor were available beverages imported to the islands. Rum, locally made from sugar cane, was a drink given to slaves, while wine was more expensive and often kept for the wealthy (Dunn, 1972).

5.5.2 West Indian Slave Diet

When the colonies in the West Indies were initially being developed all regulations concerning the treatment of slaves were left to individual plantation owners. It was not until 1685 that the French Government interceded and developed the *Code Noir*, a set of rules and regulations on how to treat and provide for slaves (McCloy, 1966). This code was not developed to provide the slaves with rights but it was to establish some standards for their owners to follow. Within the *Code Noir*, food rations and clothing allotments for slaves were prescribed, among other details, which were meant to improve the quality of their daily lives.

A typical weekly food allowance for a slave included 3-5 quarts of beans, rice or corn and 3-4 pieces of imported salted meat, beef, pork or fish. It was not uncommon for the salted meat to arrive already spoiled; slaves would often receive

this as their weekly ration and be unable to eat it (Sheridan, 1985). When various vegetables like yams, and eddoes, and grains such as millet were available they would be substituted in the same proportion in the place of meat (Abrahams and Szwed, 1983; Munford, 1991). Rum was also given out in rations to the slaves as their main beverage (Abrahams and Szwed, 1983). The main caloric portion of a slave's diet consisted of bread made from wheat, barley, oats, millet, buckwheat, rye and/or maize (Munford, 1991). Along with bread, soup was a staple in the diets. Vegetables such as radishes, carrots, turnips, leeks, cabbage and peas would be added when available along with small chunks of meat or fish. However, this soup was often no more than broth (Munford, 1991). Children were given gruel made of manioc along with crushed bananas. They were never given enough and suffered the most from poor nutrition and did not have the necessary protein for proper growth (Munford, 1991). Dietary rations were manipulated based on the type of labour an individual was performing. Individuals doing the more difficult jobs may be rewarded with a slightly larger ration. Age, sex, and size were also considered when food was being distributed (Sheridan, 1985).

There was often a lack of food supplies on the island of Guadeloupe because of unpredictable shipments, war conflicts and bad weather (McCloy, 1966; Sheridan, 1985). To compensate for the random food supply slaves were given small plots of land in which to plant their own gardens as directed in the *Code Noir*. Every slave, male or female, at the age of 14 or 15 was to get 25-35 m^2 for a garden (Abrahams and Szwed, 1983). Kitchen gardens were often a short distance from a slave's residence and were established on marginal land that was not suitable for cash crop

cultivation (McCloy, 1966; Sheridan, 1985). Cassava, manioc, maize, millet, plantains, melons and other produce were grown in these gardens (McCloy, 1966; Abrahams and Szwed, 1983; Munford, 1991). Surplus foods were taken to the Sunday market and sold; the slave kept the profit and would often buy salt beef, pork or fish (Abrahams and Szwed, 1983; Munford, 1991). Urban slaves in some West Indies islands like Trinidad and Tobago had to rely on the provisions given to them by their owners because there was not enough accessible land for them to use as gardens (Laurence, 1995). Guadeloupe was one of the more fortunate islands that had good rain supply and land for provision gardens; however owners were still relied upon in times of food shortages.

The gardens were a good idea, however, whether or not the slaves were given enough time to tend this land or have the energy to do so is another matter. Sometimes owners would avoid their responsibility of providing rations to the slaves because they felt these gardens should supply enough food, which was not always the case (Munford, 1991). Some slaves were able to take advantage of having a garden and could produce foods that supplemented their meager diet and provide them with extra money if they sold their produce at the markets (Sheridan, 1985).

Cassava is a starchy root vegetable that can be used to produce flat cakes or a starchy porridge. Cassava is difficult to prepare but was frequently grown. Maize on the other hand was easy to grow and prepare but was also easy to steal so slave owners preferred not to grow it. Yams was another crop that was better nutritionally and could be grown year round, however, it exhausted the soil quickly and would rot rapidly if wet (Munford, 1991). Imported foods that were occasionally part of a

slave's diet included salted fish and meat, flour, oatmeal, maize, beans and peas (Laurence, 1995; Munford, 1991; Sheridan, 1985). The French islands were frequently low on salted beef and flour (Munford, 1991). Slaves were considerably undernourished and always hungry because the food supply was irregular and unpredictable.

Based on the information above, if the slaves received the proper rations described by the *Code Noir*, they would be consuming approximately 1650 calories a day (Munford, 1991). Modern scientists recommend that on a regular day an individual should consume between 2000-2700 calories, and when performing hard labour the required caloric intake goes up to 3400 (Health Canada, 2009). Carbohydrates and fats are the body's main source of energy and proteins for building and repairing cells (Hunt and Groff, 1990). A slave's diet was often deficient in potassium, magnesium, calcium and other essential vitamins and especially in animal protein. It was not uncommon for the meat ration to be cut out of a slave's diet when shortages occurred (Munford, 1991). Slaves were often seen chewing on sugar cane to stop their hunger, however this just lead to further difficulties and dental caries (Munford, 1991).

The poor diet slaves had to endure caused many problems and illnesses that were sometimes fatal. Scurvy, tuberculosis and dysentery are common illnesses mentioned in the literature (Munford, 1991; Sheridan 1985).

5.6 Summary

The various segments of the Guadeloupe populations ate differently depending on the availability and accessibility of food. When food shipments arrived

and supplies were plentiful Europeans mainly consumed imported C_3 based foods similar to the diet they were used to back in France. The West Indies slave diet was also based on C_3 and C_4 plants with a larger concentration of C_4 plants because of the reliance on maize and other local crops. West African diets would have been largely based on a combination of C_3 and C_4 plants. Although the geographic regions of interest in this study have diets based on foodstuffs with similar isotopic values, the slave diet in the West Indies would have been much less variable. Livestock were also fed a diet consisting mainly of maize but may have also been fed discarded portions of sugar cane plants as supplemental food sources. These plants would have given them an isotopic signature reflecting a C_4 diet. These dietary differences should make it possible to distinguish individuals based on their isotopic data.

Chapter 6 Sites and Samples

6.1.1 Introduction to the West Indies

The West Indies has a complicated past that involved slavery during the time of colonial rule. In 1635 France claimed Guadeloupe with the intention of developing a settlement in order to produce cash crops (Delpuech, 2001; McCloy, 1966). Originally small scale tobacco farms were developed, but sugar plantations took over quite rapidly (Kelly, 2004). Many of the West Indies islands were plagued by war and disturbances during the colonial times. The French colonists on Guadeloupe also faced constant raids by the Carib Indians during the first few decades of their settlement (Crousse, 1940).

Throughout the 17th and 18th centuries Guadeloupe changed hands many times between the French and the British as a result of wars and treaties. Guadeloupe became an overseas department of France in 1946 and remains that way today (Abenon, 1992). The West Indies islands were very important to the colonizing countries because they were incredibly profitable as the sugar cane industry developed in the 1630's (Dunn 1972). Figure 6.1 is a map of the West Indies and indicates the site of L'Anse Sainte Marguerite on the island of Guadeloupe.

The sugar cane industry that developed on the West Indies islands in the 1600's was so prolific and important to the colonizers that slavery was deemed necessary to maintain the high levels of labour required to cultivate the fields (Courtaud, 1999). The sugar cane industry and the slave trade were the foundation

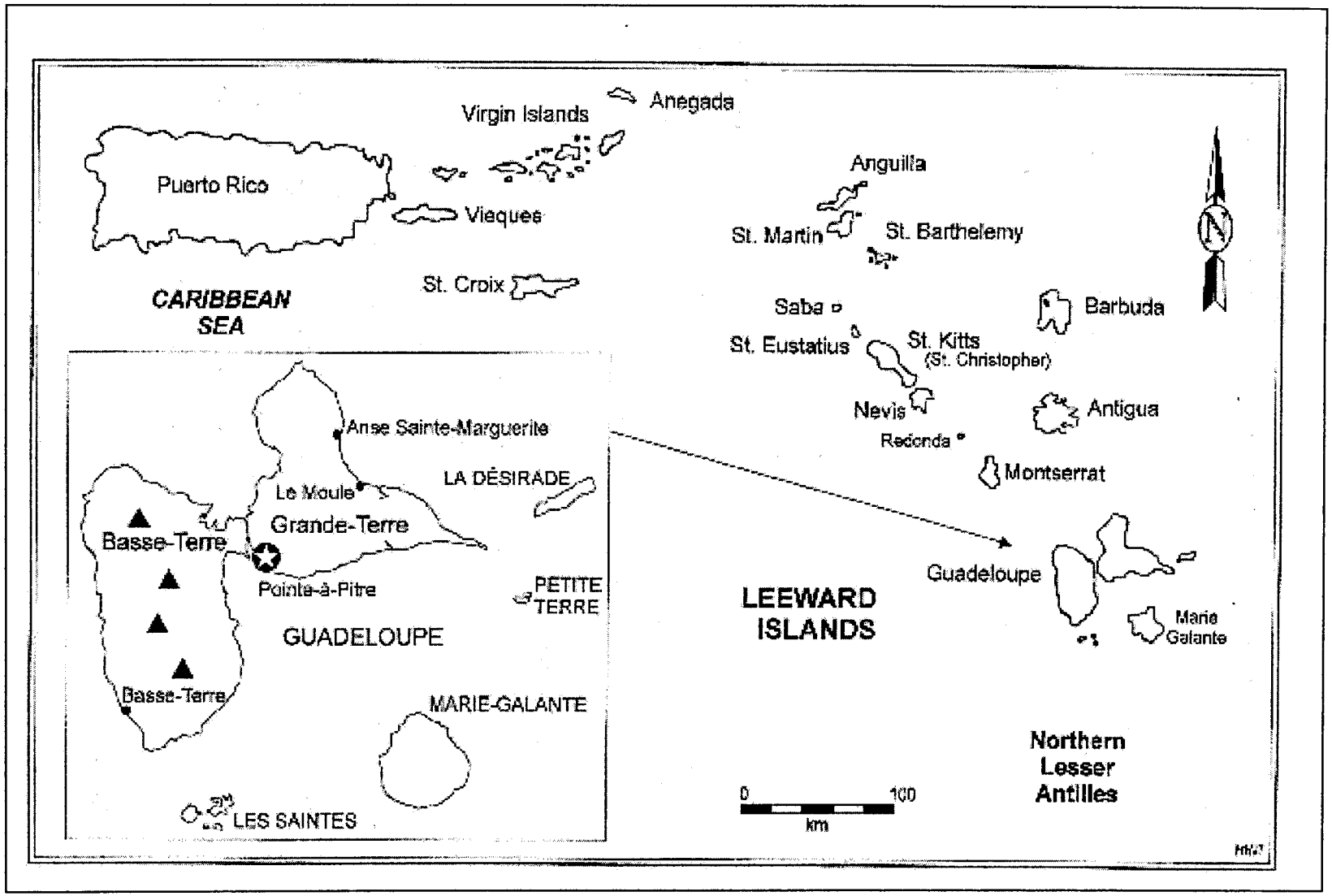

Figure 6.1: Map of the Leeward Islands and Guadeloupe illustrating Grand-Terre and Basse Terre. The site of Anse-Sainte Marguerite is indicated (map courtesy of M.H.J. Turney).

of the economy in the French West Indies (Goveia, 1965). Reports have shown that a large number of enslaved Africans were captured and transported to the West Indies during the 17th century, with an estimated 200,000 slaves being taken to Guadeloupe alone (Delpuech, 2001; Kelly, 2004; McCloy, 1995). Very shortly after this forced movement of peoples to the West Indies there was an increase in the proportion of African descended people whom rapidly came to represent the majority of the population on the islands out numbering the European colonizers. During the 18th century over 88% of the population was servile (Courtaud *et al.*, 1998). Slavery was finally abolished in the West Indies in 1848 (Kelly, 2004).

6.1.2 Treatment of Slaves

Although ethically we know and recognize that slavery is a terrible practice, at the time of colonization in the West Indies it was the main source of labour for the development and success of the West Indies colonies. Without the constant supply of workers being transported to the islands agriculture and sugar cane plantations would not have survived (Munford, 1991). Many of the enslaved people brought to the West Indies were from the West African coast ranging from Dakar in the north to Angola in the south (McCloy, 1966). During the voyage across the Atlantic Ocean many individuals perished because of poor conditions and lack of food. On average, 10-15% of the people on each ship died during the crossing but this figure could range between 5-34% depending on

the voyage (McCloy, 1966). Small pox and scurvy were two illnesses that often caused such high mortality rates (McCloy, 1966).

Once individuals were sold into slavery they were faced with more hardship and mistreatment. Poor diet, disease and violence were some of the daily obstacles they encountered (Kelley and Angel, 1987). Rural slaves were twice as likely to die as urban slaves because of unsanitary conditions and poor treatment (Kelley and Angel 1987). However, males tended to be healthier than females because they were considered to be more valuable and were rewarded for their strength and skills (Kelley and Angel, 1987).

Due to the poor treatment of the slaves in the West Indies a set of rules and standards, the *Code Noir*, was developed in 1685 by the French government (McCloy, 1966). These standards have been discussed in a previous chapter, however the main objective was to ensure that the enslaved population was receiving better rations and were being provided for in a more humane fashion. Unfortunately these regulations were not easily adopted and were seldom followed. For slaves, life in the West Indies was a difficult time that often left these individuals undernourished, ill and dejected.

6.2 Guadeloupe

West Africa generally has an arid climate while the West Indies has a variety of climates (Klein, 1999). Certain West Indies islands are very moist and humid while others are dry with low lying shrubs. The environments in West Africa and the West Indies both encourage the growth of different vegetation.

Guadeloupe is made up of two islands, Grand-Terre and Basse-Terre, divided by a small water channel. Each section is quite different in terms of geography. The eastern island, Grand-Terre, is mostly flat with a limestone layer covering the volcanic base and rises to only 200m above sea level. The vegetation on Grand-Terre has adapted to an arid environment and consists mainly of cacti and acacia trees. This low, flat land was conducive for use as agricultural fields. In contrast, Basse-Terre has rugged hills and mountains, which run north-south along the island covered with dense rainforests (Lasserre 1961). The highest peak, La Souffriere, rises 1467m above sea level. Because of the mountain range Basse-Terre receives much more rain annually compared to Grand-Terre.

6.3 Sample Population

The sample population used for this study comes from a cemetery site called L'Anse Sainte Marguerite. Although there are no physical markers indicating this land as a burial ground, people have been aware of this site for a number of years. The site of L'Anse Sainte Marguerite is located on the North East coast of Grand-Terre. This site is situated along a sandy beach, and its location has been known by local people for a significant period of time, but excavations began after hurricanes and inclement weather struck the island in 1995 and erosion endangered the site (Courtaud *et al.*, 1998; Courtaud, 1999). The land used for the cemetery was marginal land that was not suitable for agricultural purposes (Courtaud *et al.*, 1998).

When the L'Anse Sainte Marguerite cemetery population was excavated there were no clear indicators to suggest who the interred individuals were. It was assumed that the cemetery was a slave burial ground because of the large number of individuals who were interred at the site. Another possibility is that it was a "mixed" cemetery because it contained some richer burials as indicated by decorated coffins, as well as some individuals who had dental modifications commonly found in parts of Africa (Delpuech 2001). Dental modification was a tradition banned in the West Indies therefore individuals found with any dental modification can be assumed to be first generation slaves brought to the West Indies. The large percentage of enslaved individuals on the island in the colonial era would suggest that a cemetery this large would most likely contain enslaved individuals (Delpuech, 2001).

The majority of the graves were simple single burials placed in six-sided wooden coffins. Nails were found in each burial pit indicating the presence of a coffin but the wooden material had completely disappeared (Courtaud and Romon, 2004; Courtaud, 1999). There were very few associated funerary objects recovered. The individuals were oriented with their heads towards the west lying in a supine position (Courtaud *et al.*,1998). Very few individuals were placed with their heads to the East and the majority of those individuals were children. The cemetery was difficult to date precisely because of the absence of head stones or items that could be easily dated. It is estimated that this cemetery was used for over 100 years during the 18th and 19th century based on

the artefacts recovered and was closed around the time of the abolition of slavery (Courtaud *et al.*, 1998).

