Palaeodietary Reconstruction in Late Antique Spain and Assessing Means of Inter-Site Comparison



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This thesis is dedicated to my parents
for not laughing (much) when
a 3 year old said she
was getting a doctorate.

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Abstract

Dentine and bone samples from thirty-six individuals from Sanisera and thirty-five individuals from Mérida, as well as dentine and bone samples from twenty-five faunal samples from Sanisera and two from Mérida (all dating from the between the 3^{rd} - 9^{th} centuries AD) were analyzed for stable carbon and nitrogen isotopes. The remains from Sanisera originated from the Late Antique Period (5^{th} - 7^{th} centuries AD) and were taken from tombs containing multiple disarticulated inhumations. The remains from Mérida dated from the Late Roman to Islamic Periods (3^{rd} - 9^{th} centuries AD), were mostly single inhumations with multiple burial styles. The isotopic analysis showed primarily a terrestrially-based C_3 diet, which in the case of individuals from Sanisera was occasionally supplemented by marine sources. These isotopic data were compared to human and faunal results from twenty-seven published studies of fifty-three contemporary sites in Europe and North Africa to see how these two Spanish sites fit within the larger Late Antique world using a more analytical comparison. Integration of this multi-site dataset was discussed in terms of the raw data. Direct comparison of isotopic data from different sites suffers from the effects of a number factors extraneous to diet such as climate, time period, and local geography. Previous attempts to minimize these effects have proven insightful, but lack interpretive power in terms of overall dietary reconstruction. Based on the multi-site dataset, an alternative, Faunal Correction, model was proposed. This model adjusts both nitrogen and carbon isotopic values using a faunal standard developed from faunal isotopic data. Not only did this new model have the advantage of relying solely on isotopic data, it successfully reduced overall variability of both carbon and nitrogen isotope data between the sites and, because of its structure, it can easily accommodate additional factors whose impact on isotope values may be better understood in the future.

Table of Contents

Contents *i*

List of Tables *vii*

List of Figures *xiv*

1 Introduction 1

1.1 Overview 1

1.2 Reconstructing Diet with Isotopes 3

1.3 Areas of Study, Format and Objectives 5

2 Late Antique Spain: A Literature Review 11

2.1 Historical Background 12

2.1.1 Introduction 12

2.1.1.1 Climate Changes 12

2.1.1.2 Discussion of Political and Economic Changes 13

2.1.2 Roman Spain: 3rd to 5th Centuries AD 13

2.1.2.1 Government 13

2.1.2.2 Economy 14

2.1.3 Gothic Spain: 409 to 711 AD 15

2.1.3.1 Government 15

2.1.3.2 Economy 17

2.1.3.3 Plagues 17

2.1.4 Rise of Muslim Spain: 711 to 10th Century AD 19

2.1.4.1 Government 19

2.1.4.2 Economy 19

2.2 Food Sources 20

2.2.1 Agricultural Based Food Sources 21

2.2.2 Animal Husbandry 25

2.2.3 Fishing 28

2.3 Variations in Diet 32

2.3.1 Chronology 32

2.3.2 Impact of Social Status 33

2.4 Conclusion 36

3 Isotope Analysis 38
3.1 Basics and Principles 38
3.2 Carbon 40
3.2.1 Basics 40
3.2.2 Trophic Level 42
3.2.3 Variations in Carbon Isotope Values 43
3.2.3.1 Variation in C_3 Plants 43
3.2.3.2 Temporal 47
3.3 Nitrogen 47
3.3.1 Basics 47
3.3.2 Trophic Level 48
3.3.3 Variations in Nitrogen Isotope Values 49
3.4 Paleodietary Reconstruction 50
3.4.1 Bone Collagen 51
3.4.2 Stable Carbon and Nitrogen Analysis 53
3.4.2.1 Human/Faunal Comparisons 55
4 Site Backgrounds 60
4.1 Sanisera 60
4.1.1 The City 60
4.1.2 The Necropolis 63
4.2 Mérida 67
4.2.1 The City 67
4.2.2 The Necropoles 68
4.2.2.1 Site No. 1021 - Nova Romana 70
4.2.2.2 Site No. 7017 - Nova Romana III 72
4.2.2.3 Site No. 8060 - Velada 77
4.3 Comparisons 79
4.3.1 Cities 79
4.3.2 Burials 79
5 Materials and Methods 82
5.1 Osteological Analysis 82

5.1.1 Osteological Materials 82
5.1.1.1 Sanisera 84
5.1.1.2 Mérida 88
5.1.2 Osteological Methods 91
5.1.2.1 Faunal 91
5.1.2.2 Human 91
5.2 Stable Carbon and Nitrogen Isotope Analysis 95
5.3 Radiocarbon Dating 98
5.4 Meta-Analysis of Related Isotopic Data 99
5.4.1 Materials 99
5.4.2 Meta-Analysis Statistical Methods 108
5.5 Faunal Correction Model 110
6 Osteological, Isotopic and Meta-Analysis Results 113
6.1 Osteological Results 113
6.1.1 Sanisera 113
6.1.1.1 Faunal Age at Death 113
6.1.1.2 Human Age at Death 114
6.1.2 Mérida 115
6.1.2.1 Faunal Age at Death 115
6.1.2.2 Human Age at Death 116
6.2 Radiocarbon Dating Results 118
6.3 Isotopic Results 122
6.3.1 Sanisera 122
6.3.1.1 Faunal 122
6.3.1.2 Human 126
6.3.1.2.1 Bone 129
6.3.1.2.2 Dentine 133
6.3.1.2.3 Dentine/Bone Comparison 136
6.3.2 Mérida 138
6.3.2.1 Human/Faunal Results 138
6.3.2.2 Human/Faunal Comparison 142