The skeletal population recovered from this site consists of over 200 adult individuals; 48% male, 40% female and 12% indeterminate (Courtaud *et al.*, 1998). Eighty-three percent of these burials were simple primary burials, while 11% were composite secondary burials that involved moving an individual aside to place a second individual in that space. Six percent of the burials were composite primary burials, meaning that two individual were placed together most often involving a child with an adult (Courtaud *et al.*, 1998).

A sample skeletal population of 43 adult individuals was obtained for this study. Of the 43 individuals, the bone samples from 27 had been previously studied by Varney (2003). The remaining 16 bone samples were unique to this study. Dentin samples were also isolated from all 43 individuals for the present study. Sex and age data was available for the samples, 24 male and 18 female and one of indeterminate sex.

In the current study the 43 individuals of known sex are 56% male and 42% female (2% unknown sex). Osteological analysis determined that the individuals in the original population were young adults (81% are younger than 30 years of age). The age range for the sample population, based on the 27 individuals with age data, is between 15 and 30+ years. The remaining individuals could not be identified to a specific age range and are just labeled as adult; the adult designation can indicate an age range of 20 years or more. The osteological analysis conducted on this sample population showed signs of poor

health that suggested these people were involved in activities of continuous physical labour throughout their lives (Courtaud *et al.*,1998). Dental pathologies were also commonly noted for many of these individuals (Courtaud, 1999). These indicators of poor health seen in the Sainte Marguerite Cemetery population are consistent with historical accounts of poor nutrition and health.

For this study one tooth from each of the forty-three individuals has been obtained. The teeth are mainly permanent premolars and first molars from both the mandible and maxilla. Table 6.1, below, outlines the skeletal elements used from each individual.

Table 6.1: Sainte Marguerite tooth and bone samples.

Identifier	Identifier	Age	Sex	Bone/Tooth
HSM 01	TSM 02	20-29	F	rib/ max.canine
HSM 02	TSM 14	20-24	F	rib/ max. PM1
HSM 03	TSM 18	25-29	F	rib/ max. PM1
HSM 04	TSM 24	20-24	F	rib/ max. M2
HSM 05	TSM 30	25-29	F	rib/ mand. PM2
HSM 06	TSM 34	30+	F	rib/ max. PM1
HSM 07	TSM 36	15-19	F	rib/ max. PM1
HSM 08	TSM 37	30+	F	rib/ max M3
HSM 09	TSM 38	25-29	F	rib/mand. M3
HSM 10	TSM 42	20+	F	rib/ max. PM1
HSM 11	TSM 49	30+	F	rib/mand. M1
HSM 14	TSM 54	20-24	F	rib/mand. M1
HSM 15	TSM 59	25-29	F	rib/ max. PM2
HSM 16	TSM 05	Adult	M	rib/ max. PM1
HSM 17	TSM 10	20-29	M	rib/ mand. PM2
HSM 18	TSM 15	25-29	M	rib/mand PM1
HSM 19	TSM 17	30+	M	rib/ mand. PM2
HSM 20	TSM 19	Adult	M	rib/mand PM1
HSM 21	TSM 20	25-29	M	rib/ max. PM1
HSM 23	TSM 22	20-24	M	rib/ mand. PM2
HSM 24	TSM 23	30+	M	rib/ max. PM2
HSM 25	TSM 27	20-24	M	rib/ max. PM2
HSM 26	TSM 32	30+	M	rib/ max. PM1
HSM 27	TSM 35	20-24	M	rib/mand. M3
HSM 28	TSM 44	30+	M	rib/mand. M3
HSM 29	TSM 48	30+	M	rib/mand. M1

HSM 30	TSM 56	20-24	M	rib/ max. PM2
THSM 01	THSM 21	Adult	M	rib/ max M1
THSM 02	THSM 22	Adult	M	rib/max. PM2
THSM 03	THSM 23	Adult	F	rib/ mand PM2
THSM 04	THSM 24	Adult	M	rib/ max. PM1
THSM 05	THSM 25	Adult	M	Rib/ mand PM2
THSM 06*	THSM 26	Adult	M	Rib/ mand. M3
THSM 07	THSM 27	Adult	M	rib/ max. PM2
THSM 08	THSM 28	Adult	F	Rib/ mand. PM2
THSM 09	THSM 29	Adult	M	Rib/ max. PM1
THSM 10	THSM 30	Adult	M	rib/ max. PM1
THSM 11*	THSM 31	Adult	F	Rib/ max. PM2
THSM 13	THSM 33	Adult	F	Rib/ mand. PM1
THSM 14*	THSM 34	Adult	?	rib/ max. PM2
THSM 15	THSM 35	Adult	M	rib/ max. PM2
THSM 16	THSM 36	Adult	F	rib/ mand PM2
THSM 17*	THSM 37	Adult	M	rib/ mand. PM2

(Max = Maxillary (upper jaw); Mand = Mandibular (Lower Jaw); * indicates individuals with dental modification)

The teeth sampled develop at slightly different times but are within the same time span for eruption time. The 1st molars begin forming around 9 months after birth with the 1st and 2nd premolars close behind beginning around 3 years of age. The 2nd molars begin forming around 4 years of age. The crowns of all 4 teeth mentioned above are complete by 6 years of age (Hillson, 1996). Figure 3.2 in Chapter 3 illustrates the sequence of dental development and eruption. The permanent dentition begins forming around birth, completing around age 12 with the exception of the 3rd molar. The 3rd molar does not finish growing until early adulthood (approximately 21 years of age) (Hillson, 1996). Table 6.2 outlines the age range represented by each tooth.

Table 6.2: Approximate age ranges for mandibular and maxillary tooth formation to crown completion[2].

Tooth	Age Range (start of tooth growth – crown completion)
Maxillary Canine	6 months after birth – 7 years
Maxillary/ Mandibular 1st Premolar	3 – 6 years
Maxillary/ Mandibular 2nd Premolar	3 – 6 years
Maxillary/ Mandibular 1st Molar	9 months after birth – 4 years
Maxillary/ Mandibular 3rd Molar	9 – 12 years

6.4 Summary of Samples

Overall 86 collagen samples were prepared; 43 dentin samples and 43 bone samples. Each dentin sample has a corresponding bone sample from the same individual. Premolars and molars from both the mandible and maxilla were the most common type of teeth sampled. Twenty-seven of the bone collagen samples taken from rib fragments were prepared and published in a previous study (Varney, 2003). A further 17 ribs had their bone collagen isolated and analyzed in this study. Eighteen individuals were identified as females, 24 were male and one could not be identified as to its sex. Both skeletal elements were used in this research as a comparison of childhood and adult diets. Although the sample size is small it provides an accurate representation of the original population recovered from the site of L'Anse Sainte Marguerite and should provide reliable data about their diets and offer information about their life histories.

[2] All age ranged offered for tooth formation does not include a standard error value. Approximately ±3 months to 1 year depending on the tooth should be added. See Fig 3.2 in Chapter 3 for a more complete outline of tooth formation.

Chapter 7 Methods and Materials

7.1 Experimental Methods

7.1.1 Collagen Extraction from Bone

Each of the 43 individuals in this study is represented by both a bone and a dental sample. Varney (2003) has previously analyzed the bone collagen results from 27 individuals; the remaining bone samples and all 43 dentin samples were processed and analyzed for this study. For the bone samples, a rib fragment was used when available; however other skeletal elements, such as metacarpals and phalanges, were used when necessary. Ribs were preferred because their fast turn over rate makes them ideal for returning isotopic signatures from the last 5-10 years of adulthood. Bones that showed indication of pathological conditions were avoided because of the possible influence these conditions may have had on the isotopic results.

Approximately 0.75-1.25g of bone were taken from each individual and cleaned using a brush and double distilled water to remove any surface impurities. Each sample was then individually placed in a sonicator for 5 minutes to remove small impurities as well as material trapped within the trabecular bone. The samples were allowed to dry for 24 hours. Once dry the samples were weighed and placed into individual containers. Bone collagen was extracted using the procedure outlined by Sealy (1986). A 1% HCl solution was added to a container along with the bone sample. Each sample was checked on a daily basis and the HCl solution was changed as needed. When the bone had been completely demineralized the HCl solution was removed and the sample was

rinsed with double distilled water until the pH had been neutralized. The next step involved adding a 0.125M solution of NaOH to the sample for 20 hours to remove humic acid contents (Sealy *et al.*, 1995). After 20 hours the sample was rinsed with double distilled water until the pH was neutralized. The collagen sample was freeze-dried and weighed. Using a Spec freezer mill the samples were ground into a fine powder and then sent to the Stable-isotope research laboratory in the School of Geography and Earth Sciences, McMaster University, Hamilton, ON. The samples were run in respect to the standard V-PDB measurements for carbon and for nitrogen in respect to Atmospheric nitrogen. The δ^{13}C and δ^{15}N values along with %carbon and %nitrogen were calculated at the Stable-isotope research laboratory using the mass spectrometer analysis. Collagen yield and C/N ratios for all samples were calculated by this researcher to test the sample integrity and identify any outliers for both bone and dentin samples. Refer to Chapter 2 for more detail about integrity assessment techniques.

7.1.2 Collagen Extraction from Teeth

The method used in this study is based on the procedure employed by Dupras and Tocheri (2007). The teeth were cleaned by hand using a brush and double distilled water and were then placed in a sonicator for five minutes to remove any remaining surface impurities. The teeth were removed from the sonicator and allowed to dry for 24 hours. Next, dentin was separated from the enamel using a dremel and pointed diamond tipped sanding bits. Before sample collection began a layer approximately 1-2mm in thickness was removed from

the surface of the roots using the dremel to avoid any contamination from cementum and secondary dentin. Also if noticeable areas of decay, poor preservation or secondary dentin were found on a tooth then these areas were also removed using the dremel. Once this initial cleaning of the tooth was complete the work area and dremel were cleaned to remove any residual powder. This powder, if not cleaned out properly, could contaminate subsequent samples.

30-50 mg of fine powder from dentin was removed from each tooth using the dremel and was collected on Fisher Brand Weighing Paper. The powder was transferred to 1.5mL Fischer brand microcentrifuge tubes. If the dremel was left in one spot on the tooth for too long the heat generated would cause protein denaturation. Before the sample was transferred to the small test tube it was examined under a magnifying lens so that any visible pieces of enamel could be removed. Examining the sample for enamel pieces was important to avoid an overestimation of collected dentin powder, which would eventually affect the collagen yield calculations.

The microcentrifuge test tubes were weighed when empty and the scale tared so that as dentin was collected the proper weight was attained. Both weights were recorded for later use in yield calculations.

Dentin was preferentially collected from the crown, while the upper portions of the roots were taken when necessary to collect adequate sample sizes. External surfaces where cementum is found was avoided to prevent contamination. Cementum is a tissue that turns over in response to stress placed

on the teeth giving it a much older dietary signature. Lower root sections were avoided in order to maintain a small representative period of reference.

Once the desired sample weight had been collected the methods developed by Dupras and Tocheri (2007) in their work with dentin analysis was followed and will be described in detail below. Their methods were loosely based on a modified Longin method used for bone collagen extraction.

To begin processing the samples, the powdered dentin was soaked in 2mL of 2% HCl for 12 hours, rinsed and then placed in 2mL of 2% HCl for another 12 hours. The HCl soak was repeated a second time to ensure that the entire sample was demineralized and that a saturation effect did not occur the first time the sample was treated with HCl. After the first group of samples was completed a revision to this step was deemed necessary because the final result produced low collagen yields. The remaining samples were placed in a 2% HCl solution for 24 hours but the HCl solution was not changed at the 12 hour mark.

At the completion of the HCl phase the samples were placed in a micro centrifuge for 5 minutes causing the collagen to form a small pellet. The HCl was poured off and the pellet was rinsed with double distilled water. The sample was then shaken so that all dentin particles came into contact with the water. The test tube was then placed back into the centrifuge for 5 minutes. This rinsing process was repeated a minimum of three times to remove all HCl. The sample was then placed in 2mL of 0.1M NaOH for a 24 hour period. (After the first group of samples had been completed the NaOH phase was shortened to a 20 hour period in an attempt to produce a better collagen yield). The sample was

removed from NaOH and rinsed following the same procedure outlined above when removing HCl.

The next step involved sealing the container with dura seal plastic and solubilizing the collagen in 2mL of distilled water while it was baked at 90°C for 24 hours in a Fisher brand bacteriological incubator. Next if impurities were present in the sample the liquid was transferred to a new vial. If there were no visible particles in the vial it was not transferred to avoid potential loss of sample between each vial. The samples were then placed back into the incubator at 60°C for 24-48 hours or until the water had completely evaporated. Only the demineralized dentin residue was left in the vial after evaporation was complete. This final sample was collected, weighed and recorded so collagen yield calculations could be made. Finished samples were stored in a desiccator until further analysis by a Mass Spectrometer could be done. The samples were run through a Mass Spectrometer at the Stable-isotope research laboratory in the School of Geography and Earth Sciences, McMaster University (Hamilton, ON).

The dentin collagen samples were sent in micro centrifuge test tubes in a dry state to the Stable-isotope research laboratory in the School of Geography and Earth Sciences, McMaster University. At the laboratory the samples had to be reconstituted using double distilled water and pipetted into tin cups. The collagen was reconstituted in order to safely transfer the sample to the proper container for the Mass-Spectrometer. The water collagen mixture was left to evaporate leaving only collagen in the tin cups, which were then placed directly into the CG-Mass Spectrometer. A continuous flow system was used for

analyzing the samples with helium as a carrier gas. A Costech Elemental Analyzer (ECS 4010) accepted the samples and oxidized them at 1010°C and pushed the resultant gas through a copper column at 650°C to rid the samples of any left over oxygen and to convert NO_x compounds to N_2 gas. The following step involved a small Gas Chromatography (GC) column that separated N_2 and CO_2 compounds by retarding the progression of CO_2. Once through the GC column the samples passed into the Finnegan Delta Plus XP Mass Spectrometer where this machine measured the intensity of the N_2 and CO_2 peaks. Standard material was run at the same time as the samples (6 internal standards are used) and several (2 or 3) internal laboratory standards were used to calculate the delta values for carbon and nitrogen in the samples. The results for carbon were calculated with respect to V-PDB and the nitrogen values are with respect to Atmospheric Nitrogen.

For precision some samples were run in triplicate to understand the variability within the samples. The Stable-isotope research laboratory uses the following standards for isotopes: NBS21, USGS 24 and IAEA CH-7 for carbon only; IAEA N-2 for nitrogen only and USGS 40 and IAEA 600 for both carbon and nitrogen. All samples were run on a Finnegan Delta Plus XP Mass Spectrometer.

7.2 Analytical Methods

Sample integrity assessment techniques were used to identify any outliers in the sample population for both bone and dentin. C/N ratios and collagen

yields were calculated for sample quality assessment. Appendix A illustrates the integrity data used for quality analysis for all samples. See Chapter 2 for an in-depth explanation about the quality assessment techniques used in this study.

The bone and dentin $\delta^{13}C$ and $\delta^{15}N$ data were analyzed using correlation and ANOVA tests. The data were explored to reveal relationships between childhood and adulthood diet and sex and age. Dietary ranges taken from previous isotopic studies from relevant geographic regions were evaluated to understand the dietary variation of a region. These dietary signatures from various regions will act as a baseline to compare the isotopic values from the individuals in this sample population. Table 7.1 outlines the various $\delta^{13}C$ and $\delta^{15}N$ dietary ranges from relevant sites in Europe and South Africa.

The isotopic values from the European sites established from previous research illustrates that the diet was heavily reliant on C_3 terrestrial items with a $\delta^{13}C$ range from -18 to -20‰. Nitrogen isotope signatures were not reported in these studies. The isotopic studies from South African cemeteries included individuals from West Africa and are therefore relevant to this study. The $\delta^{13}C$ isotopic range was between -8 and -20‰ and the $\delta^{15}N$ was from 5 to 15‰ (Cox *et al.*, 2001; Cox and Sealy, 1997). The suggested diet for the enslaved individuals in the above studies was a C_3 based diet with a decrease in terrestrial animal protein. Certain individuals were seen to have an increase of marine protein in their diets (Cox *et al.*, 2001; Cox and Sealy, 1997).

Table 7.1: Stable carbon and nitrogen values for bone collagen from other historic cemetery populations from Europe and South Africa

Site	$\delta^{13}C$ (‰)		$\delta^{15}N$ (‰)	
	Mean	**Range**	**Mean**	**Range**
Europe				
Saint-Martin (n=23), Saint-Pierre-du-Chardonnet (n=35) and Saint-Pierre-le-Pullier (n=16) cemeteries, France (16th and 17th C)[1]	-18.8	-19.9 to -18.3	n/a	n/a
Red Bay, Newfoundland, Canada (Basque Whalers, 17th C)[1]	-17.2	-18.1 to -16.5	n/a	n/a
HMS Mary Rose, England (1545)[1]	-19.1	-19.4 to -18.1	n/a	n/a
7 sites in Northern England dating from 17th to 19th C (n=67)[2]	-19.1	-20.2 to -18.2	n/a	n/a
Vasa, Sweden (1628)[3]	-18.8	-19.9 to -17.5	n/a	n/a
South Africa				
Coburn Street Burial Ground, South Africa (n=53, c. 1750-1857)[4]	-15.5	-19.5 to -9.2	11.7	6.2 to 14.2
Pacquet Real, South Africa (n=8, 1818)[5]	-12.2	-14.2 to -7.9	7.0	5.2 to 8.6

Modified from Varney (2003). Values taken from [1]Kennedy (1989); [2]Mays (1997); [3]During (1997); [4]Cox *et al.* (2001); [5]Cox and Sealy (1997).

Predictions were then made for the expected diets for the sample population based on the dietary ranges outlined above in Table 7.1. European diet was largely C_3 terrestrial based with little variation. The predicted isotopic ranges for $\delta^{13}C$ and $\delta^{15}N$ for an individual reflecting a European diet would be -21 to -18‰ and 9 to 12‰ respectively. Individuals who showed a $\delta^{13}C$ range of -19 to -13‰ and a $\delta^{15}N$ range of 6 to 13‰ would be interpreted as being from West Africa. The West African diet should show a large amount of variability because of the multiple geographic regions of origin and various food resources. The West Indies slaves diet was mainly reliant on C_4 plants and marine

resources. The expected isotopic ranges for enslaved individuals from the West Indies would therefore be -16 to -12‰ for $\delta^{13}C$ and 13 to 16‰ for $\delta^{15}N$. The predicted dietary ranges outlined above are estimated ranges that do not account for all possible variations within the population discussed. They are however constructed based on historical records of diet and generalized to reflect a typical diet in that area.

It is expected that there will be individuals that demonstrate a change in diet from a West African signature to an isotopic signature reflecting a West Indies diet. Also it is likely that there will be individuals that show no change in diet over time and their diets may reflect a consistent West African, European or West Indian diet throughout the course of their lives.

Along with the predicted changes in childhood to adult diet the samples were also interpreted by age and sex. The sample groups for age were too small and of uneven distribution for an in-depth analysis to be possible, however sex was used as a variable for analysis. It is not expected that sex will affect diet.

Four of the 43 individuals being studied had dental modifications and were analyzed separately to understand how their diets changed from childhood to adulthood using the $\delta^{13}C$ and $\delta^{15}N$ isotope values. A visual interpretation of the isotopic values from these 4 individuals was conducted; a small sample size such as this one is not appropriate for statistical analysis.

The childhood-to-adulthood spacing for $\delta^{13}C$ and $\delta^{15}N$ values was calculated for each of the 43 individuals. The individuals that had a childhood-to-adulthood spacing greater than 2‰ (n=20) were evaluated further to explore how

their diets changed over time in order to learn what these changes may indicate about an individual's life. For this study a 2‰ enrichment of $\delta^{15}N$ values has been used to identify dietary shifts because of the narrow range of variation in the samples, this 2‰ figure accounts for the inter-tissue differences. The 2‰ figure was used in studies by many researchers including Cox *et al.* (2001), DeNiro and Schoeninger (1983) and Sealy *et al.* (1993) because a 2‰ variation in isotopic results is likely caused by dietary changes and not regular physiological variation (Cox *et al.*, 2001). Twenty-seven individuals showed an increase of 2‰ or more in their $\delta^{13}C$ signatures, while 25 individuals showed an increase in their $\delta^{15}N$ values. Only 20 individuals showed a 2‰ change in both $\delta^{13}C$ and $\delta^{15}N$ values. The $\Delta\delta^{13}C_{bone\text{-}dentin}$ dietary signatures and the $\Delta\delta^{15}N_{bone\text{-}dentin}$ dietary signatures for the 20 individuals can be found in Appendix E. A pair-wise analysis was conducted of all the individuals with a dietary spacing greater than 2‰.

Chapter 8: Results

8.1 Sample Integrity and Predicted Dietary Values

The skeletal population used for this study was, upon excavation, well preserved according to published data from the site archaeologists (Courtaud, 1999). C/N ratios and collagen yields were calculated for all bone and dentin samples in order to assess their integrity (see Appendix A).

Figure 8.1 illustrates the predicted dietary values established in Chapter 7 for European, West African and West Indian diets during the colonial period. These expected values will be used to interpret the isotopic results from this skeletal population. These values apply to both bone and dentin isotopic results because they are expected dietary values for a specific geographic region.

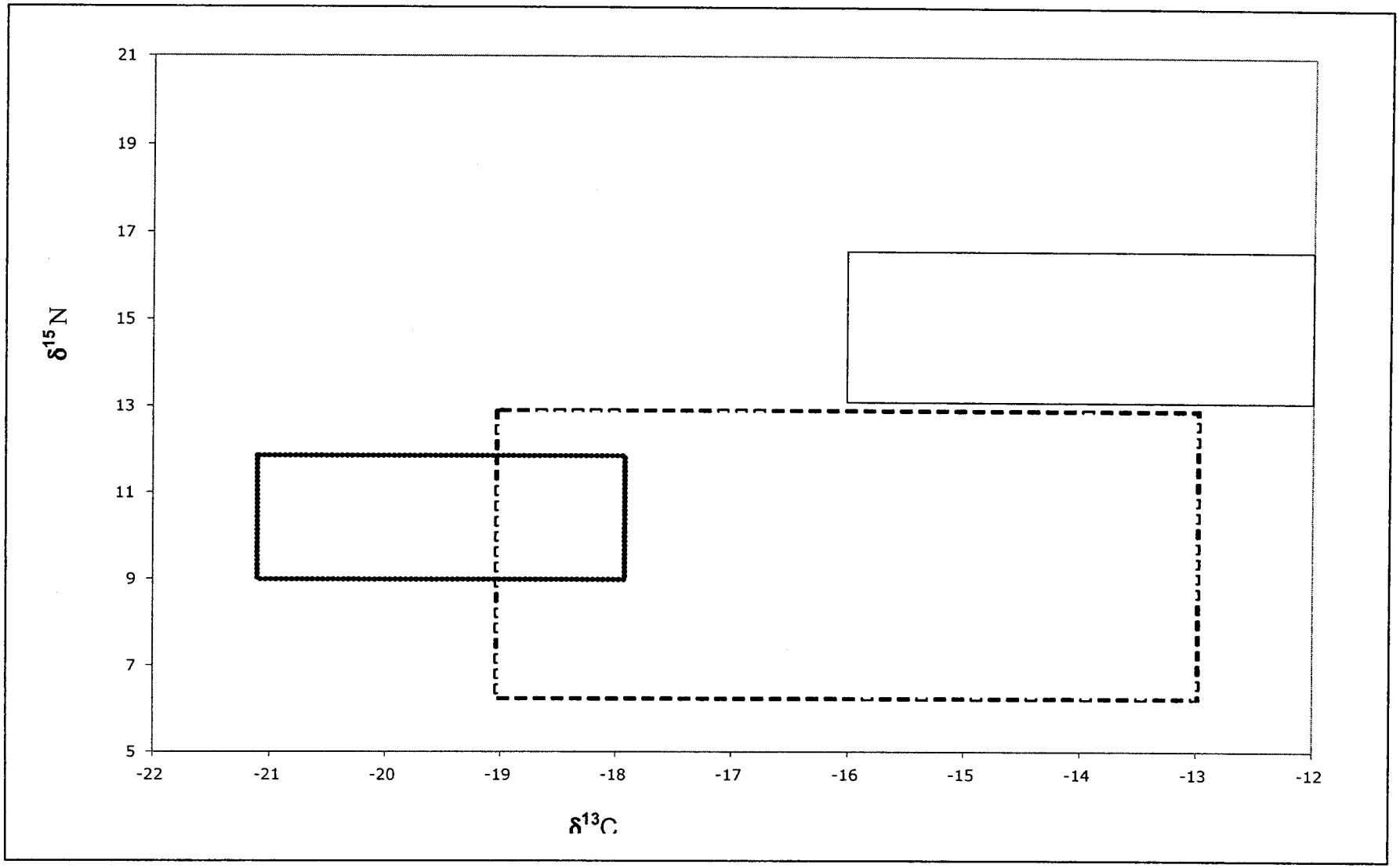

Figure 8.1: Predicted dietary ranges for Europe , West Africa , and the West Indies .

8.2.1 Stable Isotope Values for Bone Collagen

Ribs were selected and used for all samples. Table 8.1 and Table 8.2 contain descriptive statistics for $\delta^{13}C$ and $\delta^{15}N$ data for bone collagen samples respectively. A complete list of the stable isotope data is listed in Appendix B.

The minimum $\delta^{13}C$ values in Table 8.1 for the total population is in the range of C_3 foods compared to the high maximum value which falls into a C_4 plant range. The average values for males and females show no statistically significant difference between the two sexes. Although visually the females do tend to plot slightly higher (see Figure 8.2) showing a small $\delta^{15}N$ enrichment. There is no real observed difference in diet between the sexes.

Table 8.1: Summary Statistics for $\delta^{13}C$ from bone as a whole and partitioned by sex.

Sample	N	Mean $\delta^{13}C$ (‰)	Min	Max	Std dev	Var
Total	43	-15.00	-20.53	-12.9	1.73	2.99
Male	24	-14.76	-18.80	-12.9	1.67	2.68
Female	18	-15.27	-20.53	-13.2	1.84	3.41

Table 8.2: Summary Statistics for $\delta^{15}N$ from bone as a whole and partitioned by sex.

Sample	N	Mean $\delta^{15}N$ (‰)	Min	Max	Std dev	Var
Total	43	14.74	9.33	17.10	2.20	4.86
Male	24	14.57	10.07	17.10	2.11	4.64
Female	18	15.08	9.33	17.6	2.31	5.33

Figure 8.2 represents the bone collagen data arranged according to sex. A correlation between female $\delta^{13}C$ and $\delta^{15}N$ bone collagen values were tested and a strong positive correlation that showed statistical significance was the result (r=

.807, $p < .001$)[3]. The correlation between male $\delta^{13}C$ and $\delta^{15}N$ bone collagen values was also a strong positive significant relationship ($r = .933$, $p < .001$). However, there was no observed correlation between $\delta^{13}C$ or $\delta^{15}N$ values and sex. The number of individuals in this study was small therefore these tentative conclusions require further study to better understand the relationship between diet and sex.

When comparing the expected dietary ranges from the various geographic regions to the bone collagen results it can be seen that one female individual corresponds with the predicted European dietary signature. Two females and 5 males have dietary signatures reflective of the predicted West African diet, while the majority of the individuals (17 male, 10 female) have isotopic values predicted for typical West Indian diet.

There is one female and one male who have dietary signatures that fall between the expected European and West African dietary ranges. Also 5 individuals (1 male, 4 female),have enriched nitrogen levels compared to the West Indies diet.

[3] The relative strength of each r-value used in this study was assigned using accepted r-value ranges reflecting the strength of a correlation. A r-value of 0 shows no correlation; weak r = ±0.01 to ±030; moderate r = ±0.31 to ± 0.70; strong r = ±0.71 to 0.99; perfect r = 1.00 (Elifson *et al.*, 1990)

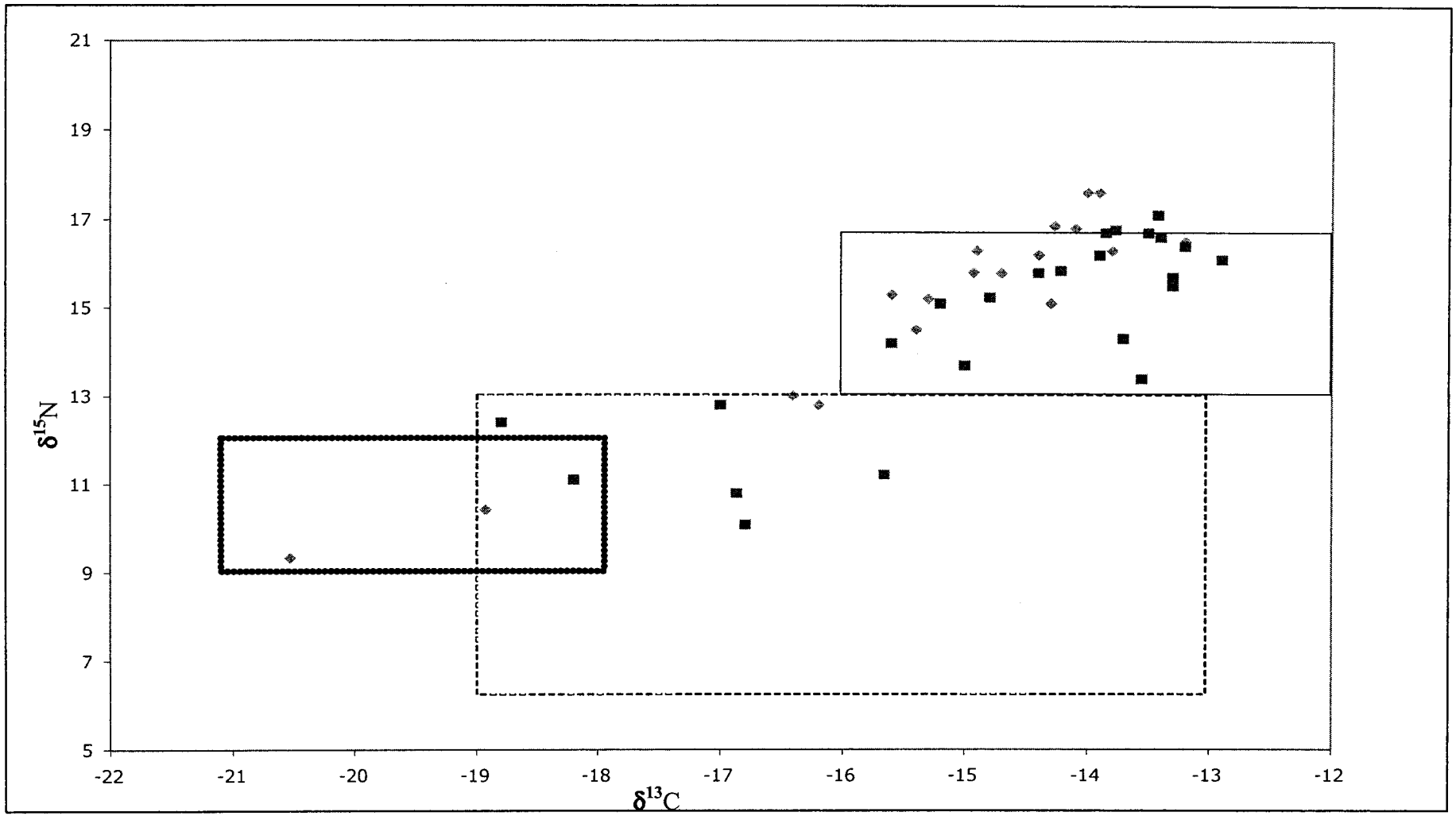

Fig. 8.2: $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen samples sorted by sex. (n=42) ■= male, ◆= female.
Predicted dietary ranges for Europe, West Africa, and the West Indies.

An analysis of variance (ANOVA) was conducted to explore male and female data for $\delta^{13}C$ and $\delta^{15}N$ in bone collagen. $\delta^{13}C$ bone collagen values did not reveal any significant difference between male and female values (p=0.359). Statistically significant differences were not found for $\delta^{15}N$ bone collagen values for males and females either (p=0.469). Table 8.3 and 8.3 provide the ANOVA table.

Table 8.3: ANOVA table for $\delta^{13}C$ bone collagen by sex.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.639	1	2.639	.863	.359
Within Groups	122.341	40	3.059		
Total	124.980	41			

Table 8.4: ANOVA table for $\delta^{15}N$ bone collagen by sex.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.636	1	2.636	.534	.469
Within Groups	197.579	40	4.939		
Total	200.216	41			

8.2.2 Stable Isotope Values for Dentin Collagen

Dentin collagen samples were prepared using one tooth from each individual. Premolars and molars were preferentially selected, however when they were not available canines were used in their place. A complete list for the skeletal elements used for the dentin samples can be found in Appendix D.

Summary statistics for $\delta^{13}C$ and $\delta^{15}N$ values of dentin are reported in Table 8.5 and Table 8.6 respectively. A full list of all sample data can be found in Appendix B. The mean $\delta^{13}C$ and $\delta^{15}N$ values for males and females are less then 1‰ difference (see Tables 8.5 and 8.6).

Table 8.5: Summary statistics for $\delta^{13}C$ values from dentin, partitioned as a group and by sex.

Sample	N	Mean $\delta^{13}C$ (‰)	Min	Max	Std dev	Var
Total	43	-17.37	-20.98	-12.28	2.30	5.30
Male	24	-17.33	-20.98	-12.28	2.36	5.59
Female	18	-17.51	-20.58	-14.24	2.17	4.74

Table 8.6: Summary statistics for $\delta^{15}N$ values from dentin, partitioned as a group and by sex.

Sample	N	Mean $\delta^{15}N$ (‰)	Min	Max	Std dev	Var
Total	43	12.62	6.46	19.84	3.08	9.46
Male	24	12.38	8.14	19.84	2.97	8.83
Female	18	13.09	6.46	17.05	3.26	10.63

Figure 8.3 shows the $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen separated by sex. There is no obvious separation of the data or discernable pattern when the dentin samples are plotted this way. There is a moderate to strong positive correlation between $\delta^{13}C$ and $\delta^{15}N$ dentin isotopic values ($r = .527$, $p < 0.001$).

There is a seemingly random distribution with a possible slight tendency for the male samples to have lower $\delta^{15}N$ values when arranged according to sex. Male $\delta^{13}C$ and $\delta^{15}N$ dentin collagen values showed a stronger correlation than the female samples in this study. Males had a moderate positive correlation ($r= .884$, $p < 0.001$), while the female samples also showed no significance ($r= .550$, $p = 0.052$).

An ANOVA test was done for both $\delta^{13}C$ and $\delta^{15}N$ values to compare males and females; no significance was found between the sexes ($\delta^{13}C$ $p=0.595$; $\delta^{15}N$ $p=0.466$).

Table 8.7: ANOVA table for $\delta^{13}C$ dentin isotopic values

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.506	1	1.506	.288	.595
Within Groups	209.283	40	5.232		
Total	210.789	41			

Table 8.8: ANOVA table for $\delta^{15}N$ dentin isotopic values.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.199	1	5.199	.542	.466
Within Groups	383.992	40	9.600		
Total	389.191	41			

When the expected dietary values for the three geographic diets mentioned in the previous section were overlaid the isotopic results for dentin collagen showed certain individuals falling into these categories. There were 6 male and 4 female individuals with the expected European isotopic signatures. The expected West African dietary range included 5 male and 3 female. Five male and 5 female have the expected West Indies dietary signatures. There were 14 individuals who did not fall into one of the three specific dietary categories.

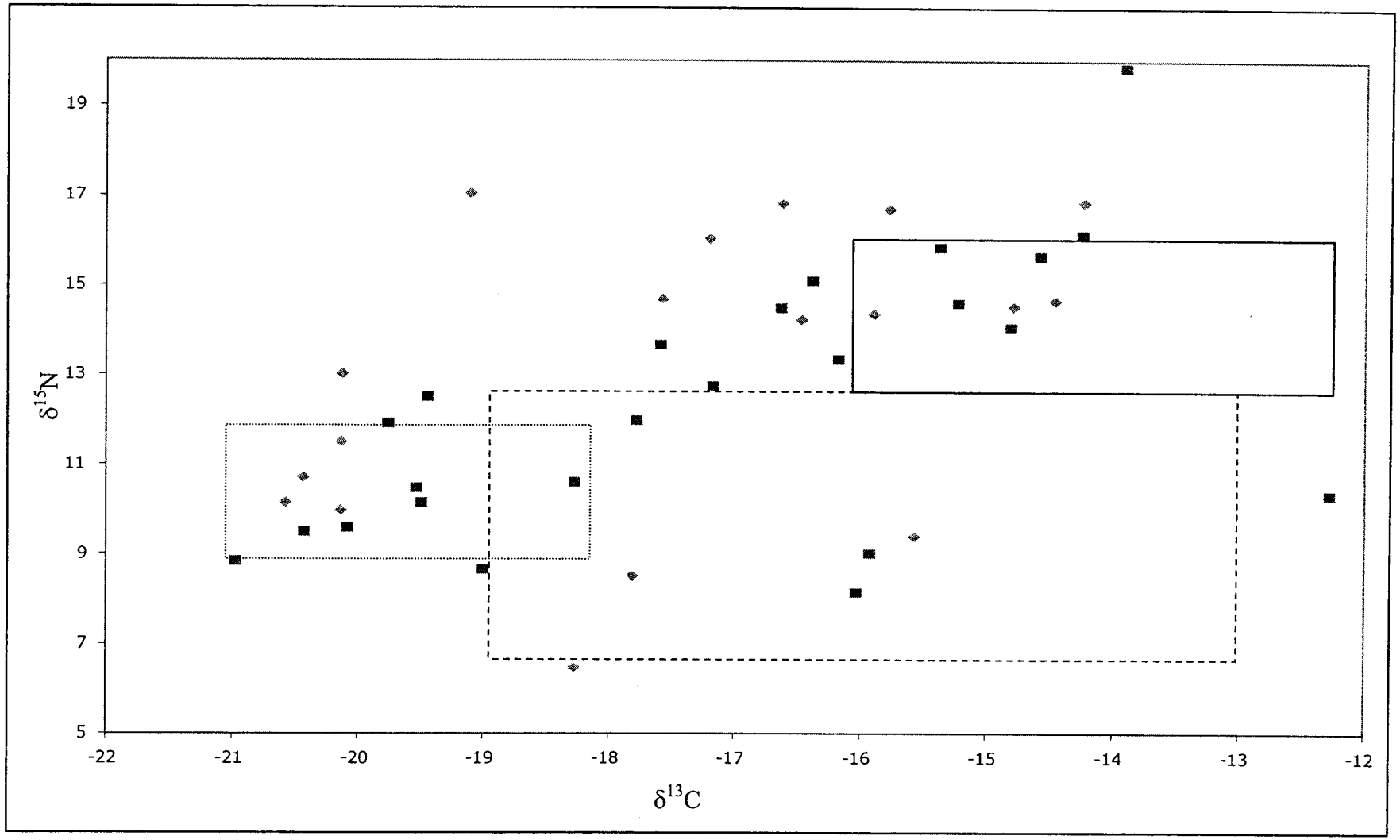

Fig. 8.3: $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen samples sorted by sex. ■ = male, ◆ = female. Predicted dietary ranges for Europe ⬚, West Africa ⬚, and the West Indies ⬚.

8.3 Comparison of Stable Isotope Values for Bone and Dentin

This section provides results that compare dentin collagen to bone collagen. Figure 8.4 illustrates the average $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen and bone collagen. The standard deviation around the mean values for both tissues is provided to illustrate the overlapping range of these two groups. The average $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen is -17.37‰ and 12.62‰ respectively. Likewise, the bone collagen averages for $\delta^{13}C$ and $\delta^{15}N$ values are -15‰ and 14.74‰.

Figure 8.5 shows the individual $\delta^{13}C$ and $\delta^{15}N$ values for dentin and bone collagen plotted together. This illustrates nicely that on average the bone samples have higher $\delta^{13}C$ and $\delta^{15}N$ values compared to the dentin samples, and the latter samples have a greater range of distribution. There has been a positive shift in both $\delta^{13}C$ and $\delta^{15}N$ values for bone samples. As mentioned in previous sections the bone collagen $\delta^{13}C$ and $\delta^{15}N$ values have a strong positive statistically significant correlation ($r = .846$, $p < 0.001$), while dentin collagen $\delta^{13}C$ and $\delta^{15}N$ values have only a moderate to strong positive correlation ($r = .527$, $p < 0.001$).

An independent samples t-test was done to compare dentin collagen isotope data to bone collagen isotope data. Both $\boldsymbol{\delta}^{13}C$ and $\delta^{15}N$ values were compared. When $\boldsymbol{\delta}^{13}C$ values of dentin collagen were compared to $\boldsymbol{\delta}^{13}C$ values of bone collagen a significant relationship was found ($p< 0.005$). The mean $\boldsymbol{\delta}^{13}C$

value for dentin was -17.37‰ with a standard deviation of 2.3 and the mean $\delta^{13}C$ value for bone was -14.99‰ with a standard deviation of 1.72.

$\delta^{15}N$ values of dentin and bone collagen were also compared using an independent samples t-test. There is also a significant difference between these two groups ($p<0.005$). The mean $\delta^{15}N$ value for dentin was 12.61‰ with a standard deviation of 3.07 and the mean $\delta^{15}N$ value for bone was 14.74‰ (std. dev = 2.20), a 2‰ increase from dentin.

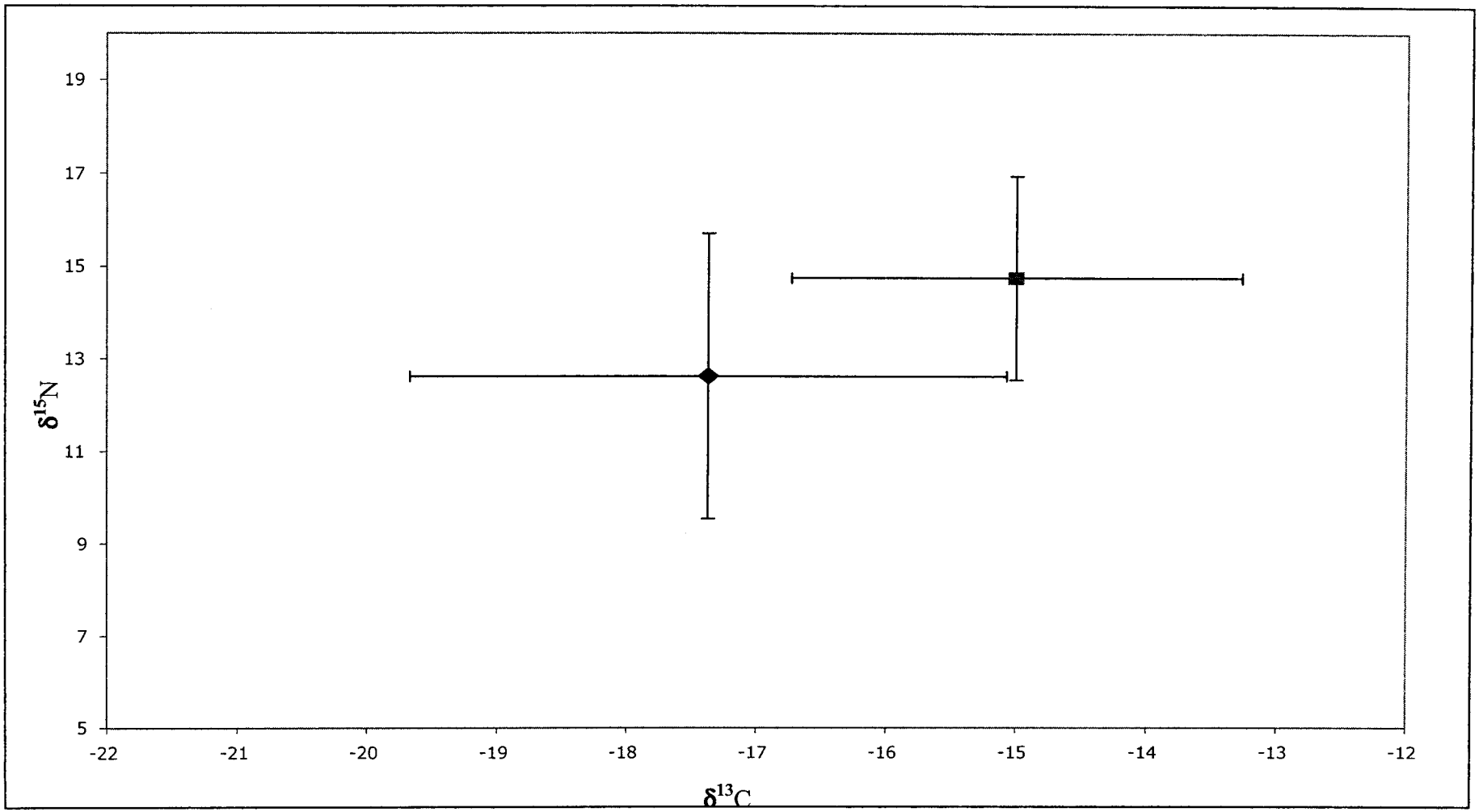

Fig. 8. 4: Average $\delta^{13}C$ and $\delta^{15}N$ isotopic values for dentin and bone collagen. The error bars on the graph represent the standard deviation for both sample groups. ■ = bone, ◆ = dentin. Predicted dietary ranges for Europe , West Africa , and the West Indies .

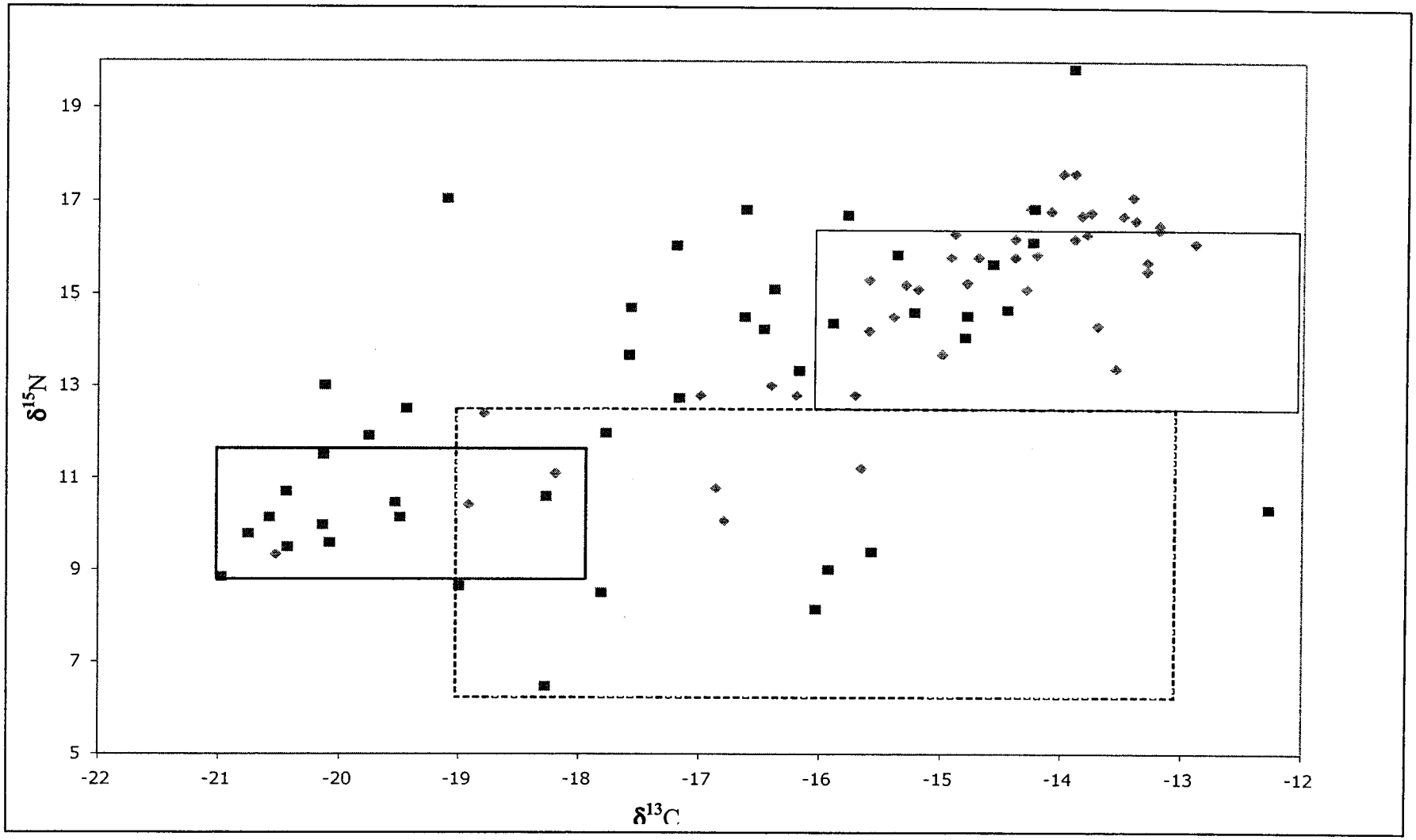

Fig. 8. 5: $\delta^{13}C$ and $\delta^{15}N$ isotopic values for dentin and bone collagen. ■ = Dentin, ◆ = Bone. Predicted dietary ranges for Europe ⬚, West Africa ⬚, and the West Indies ⬚.

8.4 Comparison of Stable Isotope Values for Bone and Dentin by Sex

This section presents isotopic values defined by sex. As mentioned previously of the 43 samples, 24 are male and 18 are female and one is of indeterminate sex. A list of the full isotopic data for sex can be found in Appendix D.

Two figures (Fig. 8.6, Fig. 8.7) were prepared to illustrate the sex-related differences in the isotopic values for the samples. Figure 8.6 demonstrates the average distribution of $\delta^{13}C$ and $\delta^{15}N$ values for dentin collagen and bone collagen for each sex. The bone collagen $\delta^{15}N$ results are enriched compared to those of dentin. Female $\delta^{15}N$ values are enriched compared to males for both tissues. There is no statistically significant difference between the increased female and male $\delta^{15}N$ values for either bone or dentin. However the average values calculated for male and female samples show that female values are slightly enriched for both tissues (see Figure 8.6). There was no significant difference in the $\delta^{13}C$ values between the sexes when comparing either tissue.

Figure 8.7 is a comparison of male and female data for individual $\delta^{13}C$ and $\delta^{15}N$ isotopes values. The female values tend to be enriched in $\delta^{15}N$. The isotope data for male and female bone samples tend to cluster more tightly together compared that for the dentin samples. Bone samples for both males and females have higher $\delta^{15}N$ levels and less negative $\delta^{13}C$ values. The male and female dentin groups have wider ranges of variability in $\delta^{13}C$ and $\delta^{15}N$ values.

The range of $\delta^{13}C$ values for dentin collagen samples from males is between -12‰ and -21‰, similarly the range for $\delta^{13}C$ values for bone collagen from male samples is -12‰, and -19‰. The $\delta^{13}C$ values of dentin collagen samples from females have a range between -14‰ to -21‰. The $\delta^{13}C$ values for bone collagen of females fall between -12‰ and -21‰. The $\delta^{13}C$ values for dentin collagen from females show the smallest range of variation out of the four categories. All four groups returned weak positive correlations when values for the two tissues are compared. The $\delta^{13}C$ values for bone and dentin of males showed a moderate correlation (r= .588, p=.027). Female $\delta^{13}C$ and $\delta^{15}N$ values for bone and dentin had the weakest correlations (r= 0.308, p = 306, r= .336, p= .262 respectively). A comparison of male $\delta^{15}N$ values for dentin and bone also resulted in a moderate correlation (r= .405, p=.151).

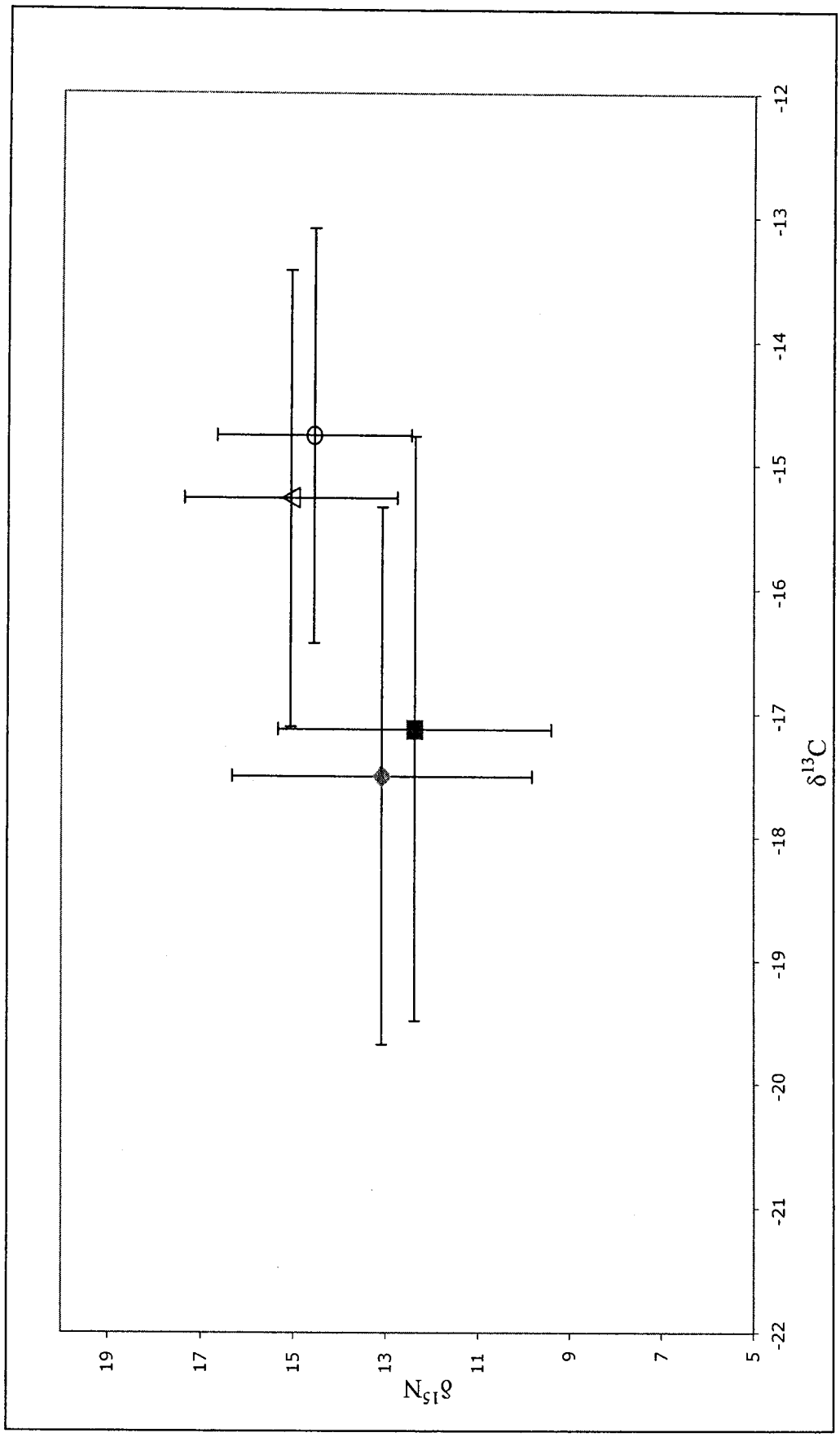

Fig. 8. 6: Average $\delta^{13}C$ and $\delta^{15}N$ values for Bone and Dentin Collagen sorted by sex. (Error bars represent standard deviation for $\delta^{13}C$ and $\delta^{15}N$ values for each variable displayed) ■ = male dentin, ◆ = female dentin, ○ = male bone, △ = female bone. Predicted dietary ranges for Europe, West Africa, and the West Indies.

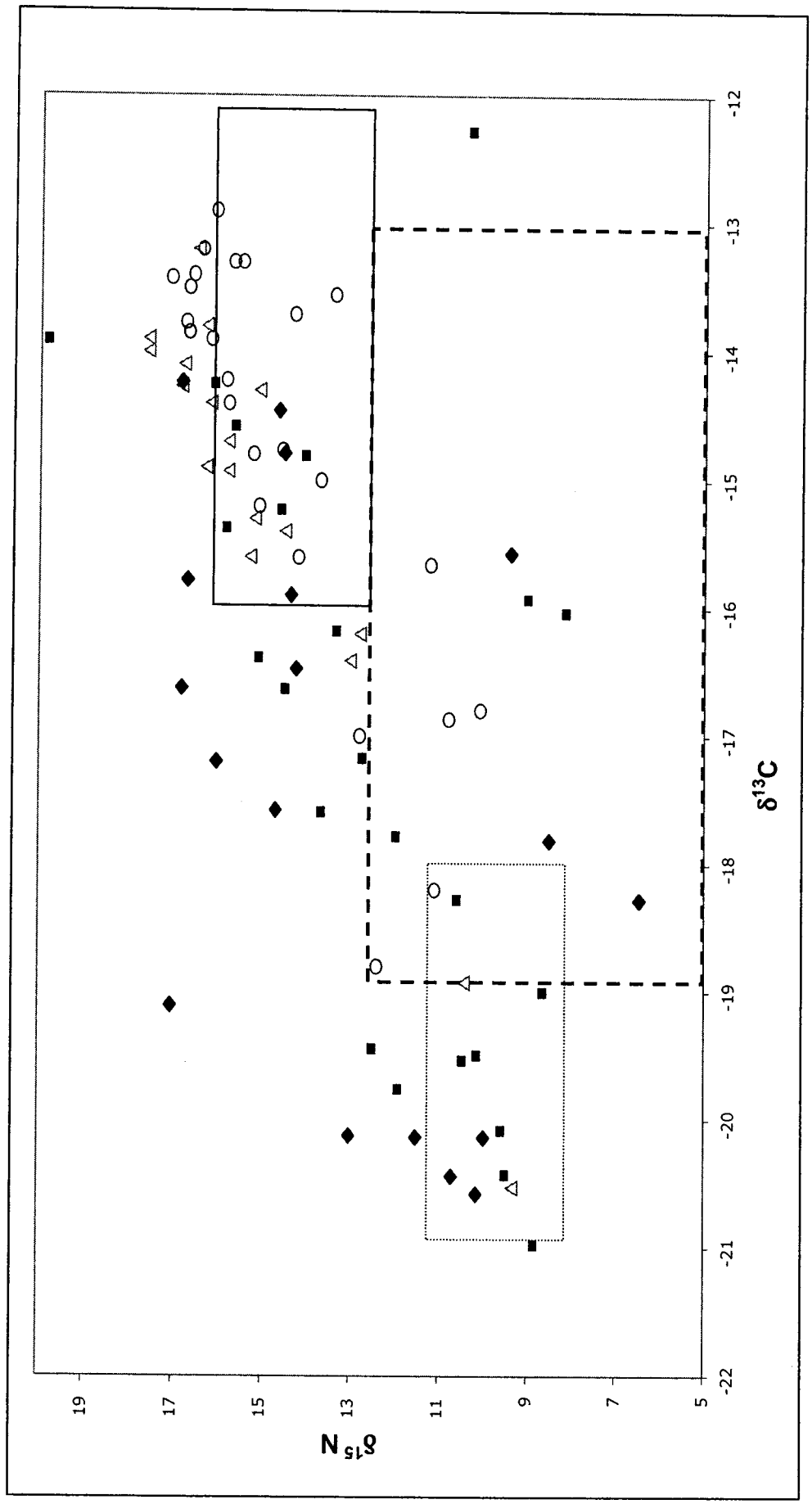

Fig. 8. 7: $\delta^{13}C$ and $\delta^{15}N$ isotopic values for male and female bone and dentin collagen. ■ = Male dentin, ◆ = Female dentin, ○ = Male bone, △= Female bone. Predicted dietary ranges for Europe ⬚, West Africa ⬚, and the West Indies ⬚.

8.5 Results From Individuals With Dental Modification

Four of the 43 individuals sampled were documented as having dental modifications. Figure 8.8 illustrates the δ^{13} C and δ^{15}N dentin and bone isotope values for these four individuals. In this graph it is clear that diet did change as these individuals progressed into adulthood. The dentin δ^{13} C isotope results range between -19‰ to -21‰ and the δ^{15}N values also show a small range between 8 to10‰. The bone samples have a δ^{13} C isotope range of -17‰ to -13‰ and a δ^{15}N range of 10-16‰. The samples show no overlap between the childhood and adulthood diet. These four individuals will be discussed in greater detail in Chapter 9.

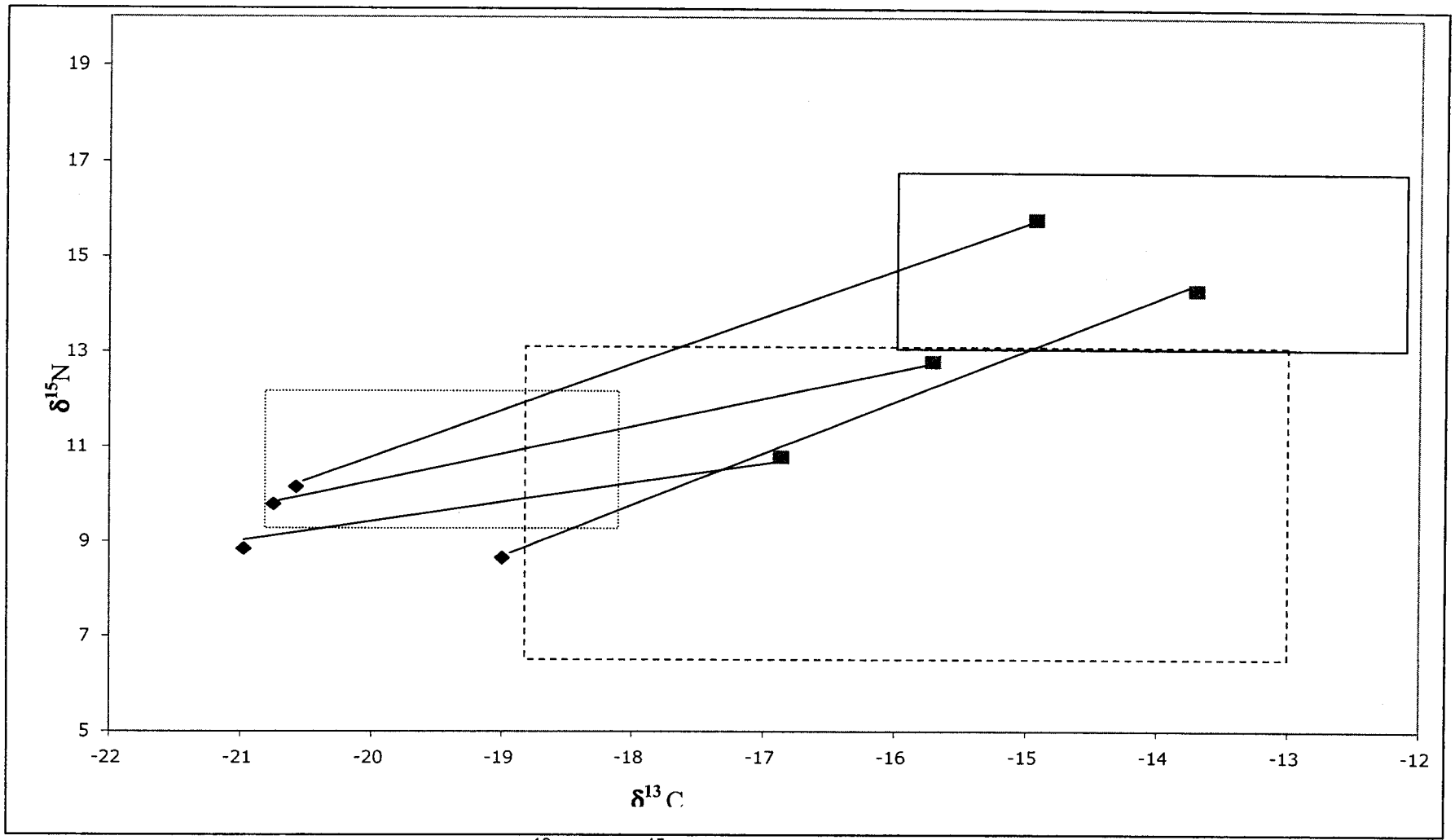

Fig. 8. 8: Comparison of dentin and bone δ^{13}C and δ^{15}N isotope values from individual samples with dental modifications. ■ = Bone, ◆ = Dentin. Predicted dietary ranges for Europe ⬚, West Africa ⬚, and the West Indies ⬚.

8.6 Sample results from individuals with 2‰ dietary spacing

A dietary shift of 2‰ or greater has been shown in previous research to be the result of a dietary change that is beyond that expected by normal biological variation between body tissues. Twenty individuals show a 2‰ enrichment in both δ^{13}C and δ^{15}N dentin values to bone δ^{13}C and δ^{15}N values. The dentin and bone isotopic values for these individuals can be found in Figure 8.9 where each dentin-bone pair was assigned a number in order to evaluate the dietary shift more easily. The calculated dietary spacing for each individual in the sample population is given in Appendix E. The predicted dietary ranges are outlined in figure 8.9 to demonstrate how individual diets changed over time.

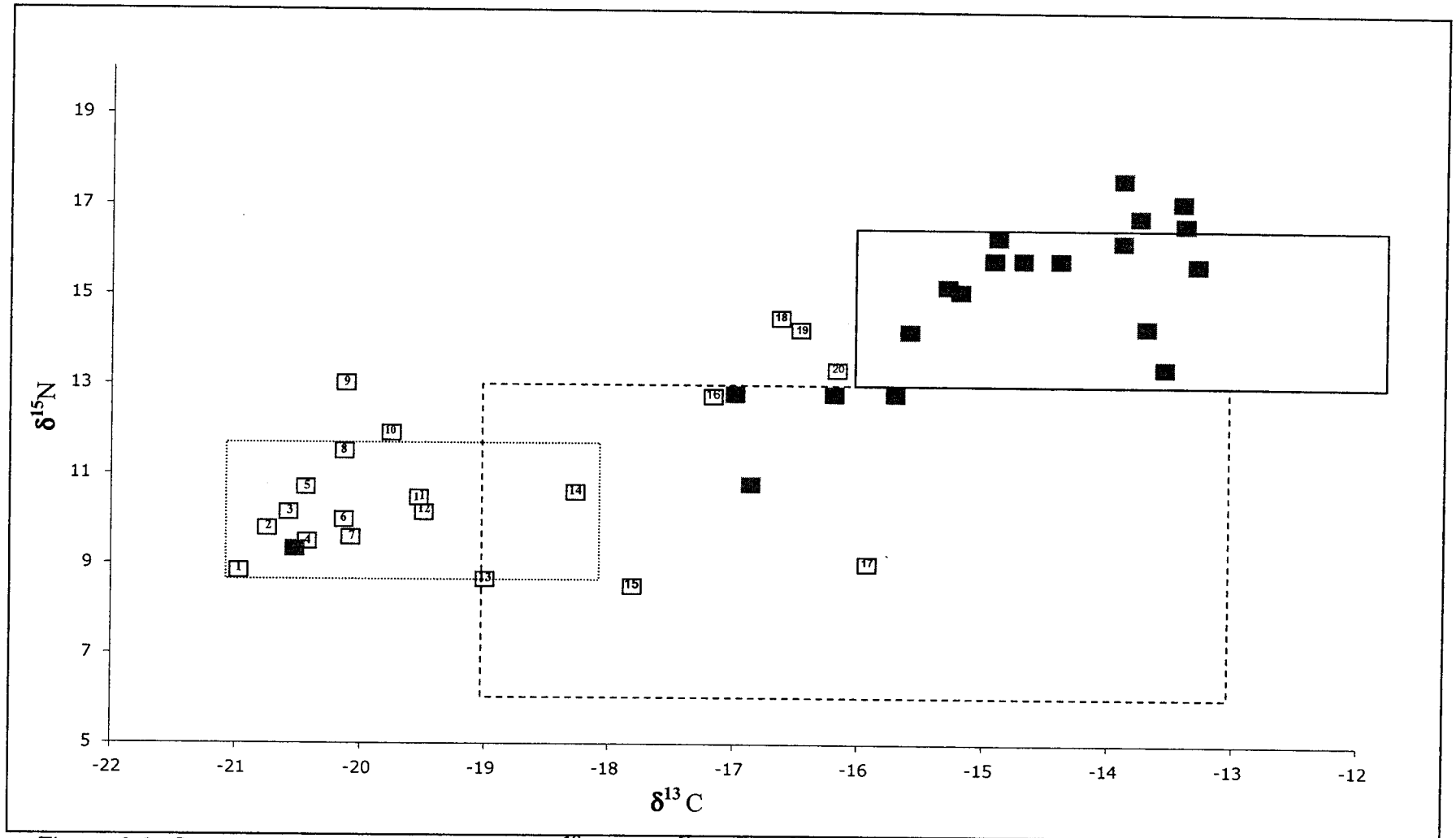

Figure 8.9: Comparison of dentin and bone $\delta^{13}C$ and $\delta^{15}N$ values from individuals with $\Delta\delta^{13}C_{dentin\text{-}bone}$ and $\Delta\delta^{15}N_{dentin\text{-}bone}$ of 2‰ of more. ☐ = dentin, ■ = bone. Predicted dietary ranges for Europe ⬚, West Africa ⬚, and the West Indies ⬚.

8.7 Summary

The purpose of this chapter was to present the isotopic data from the 43 samples used from the l'Anse Sainte Marguerite site, Guadeloupe. Overall when $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen were compared to those for dentin collagen it was apparent that the dentin samples had a much wider isotopic range. The bone samples also had more positive values overall for both $\delta^{13}C$ and $\delta^{15}N$ values.

When the data was sorted by sex, some interesting separation between the sexes was apparent when the data was plotted. In many of the graphs the female bone samples had the most enriched average $\delta^{15}N$ values ($\delta^{15}N$ = 15.27). Overall, the $\delta^{15}N$ values for female dentin collagen also appeared to be higher than those for the male dentin collagen samples. The average values for females ($\delta^{15}N$ = 13.09) were also higher than those for males ($\delta^{15}N$ = 12.38). However, these trends are not statistically significant. The majority of the samples (84%) did show an increase in $\delta^{15}N$ bone values between dentin and bone with 70% having $\delta^{15}N$ values that increased by 2‰. Although visually there is a small difference between male and female samples it does not appear as though sex affects diet.

Interpretations of the results presented in this chapter are discussed in Chapter 9. Diet and colonial history discussed previously in this paper will influence the context of the interpretations.

Chapter 9: Discussion

9.1 Introduction

When discussing the results from this study the historical context of the islands must be kept in mind to properly reconstruct diet and life histories for the individuals in the sample population. Knowledge of the foods available on the island at the time and the isotopic signatures expected as a result of their consumption will aid in determining what people were consuming when interpreting the isotopic data from the sample skeletal remains[4]. Determining the cause of the observed dietary changes can help recreate life histories and comprehend what transpired over the course of a person's life. Dietary shifts can be the result of age related changes (eg. weaning) and/or residential movements or be the results of a change in the availability of foodstuffs.

Dietary ranges in terms of $\delta^{13}C$ and $\delta^{15}N$ values were predicted for the possible diets found on the Island of Guadeloupe during colonial times. These dietary ranges are illustrated in Figure 8.1 and will be used to interpret the isotopic results from this study.

In addition, figure 2.2 that has been mentioned previously, illustrates the different plants and animals that would have been available for consumption along with their corresponding isotopic values. Stable carbon and nitrogen isotopes were used together in this study because it is not possible to distinguish

[4] When evaluating dietary signatures from isotopic values and attempting to reconstruct dietary habits of an individual it is important to remember that human choice must always be considered. Although a variety of foods may have been available, the items chosen for consumption may only be a small fraction.

between CAM plants, C_4 plants and marine resources in the diet using $\delta^{13}C$ values alone. CAM plants, based on historical records, did not form a significant portion of the diet therefore the complications involved with CAM plants do not affect this project. There is however an overlap in the ranges of $\delta^{13}C$ values for C_4 plants and marine resources, which does create a challenge for this study. The inclusion of $\delta^{15}N$ analysis often resolves this obstacle for many environments but it does not do so when dealing with the West Indies. Many of the common plants have $\delta^{15}N$ values that overlap with marine resources and terrestrial domestic animals. Specifically, shellfish, land crabs, sea turtles and reef fishes all have very low $\delta^{15}N$ values in comparison to domestic animals like cattle (Keegan and DeNiro, 1988). Even with the complications mentioned above it should still be possible to interpret the isotopic results and reconstruct diet.

9.2 Dietary Reconstruction

When $\delta^{13}C$ and $\delta^{15}N$ values for bone collagen are plotted against each other (Fig. 8.2), the data point form a linear arrangement with more samples clustering towards the higher $\delta^{13}C$ and $\delta^{15}N$ values. The $\delta^{13}C$ and $\delta^{15}N$ values for the samples with higher isotopic ranges were greater than -16‰ (falling between -16and -12‰) and 13‰ (falling in the range of 13to 17‰) respectively. Twenty-nine individuals (17 male, 12 female) have isotopic values that fall within the predicted dietary range for a slave diet from the West Indies. $\delta^{13}C$ values in this range suggest a diet of mainly C_4 plants. C_4 plants, such as maize and millet, were often eaten as staple foodstuffs with C_3 plants used as supplemental items (Kiple, 1984). A higher dependence on imported marine fishes, but also including local reef fishes to provide dietary protein in the diets of these individuals would result in the observed enriched $\delta^{15}N$ isotope values (Keegan and DeNiro, 1988). The bulk of protein for slaves was in the form of imported salted fish brought to the islands from North America or Europe (Dunn, 1972). Locally caught fish was also a common means for subsistence on the island (Abrahams and Szwed, 1985).

In addition to the 29 individuals with high $\delta^{13}C$ and $\delta^{15}N$ values, there are three others (2 female, 1 male) that have isotopic signatures that are enriched in ^{15}N placing them slightly higher than the predicted range for the slave diet in the West Indies. While the $\delta^{13}C$ values remain in the expected range for this predicted diet, the $\delta^{15}N$ value suggests these three individuals were consuming a greater amount of marine protein than the majority of the individuals sampled in this study.

Seven individuals (5 male, 2 female) had dietary signatures consistent with the expected West African diet. One female individual had isotopic values that fell within the predicted range for European diet. There were 2 individuals (1 male, 1 female) who had isotopic values that were in the overlapping dietary ranges between Europe and West Africa. Two scenarios are suggested to explain the data for these latter two groups. The first that these individuals might represent people enslaved and transported from Africa to the West Indies that did not survive for a long period of time in the West Indies. Alternatively, these individuals may have consumed a diet that was different from the majority, perhaps due to differential access to certain foodstuffs.

An ANOVA test demonstrated that there was no significant difference between the sexes for bone collagen $\delta^{13}C$ or $\delta^{15}N$ values (See table 8.3). The majority of individuals of both sexes were eating a relatively homogeneous diet with high $\delta^{13}C$ and $\delta^{15}N$ isotope values. Similarly, the small number of samples with low $\delta^{13}C$ and $\delta^{15}N$ values did not show significant differences between male and female samples. Individuals who were eating higher trophic protein sources as indicated by their high $\delta^{15}N$ values were most likely consuming a diet more reliant on C_4 plants. However, high levels of marine protein in the diet also influence $\delta^{13}C$ values. Generally marine plants and animals have higher $\delta^{13}C$ values than terrestrial plants and animals because dissolved marine carbonate has a higher $\delta^{13}C$ ratio (0‰) compared to the atmosphere (-7‰) (Schoeninger and DeNiro, 1984). Therefore, the less negative $\delta^{13}C$ values of some individuals are still consistent with a reliance on marine resources, but the more moderate $\delta^{13}C$ values (-19‰ to -16‰) indicate more

reliance on C_3 type plants than C_4. In other words, more reliance on root crops and starches such as rice and/or wheat rather than maize and millet would be consistent with these dietary signatures.

As well, North American or locally raised livestock fed on C_4 plants that are included in the diet could explain the isotopic values from the individuals mentioned above with less negative $\delta^{13}C$ values. Similarly the individuals demonstrating low nitrogen values correspond with more negative carbon values. The isotopic data in figure 8.2 agrees with the expected isotope values from the regional predicted diets of the West Indian slaves and much of West Africa. There is variability in the bone collagen results, which is expected because of the individual variation in dietary preference and differential access to food resources. However, even with this variation within the samples the dietary signatures for 32 of the 43 individuals fall within the predicted dietary range for a West Indies slave diet.

The isotopic results for dentin collagen were examined using the same comparisons and tests for the bone collagen samples. When comparing $\delta^{13}C$ and $\delta^{15}N$ values for the two tissues a seemingly random distribution was produced (Figure 8.3). There was a wider range of variability in the dentin isotopic signatures suggesting that these individuals grew up in a variety of geographic locations with different available foods resources. A second explanation for the dietary variation in childhood is that enslaved individuals in the West Indies were commonly traded between islands and plantations (Handler and Lange, 1978). The variation in locally available foodstuffs on various islands in the West Indies could account for some of

the dietary differences observed for those individuals with a childhood signature closely related to the predicted West Indies diet.

Ten individuals (6 males, 4 female) had dietary signatures (see Figure 8.3) that matched the predicted values for a European diet while seven individuals (5 male, 2 female) reflected predicted value for West African Diet. The isotopic ranges for these groups would suggest that these individuals were consuming a diet heavily reliance on staples based on C_3 plants with terrestrial based protein sources.

Eight individuals (5 male, 3 female) had a dietary signature reflective of a slave diet in the West Indies. These individuals had higher $\delta^{15}N$ values that are most likely the result of fish comprising a substantial portion of their dietary protein. Their $\delta^{13}C$ values reflected a diet heavily based on C_4 plants. Maize and millet are C_4 plants that were commonly consumed by slaves in the West Indies (Handler and Lange, 1978). The remaining 17 individuals had dietary signatures that were not within the predicted dietary ranges. Many individuals (n=13) were however within 1‰ or less for both $\delta^{13}C$ and $\delta^{15}N$ values of one of the predicted dietary ranges making it difficult to suggest which area of origin these individuals were from. Overall, the dentin values, in comparison to the bone samples, show much more dietary variability suggesting that these individuals had multiple places of origin or access to a more diverse diet.

When the data in figure 8.3 are examined, females do have a slightly higher average $\delta^{15}N$ value (13.75‰) compared to males (13.26‰). However this difference is not statistically significant indicating that sex did not affect overall diet in the West Indies.

Figure 8.4 is a representation of the average values and standard deviation of $\delta^{13}C$ and $\delta^{15}N$ values for both bone and dentin. The positive shift in $\delta^{13}C$ and $\delta^{15}N$ isotope values indicates that C_4 foods and marine protein were introduced or their contribution to diet increased later in life. Also the dentin samples have larger standard deviation values, indicating greater variability in diet during childhood than adulthood. However, there is no significant different in diet when the samples are interpreted as a homogeneous group. The entire population did not experience the same dietary changes throughout life.

The distribution $\delta^{13}C$ and $\delta^{15}N$ values for individual dentin and bone samples also illustrates the increase in both $\delta^{13}C$ and $\delta^{15}N$ values for bone over dentin samples (Figure 8.5). As mentioned above, the adult diet indicated is significantly reduced in diversity as compared to the dietary signatures from the childhood dentin samples. The available foodstuffs on Guadeloupe far exceed the limited range of the adult diet suggesting that these individuals were eating a very regimented diet with little variety.

The adult bone collagen samples show that a majority of the individuals (n=24) have isotopic signatures consistent with the predicted West Indies slave diet that was dominated by C_4 plants and fish.

The shift in the $\delta^{13}C$ values between dentin and bone indicated a dietary shift from childhood to adulthood that was most likely caused by an increase in the proportion of C_4 foods introduced into the diet. Another potential cause could be marine foods, which tend to have higher $\delta^{13}C$ values than terrestrial food (Schoeninger and DeNiro, 1984). Therefore, an increase in either or both C_4

sources and marine protein, the latter being most probable, could have caused the change between the childhood and adult diet. These individuals also had enriched $\delta^{15}N$ signatures that corroborate the suggestion of increased marine protein in the diet.

Figure 8.6 illustrates the average $\delta^{13}C$ and $\delta^{15}N$ isotope values of bone and dentin categorized by sex. There is no significant difference by sex when the data are explored using correlations. Also the average values for the male and female dentin and bone categories are very similar and there is considerable overlap between the dentin and bone tissues (Fig. 8.6).

The fact that both sexes were eating a similar diet is further emphasized when the individual isotopic data points are viewed (Figure 8.7) and the obvious overlap in values for dentin and bone are seen. The dentin values for males have the widest range of variability within the $\delta^{13}C$ and $\delta^{15}N$ values (Figures 8.6 and 8.7). This large range of values shows that males had various places of origin or alternatively that they had a varied diet with access to many different plant and protein sources during childhood.

9.3 Samples with Dental Modifications

Dental modification was a common practice in parts of Africa during colonial periods and into the 18th and 19th centuries (Finucane *et al.*, 2008). Dental modification involved individuals of both sexes in conjunction with various rites of passage including but not limited to puberty, childbirth or for aesthetic reasons

(Goose, 1963). The anterior teeth were most often subject to modification because these teeth are most visible.

Individuals recovered from archaeological sites in the West Indies who possess dental modification are often assumed to be first generation slaves that were captured in Africa and brought to the West Indies. Dental modification was a practice that was banned in the West Indies by European colonizers in an attempt to homogenize the enslaved population (Handler and Corruccini, 1983).

The isotopic ranges for carbon and nitrogen for dentin (Figure 8.8) make it clear that as young individuals the diet consisted of C_3 plants and terrestrial proteins. Although the childhood diet indicated for these four individuals is closest to the predicted values for a European diet, it is unlikely that they were originally from Europe. The dental modification suggests that these people were from West Africa consuming a diet of terrestrial protein and C_3 plants. Dental modification is not practiced in European cultures. The region of West Africa that is now known as Guinea, Sierra Leone and Liberia was once known as the Rice Coats because of the prominence of this C_3 plant (Schroeder *et al.*, 2009). Individuals from this area would produce a dietary signature similar to the four individuals with dental modification mentioned above.

Comparison of the stable isotopes values for dentin to those for bone indicates that they experienced a shift in diet from C_3 to C_4 plants and from terrestrial to marine proteins sometime in adulthood. Two individuals have a clear isotopic signature from their bone collagen reflecting the predicted West Indian slaves diet with a third individual's values approaching that range. The fourth individual shows

an increase in both $\delta^{13}C$ and $\delta^{15}N$ isotope values but remains in the West African dietary range. The West African dietary signature could be maintained by selecting and consuming a diet that closely reflects an African diet while living in the West Indies. Some enslaved individuals would have had greater access to resources than others allowing them more freedom to choose desired foods affecting their stable isotope signature (Klippel, 2001). An alternative interpretation might be that this individual lived elsewhere in the West Indies and was then traded to Guadeloupe; however, the dental modifications make this scenario unlikely. Alternatively this individual may have been in Guadeloupe for an intermediate length of time that did not allow full turn over of the bone to reflect a new diet causing this intermediate signature. Based on the historical context of the site and the presence of dental modification in these individuals, the most plausible interpretation is that they likely originated from West Africa and moved to the West Indies as slaves and lived there into their adult lives. The variability in isotopic values and indicated diets is most likely reflective of the large area and diversity of cultures that people were enslaved from in Africa.

9.4 Individuals with Dietary Spacing of 2‰ or more

Figure 8.9 was included in order to display individual dietary shifts within this skeletal population. Only individuals who showed a dietary change of 2‰ or more were selected. For this study a 2‰ enrichment of $\delta^{13}C$ and $\delta^{15}N$ values has been used to identify 'real' dietary shifts between childhood and adulthood samples.

Twenty individuals demonstrate a shift in isotopic values between their dentin and bone tissues of 2‰ or more and therefore are identified as having had a substantial dietary change from childhood to adulthood. The isotope values for dentin include 12 individuals with a dietary signature that corresponds with the predicted dietary range for European diets. These individuals could in fact be of European, West Africans or West Indian descent that fall slightly out of the predicted dietary range for those groups. It is possible that these individuals were indentured servants who came from Europe and worked as slaves, however this is not very plausible given that the French did not have indentured servants (Crousse, 1977). European indentured servants were only used in early Colonial times and they were relatively uncommon (Dyde, 2000). These individuals may have been from parts of West Africa that relied on C_3 crops like rice causing a stable isotope signature similar to the European range. The reason for suggesting that they were of African descent is because of the dietary shift seen in their adult life. These individuals made a significant dietary change in their lives and the adult isotopic signatures reflect the predicted values for the West Indies slave diet.

Six individuals had a childhood isotopic signature matching expectations for a West African diet. All of these individuals have enriched bone collagen $\delta^{13}C$ and $\delta^{15}N$ values. Only two individuals had values approximating that expected for a West Indian diet during childhood. These two latter individuals most likely originated in the West Indies, however what is interesting is that in adulthood one individual's diet became enriched and moved into the expected range for West Indian slave diet, the other individual was the only one to have decreased $\delta^{13}C$ and $\delta^{15}N$ isotopic values.

This individual (THSM 36) may have become chronically ill later in life changing the diet she was consuming. Another possible explanation is that perhaps this individual was not enslaved and therefore did not have dietary restrictions. Lastly, this individual may have had a different status that provided her with access to different foods. Varney (2007) examines how isotopic studies can be used to identify differences within a group based on diet. Often slave populations are considered to be a homogeneous group when in fact there was opportunity for variation in their dietary habits: status, plantation, and personal preference are among some of the possible reasons for the observed variation. If in fact she is, as is suggested, an enslaved individual from Africa, this female is a good example of the variation and different life histories that can be found within a population. The historical context and size of the l'Anse Sainte Marguerite cemetery where these individuals were recovered suggests that this was a slave burial ground therefore strengthening the assumption that this individual would have been a slave (Courtaud *et al.*, 1998).

It does appear as though most of these individuals lived in the West Indies as slaves based on their isotopic signatures from their adult bone collagen results. Fifteen individuals had a change in isotopic values reflecting a dietary shift towards a West Indian slave diet. There were 4 other individuals who had dietary signatures approaching this predicted West Indian dietary range. The 4 individuals with dental modification (samples labeled 1,2,3,13 in figure 8.9) are assumed to be individuals who originated in West Africa and were moved to the West Indies to live as slaves. The individuals with dental modification can be used as a model for the rest of the sample population demonstrating a 'real' dietary shift of 2‰ or more (fig. 8.9).

Although certain individuals did not reflect the predicted West African diet in childhood it is still possible that they were from this area. As mentioned above the predicted ranges are estimates and do not account for all possible variations within Africa. Also individuals from the 'Rice Coast' would have isotopic signatures different from the predicted West African range offered in this study. It cannot be ruled out that these individuals were of European descent who move to the West Indies and consumed a diet based on marine resources and C_4 plants. It is well known that the imported foods were unpredictable and often in short supply therefore Europeans would have had to supplement their diets with locally available foods which may have altered their isotopic signatures. However this suggestion is not plausible because of historical accounts of diet for Guadeloupe and as mentioned before it is probable that the cemetery was used as a slave burial ground therefore these individuals are unlikely to be of European descent (Courtaud *et al.*, 1998).

9.5 Summary

In summary this chapter has demonstrated that there was variability within the dietary habits of the slave population on the island of Guadeloupe. Age and sex do not seem to have been influential variables on the isotopic composition of an individual's adult diet. The sex of an individual also did not influence the types of food being consumed at a young age according to the dentin collagen isotope results.

What is obvious from this data is that 63% of these individuals did show an increase in $\delta^{13}C$ isotopic values and 51% showed an increase in $\delta^{15}N$ isotopic values of 2‰ or greater from a young (4-12 years) to an older age (15 + years). This is most likely a result of a geographic movement that the individuals would have experienced Africa or Europe to the West Indies. However this change could also be the result of a culturally constructed difference between adult and childhood foods. A change in diet may result if children were being purposefully fed a different diet.

Even though people may have been consuming imported foods from North America or Europe it is not where the food comes from that that will influence the isotopic signature, it is what people are choosing to eat. Wheat may have some variation in isotopic values depending on where it was grown but it is always a C_3 plant and its isotopic values do not overlap with C_4 plants like maize or millet making it possible to observe the difference in dietary signatures.

The best evidence for a geographic movement comes from the four individuals in this study with dental modification. When their dentin collagen isotopes signatures was compared to the bone collagen values it was clear that a significant dietary shift had occurred during their lives. The dentin values reflected a C_3 diet with low nitrogen values that then changed to a diet based on C_4 foods and higher $\delta^{15}N$ values indicating protein sources from higher trophic levels. The change from childhood to adult diet seen in the samples from the individuals with dental modifications was a clear and well defined shift in isotopic values with no overlap.

The plant foods available to the slaves on Guadeloupe were limited to maize, millet, yams and other starchy foods. The increased $\delta^{15}N$ values suggest that the

diet was reliant on protein such as fish from marine systems with higher trophic levels. Fish, such as salt cod from North America, were often referred to as the 'meat of the West Indian slave' because it was a heavily relied upon resources (Handler and Lange, 1978:87 quoting a document entitled the Substance of the Evidence on the Petition 1775:14). Salt beef would also have been consumed but not at the levels originally assumed based on the historical documents.

The isotopic results from this population indicate a substantial dietary change over the period of these individual's lives. Perhaps the dietary variation is a reflection of a cultural change during an individual's life, but more likely it is the results of a major geographic movement after the juvenile years.

Chapter 10: Conclusion

10.1 Important Contributions and Findings

Stable isotope analysis of historical populations in the West Indies has not been a commonly used tool for assessing skeletal samples. Varney (2003) conducted the first isotopic research in the West Indies on a historical population using bone collagen and apatite in conjunction with enamel apatite to access different periods in an individual's life by using dietary reconstruction. Dentin collagen and bone collagen was used in this study to compare different periods of an individuals life to understand more about their history.

In addition to learning about the past life histories of the individuals in this study it was also a goal to demonstrate that the use of dentin collagen was a reliable source for isotopic analysis in geographic regions like Guadeloupe. In the field of stable isotope analysis dentin has not been commonly used because of concerns surrounding the preservation of this tissue. The results from this study showed good sample integrity and provided quality data for analysis. Enamel is more resistant to diagenesis so was preferentially used in previous studies. Studies by Sealy and colleagues (1993) have used dentin as a resource for comparison to bone collagen effectively, but not extensively. This study aimed to produce useable isotopic results from dentin to support the notion that dentin is a suitable tool for this type of study. Researchers in the past have been apprehensive to use dentin because of possible diagenetic factors, however this study established that the use of this tissue is a good technique to isolate a childhood signature from adult remains.

Although the sample size in this research was small, differences between dentin and bone isotope results were shown. The isotopic profiles for many individuals (n=20) in this study clearly reflect a substantial change in diet of 2‰ from childhood to adulthood. No significant dietary differences between the sexes were identified and the dietary results did not show changes related to an individual's age.

The isotopic signatures of dentin collagen show a greater range of variability than those of bone, which suggests more variety in the childhood diets or multiple areas of origin with different food resources available. The adult bone collagen profile shows a marked decrease in variability. In adulthood 15 of the 20 individuals with a dietary change of 2‰ or more were eating a homogeneous diet reflecting that of a slave in the West Indies. The adult bone isotopic signature agrees with the historical accounts of slave provisions and diet.

As mentioned in the previous chapter the best evidence for a dietary shift that reflects individuals being transported from Africa to the West Indies, most likely as slaves, comes from the four individuals with dental modification. These individuals showed dietary changes from childhood to adulthood with no overlap in isotopic values. Also these individuals reflected childhood diets with low $\delta^{13}C$ and $\delta^{15}N$ values that correspond with the foodstuffs available in West Africa at the time when Colonial influences were strong. The isotopic values for the adult diet for these four individuals had $\delta^{13}C$ values indicative of a diet based on C_4 plants and $\delta^{15}N$ values suggesting a reliance on marine protein like fish.

This study involved 43 unknown individuals from the island of Guadeloupe. Although these individuals are still unknown, aspects of their past have now been

reconstructed and a better understanding of their lives has been produced through the isotopic data.

10.2 Further Research Considerations

This study has provided the basis for isotopic study of diet over life stages, using dentin as a proxy for childhood in the West Indies. Further research areas could include analyzing the enamel apatite values from these individuals for more in-depth comparisons and further elucidate details of childhood diet in this enslaved population. Enamel is often more resistant to diagenetic processes therefore, having the apatite values would be another indicator of sample integrity. Apatite also reflects the whole diet so it could indicate different changes that are not apparent when compared to dentin signatures. Also if infant skeletal remains were available bone collagen could be used as a way to check the isotopic results from the teeth. The use of oxygen or strontium isotopes in future studies could also aid in tracing geographic movement or area of origin for individuals.

This study has shown that the dentin isotope values do show a significant difference between the bone collagen results. Having access to a larger population would make age and sex analysis a possibility. The sample size in this study was too small to determine the effects of age and sex on diet because data were missing for 17 individuals. Acquiring the missing data for these samples would allow for a better comparison however, a larger sample population would be able to answer these questions more accurately.

Another possible avenue to explore would be to compare different African populations from approximately the same time period and create dietary profiles that

could then be compared to the data in this study. The bone or tooth collagen results from an African population could be compared to the dentin results from the individuals from the l'Anse Sainte Marguerite cemetery to determine if the childhood profiles from the West Indies individuals were similar to the individuals from Africa. There are many countries in Africa that were affected by the slave trade; as a result a large sampling of the many populations in Africa would create a geographic isotopic map useful for comparison to understand how far the slave trade industry extended.

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Appendix A: Sample quality assessment indicators, c/n ratios and collagen yield (%) for bone and dentin samples.

Bone Identifier	Dentin Identifier	Site Identifier	Yield (%) (Bone)	c/n (Bone)	Yield(%) (Dentin)	c/n (Dentin)
TSM 02	HSM 01	S7	11.5	3.20	1.78	3.37
TSM 14	HSM 02	S36	10.7	3.23	22.44	5.37
TSM 18	HSM 03	S45	7.4	3.33	0.31	3.54
TSM 24	HSM 04	S60	15.8	3.24	8.52	3.76
TSM 30	HSM 05	S70	9.4	3.21	-0.52	3.57
TSM 34	HSM 06	S88	14.5	3.24	-0.71	3.43
TSM 36	HSM 07	S91	6.2	3.24	-2.32	3.47
TSM 37	HSM 08	S95	12.1	3.25	0.46	3.82
TSM 38	HSM 09	S97	9.3	3.29	1.31	3.45
TSM 42	HSM 10	S106	10.8	3.23	-2.12	3.5
TSM 49	HSM 11	S128	9.7	3.20	-1.1	3.47
TSM 54	HSM 14	S140	14.7	3.24	0.33	3.67
TSM 59	HSM 15	S152	14.8	3.27	-0.54	3.34
TSM 05	HSM 16	S12	6.2	3.29	0.51	3.28
TSM 10	HSM 17	S27	15	3.17	0.8	3.35
TSM 15	HSM 18	S40	5.1	3.24	-0.61	3.34
TSM 17	HSM 19	S43	11.8	3.19	-2.15	3.42
TSM 19	HSM 20	S46	8.6	3.21	0.28	3.53
TSM 20	HSM 21	S49	19.4	3.22	2.72	3.37
TSM 22	HSM 23	S56	15.2	3.16	0.91	3.54
TSM 23	HSM 24	S47	3.4	3.43	-0.2	3.38
TSM 27	HSM 25	S67	5.8	3.25	1.22	3.38
TSM 32	HSM 26	S85	10.1	3.26	0.18	3.25
TSM 35	HSM 27	S90	10.2	3.18	0.93	3.55
TSM 44	HSM 28	S155	8.6	3.15	3.45	3.29
TSM 48	HSM 29	S128	12.3	3.17	2.76	3.27
TSM 56	HSM 30	S146	8.6	3.35	1.9	3.28
THSM 21	THSM 01	S257	7.12	3.54	3.66	2.61
THSM 22	THSM 02	S213	4.43	3.33	1.79	5.4
THSM 23	THSM 03	S231	5.16	3.35	0.71	3.36
THSM 24	THSM 04	S179	7.23	3.33	2.45	4.83
THSM 25	THSM 05	S256	7.41	3.32	1.17	5.1
THSM 26	THSM 06	S250	5.60	3.36	0.29	6.37
THSM 27	THSM 07	S221	8.75	3.24	3.95	6.43
THSM 28	THSM 08	S252	11.89	3.28	2.46	8.21
THSM 29	THSM 09	S241	9.38	3.36	0	3.39
THSM 30	THSM 10	S253	11.49	3.21	0	4.05
THSM 31	THSM 11	S223	11.26	3.32	0.46	5.33
THSM 33	THSM 13	S240	3.90	3.47	1.46	5.48
THSM 34	THSM 14	S262	7.72	4.08	0.09	5.64
THSM 35	THSM 15	S224	12.99	3.25	-0.26	4.96
THSM 36	THSM 16	S237	8.33	3.33	-0.1	3.59
THSM 37	THSM 17	S225	10.80	3.62	1.42	6.34

Appendix B: Stable isotope and sample integrity data for the Bone Collagen data.

Bone Identifier	Site Identifier	Model	yield (%)	c/n	%C	%N	δ13C (Bone)	$\delta^{15}N$ (Bone)
TSM 02	S7	good	11.5	3.20	43.3	15.8	-13.8	16.3
TSM 14	S36	good	10.7	3.23	44.6	16.1	-14	17.6
TSM 18	S45	good	7.4	3.33	47.4	16.6	-14.4	16.2
TSM 24	S60	good	15.8	3.24	48	17.3	-13.2	16.5
TSM 30	S70	good	9.4	3.21	49.2	17.9	-15.4	14.5
TSM 34	S88	good	14.5	3.24	55	19.8	-14.3	15.1
TSM 36	S91	good	6.2	3.24	48.1	17.3	-13.9	17.6
TSM 37	S95	good	12.1	3.25	48.7	17.5	-15.6	15.3
TSM 38	S97	good	9.3	3.29	48.2	17.1	-14.1	16.8
TSM 42	S106	good	10.8	3.23	46.8	16.9	-16.2	12.8
TSM 49	S128	good	9.7	3.20	46.1	16.8	-15.3	15.2
TSM 54	S140	good	14.7	3.24	45.8	16.5	-14.9	16.3
TSM 59	S152	good	14.8	3.27	48.2	17.2	-14.7	15.8
TSM 05	S12	good	6.2	3.29	45.2	16	-13.5	16.7
TSM 10	S27	good	15	3.17	47.6	17.5	-13.9	16.2
TSM 15	S40	good	5.1	3.24	46.9	16.9	-18.8	12.4
TSM 17	S43	good	11.8	3.19	45.9	16.8	-12.9	16.1
TSM 19	S46	good	8.6	3.21	47.4	17.2	-17	12.8
TSM 20	S49	good	19.4	3.22	46.4	16.8	-18.2	11.1
TSM 22	S56	good	15.2	3.16	48.3	17.8	-13.4	16.6
TSM 23	S47	good	3.4	3.43	45.3	15.4	-13.3	15.5
TSM 27	S67	good	5.8	3.25	45.7	16.4	-14.4	15.8
TSM 32	S85	good	10.1	3.26	46.1	16.5	-15.6	14.2
TSM 35	S90	good	10.2	3.18	47.5	17.4	-15.2	15.1
TSM 44	S155	good	8.6	3.15	45.6	16.9	-13.2	16.4
TSM 48	S128	good	12.3	3.17	47.3	17.4	-15	13.7
TSM 56	S146	good	8.6	3.35	46.3	16.1	-13.3	15.7
THSM 21	S257	good	7.12	3.54	24.8	8.2	-14.2	15.9
THSM 22	S213	good	4.43	3.33	41.1	14.4	-13.4	17.1
THSM 23	S231	good	5.16	3.35	41.9	14.6	-14.3	16.9
THSM 24	S179	good	7.23	3.33	41.5	14.5	-13.8	16.8
THSM 25	S256	good	7.41	3.32	41.7	14.6	-15.7	11.2
THSM 26	S250	good	5.60	3.36	41.7	14.5	-13.7	14.3
THSM 27	S221	good	8.75	3.24	41.4	14.9	-16.8	10.1
THSM 28	S252	good	11.89	3.28	41.2	14.7	-16.4	13.0
THSM 29	S241	good	9.38	3.36	41.5	14.4	-13.8	16.7
THSM 30	S253	good	11.49	3.21	41.9	15.2	-14.8	15.2
THSM 31	S223	good	11.26	3.32	33.4	11.7	-14.9	15.8
THSM 33	S240	good	3.90	3.47	42.7	14.3	-18.9	10.4
THSM 34	S262	good	7.72	4.08	16.1	4.6	-15.7	12.8
THSM 35	S224	good	12.99	3.25	41.9	15.0	-13.6	13.4
THSM 36	S237	good	8.33	3.33	42.5	14.9	-20.5	9.3
THSM 37	S225	good	10.80	3.62	11.6	3.7	-16.9	10.8

Appendix C: Stable isotope and sample integrity for Dentin collagen.

Dentin Identifier	Site Identifier	Model	Yield (%)	c/n	%C	%N	$\delta^{13}C$ (Dentin)
HSM 01	S7	good	1.78	3.37	44.37	15.34	-14.46
HSM 02	S36	good	22.44	5.37	46.17	10.02	-19.11
HSM 03	S45	good	0.31	3.54	40.89	13.48	-14.79
HSM 04	S60	good	8.52	3.76	38.94	12.07	-17.58
HSM 05	S70	good	-0.52	3.57	43.8	14.3	-16.63
HSM 06	S88	good	-0.71	3.43	46.7	15.9	-15.90
HSM 07	S91	good	-2.32	3.47	48.8	16.4	-20.12
HSM 08	S95	good	0.46	3.82	45.6	13.9	-17.20
HSM 09	S97	good	1.31	3.45	47.9	16.2	-14.24
HSM 10	S106	good	-2.12	3.50	46.8	15.6	-20.44
HSM 11	S128	good	-1.1	3.47	45.4	15.3	-17.82
HSM 14	S140	good	0.33	3.67	45.4	14.4	-20.13
HSM 15	S152	good	-0.54	3.34	45.1	15.7	-20.14
HSM 16	S12	good	0.51	3.28	48.6	17.3	-14.81
HSM 17	S27	good	0.8	3.35	47.4	16.5	-20.43
HSM 18	S40	good	-0.61	3.34	47.8	16.7	-19.44
HSM 19	S43	good	-2.15	3.42	46.6	15.9	-15.37
HSM 20	S46	good	0.28	3.53	47.5	15.7	-20.08
HSM 21	S49	good	2.72	3.37	44.74	15.48	-17.78
HSM 23	S56	good	0.91	3.54	48.4	15.9	-16.63
HSM 24	S47	good	-0.2	3.38	47.1	16.3	-15.23
HSM 25	S67	good	1.22	3.38	47.9	16.5	-19.76
HSM 26	S85	good	0.18	3.25	47.9	17.2	-19.49
HSM 27	S90	good	0.93	3.55	47.6	15.7	-17.17
HSM 28	S155	good	3.45	3.29	44.55	15.78	-13.91
HSM 29	S128	good	2.76	3.27	44.82	15.96	-16.39
HSM 30	S146	good	1.9	3.28	44.66	15.87	-16.18
TSM 01	S257	good	3.66	2.61	35.04	15.650	-14.579
TSM02	S213	good	1.79	5.40	41.73	9.009	-15.930
TSM03	S231	good	0.71	3.36	48.2	16.706	-15.782
TSM04	S179	good	2.45	4.83	43.34	10.466	-19.535
TSM05	S256	good	1.17	5.10	45.14	10.331	-12.278
TSM 06	S250	good	0.29	6.37	47.2	8.648	-19.001
TSM 07	S221	good	3.95	6.43	44.92	8.142	-16.032
TSM 08	S252	good	2.46	8.21	45.48	6.461	-18.278
TSM 09	S241	good	0	3.39	46.9	16.124	-14.246
TSM 10	S253	good	0	4.05	47.4	13.672	-17.593
TSM 11	S223	good	0.46	5.33	46.3	10.142	-20.580
TSM 13	S240	good	1.46	5.48	44.15	9.395	-15.572
TSM 14	S262	good	0.09	5.64	47.3	9.784	-20.751
TSM 15	S224	good	-0.26	4.96	45.1	10.598	-18.276
TSM 16	S237	good	-0.1	3.59	43.8	14.236	-16.475

Appendix D: Bone samples (TSM) and Dentin samples (HSM) sorted by sex, skeletal element and age (** = individuals with dental modification).

Bone Identifier	Dentin Identifier	Site Identifier	Sex	Element	Age
TSM 02	HSM 01	S7	Female	rib/ max. canine	20-29
TSM 14	HSM 02	S36	Female	rib/ max. PM1	20-24
TSM 18	HSM 03	S45	Female	rib/ max. PM1	25-29
TSM 24	HSM 04	S60	Female	rib/ max. M2	20-24
TSM 30	HSM 05	S70	Female	Rib/ Mand. PM2	25-29
TSM 34	HSM 06	S88	Female	rib/max. PM1	30+
TSM 36	HSM 07	S91	Female	rib/ max. PM1	15-19
TSM 37	HSM 08	S95	Female	rib/ max. M3	30+
TSM 38	HSM 09	S97	Female	rib/ mand. M3	25-29
TSM 42	HSM 10	S106	Female	rib/ max. PM1	20+
TSM 49	HSM 11	S128	Female	rib/ mand M1	30+
TSM 54	HSM 14	S140	Female	rib/ mand M1	20-24
TSM 59	HSM 15	S152	Female	rib/max. PM2	25-29
TSM 05	HSM 16	S12	male	rib/ max. PM1	adult
TSM 10	HSM 17	S27	male	Rib/ Mand. PM2	20-29
TSM 15	HSM 18	S40	male	rib/mand. PM1	25-29
TSM 17	HSM 19	S43	male	Rib/ Mand. PM2	30+
TSM 19	HSM 20	S46	male	rib/ max. PM1	adult
TSM 20	HSM 21	S49	male	rib/ max. PM1	25-29
TSM 22	HSM 23	S56	male	rib/max. PM2	20-24
TSM 23	HSM 24	S47	male	rib/max. PM2	30+
TSM 27	HSM 25	S67	male	rib/max. PM2	20-24
TSM 32	HSM 26	S85	male	rib/max. PM1	30+
TSM 35	HSM 27	S90	male	rib/ mand. M3	20-24
TSM 44	HSM 28	S155	male	rib/ mand. M3	30+
TSM 48	HSM 29	S128	male	rib/ mand M1	30+
TSM 56	HSM 30	S146	male	rib/max. PM2	20-24
THSM 21	THSM 01	S257	male	rib/ max M1	adult
THSM 22	THSM 02	S213	male	rib/max. PM2	adult
THSM 23	THSM 03	S231	Female	rib/mand. PM2	adult
THSM 24	THSM 04	S179	male	rib/max. PM1	adult
THSM 25	THSM 05	S256	male	rib/mand. PM2	adult
THSM 26	THSM 06	S250	male	rib/mand M3	adult**
THSM 27	THSM 07	S221	male	rib/max. PM2	adult >30y
THSM 28	THSM 08	S252	Female	rib/mand. PM1	adult
THSM 29	THSM 09	S241	male	rib/max. PM1	adult
THSM 30	THSM 10	S253	male	rib/max. PM1	adult
THSM 31	THSM 11	S223	Female	rib/max. PM2	adult**
THSM 33	THSM 13	S240	Female	rib/mand. PM1	adult
THSM 34	THSM 14	S262	?	rib/max. PM2	adult**
THSM 35	THSM 15	S224	male	rib/max. PM2	adult >50y
THSM 36	THSM 16	S237	Female	Rib/ Mand. PM2	adult
THSM 37	THSM 17	S225	male	Rib/ Mand. PM2	adult**

Appendix E: Isotopic values and dietary spacing from 20 individuals with $\Delta\delta 13C_{dentin\text{-}bone}$ spacing of 2‰ or more. (*= individuals with dental modification)

Number	Bone Identifier	Dentin Identifier	Site Identifier	$\delta^{13}C$ Dentin	$\delta^{15}N$ Dentin	$\delta^{13}C$ Bone	$\delta^{15}N$ Bone	δ13C spacing
*1	THSM 37	THSM 17	S225	-20.98	8.84	-16.87	10.79	4.11
*2	THSM 34	THSM 14	S262	-20.75	9.78	-15.71	12.80	5.04
*3	THSM 31	THSM 11	S223	-20.58	10.14	-14.93	15.80	5.65
4	TSM 19	HSM 20	S46	-20.08	9.59	-17.00	12.80	3.08
5	TSM 42	HSM 10	S106	-20.44	10.70	-16.20	12.80	4.24
6	TSM 10	HSM 17	S27	-20.43	9.49	-13.90	16.20	6.53
7	TSM 59	HSM 15	S152	-20.14	9.98	-14.70	15.80	5.44
8	TSM 54	HSM 14	S140	-20.13	11.51	-14.90	16.30	5.23
9	TSM 36	HSM 07	S91	-20.12	13.02	-13.90	17.60	6.22
10	TSM 27	HSM 25	S67	-19.76	11.92	-14.40	15.80	5.36
11	THSM 24	THSM 04	S179	-19.54	10.47	-13.77	16.76	5.77
12	TSM 32	HSM 26	S85	-19.49	10.14	-15.60	14.20	3.89
*13	THSM 26	THSM 06	S250	-19.00	8.65	-13.71	14.31	5.29
14	THSM 35	THSM 15	S224	-18.28	10.60	-13.56	13.40	4.72
15	TSM 49	HSM 11	S128	-17.82	8.50	-15.30	15.20	2.52
16	TSM 35	HSM 27	S90	-17.17	12.74	-15.20	15.10	1.97
17	THSM 22	THSM 02	S213	-15.93	9.01	-13.42	17.10	2.50
18	TSM 22	HSM 23	S56	-16.63	14.49	-13.40	16.60	3.23
19	THSM 36	THSM 16	S237	-16.48	14.24	-20.53	9.33	-4.05
20	TSM 56	HSM 30	S146	-16.18	13.34	-13.30	15.70	2.88