6.3.2.3 Analysis of Human Samples 144
6.3.2.3.1 By Sex 146
6.3.2.3.2 By Age at Death 147
6.3.2.3.3 By Necropolis 150
6.3.2.3.4 By Time Period 152
6.4 Meta-Analysis 154
6.4.1 Faunal Analysis 154
6.4.1.1 Time Period 162
6.4.1.2 Coastal vs Inland 166
6.4.1.3 By Climate Classification 169
6.4.2 Human Analysis 174
6.4.2.1 Time Period 181
6.4.2.2 Location 183
6.4.2.2.1 Coastal versus Inland 186
6.4.2.3 Climate Variation 190
6.4.2.3.1 Temperature and Precipitation 190
6.4.2.3.2 Climate Classification 196
7 Osteological, Isotopic and Faunal Correction Model Discussion 198
7.1 Sanisera 198
7.1.1 Dentine 198
7.1.2 Dentine to Bone 199
7.1.3 Outliers 205
7.1.3.1 Dentine 205
7.1.3.2 Bone 206
7.1.3.3 Dentine to Bone 209
7.2 Mérida 211
7.2.1 Dentine 211
7.2.2 Multiple Materials 214
7.2.3 Human Outliers 216
7.2.3.1 Low $\delta^{13}C$ values 216
7.2.3.2 Interpretation of Isotope Values 218

7.2.3.3 Low δ^{15}N Values 220
7.2.4 Faunal Outlier 221
7.3 Contemporary Comparisons 221
7.3.1 Background 221
7.3.2 Comparison Site Introduction 222
7.3.2.1 Balearic Islands 223
7.3.2.2 Mainland Spain 223
7.3.2.3 Other Sites 223
7.3.3 Contemporary Comparison Analysis 224
7.3.3.1 Faunal 224
7.3.3.2 Human 228
7.4 Meta-Analysis Discussion 232
7.4.1 Direct Comparisons 234
7.4.1.1 Faunal Comparisons 234
7.4.1.1.1 Time Period 234
7.4.1.1.2 Geography 236
7.4.1.1.2.1 Coastal versus Inland 236
7.4.1.1.3 Climate 238
7.4.1.2 Human Comparisons 239
7.4.1.2.1 Time Period 241
7.4.1.2.2 Geography 241
7.4.1.2.2.1 Longitude, Latitude and Altitude 241
7.4.1.2.2.2 Coastal versus Inland 243
7.4.1.2.3 Climate 244
7.4.1.2.3.1 Individual Variables 244
7.4.1.2.3.2 Climate Classification 246
7.4.3 Importance of Climate 249
7.4.3.1 Correcting for Climate: Van Klinken *et al.* 250
7.4.3.2 Discussion of the Van Klinken Model 254
7.4.4 Human/Faunal Comparison 255
7.4.4.1 Sanisera Comparison 256

7.4.4.2 Mérida Comparison 258
7.4.4.3 Meta-Data Comparison 259
7.4.4.3.1 Data Set and Source 259
7.4.4.3.2 Human-Faunal Differences 261
7.4.5 Faunal Correction Model 262
7.4.5.1 Model Application 262
7.4.5.1.1 Results by Climate Classification 264
7.4.5.1.2 Results by Coastal versus Inland 265
7.4.5.1.3 Results by Time Period 266
7.4.5.1.4 Results by Location 269
8 Conclusion 271
8.1 Sanisera and Mérida 272
8.2 Meta-Analysis 273
8.3 Future Research 277
Bibliography 279
Appendices 313
A. Materials Catalogue 313
A.1 Sanisera Human 313
A.2 Mérida Human 331
A.3 Sanisera Faunal 353
A.4 Mérida Faunal 365
B. Dental Wear 366
B.1 Sanisera 366
B.2 Mérida 369
C. Results 371
C.1 Sanisera 371
C.2 Mérida 374

List of Figures

2.1	Map of Spain in the Late Roman Empire (taken from O'Callaghan 2013; 29, Map 1).	14
2.2	Map of olive distribution across the Mediterranean Region (taken from Renfrew 1973; 132, Figure 82).	25
3.1	Theoretical plot with the range of $\delta^{13}C$ values from different plant sources as well as the mean used in mixing models (data taken from Fry & Sherr 1989, Table 12.1).	41
3.2	Theoretical $\delta^{13}C$ and $\delta^{15}N$ plot with terrestrial C_3 and marine ecosystems outlined. Points and error bars, indicated typical range for different animals, while ellipses indicated mean $\delta^{13}C$ and $\delta^{15}N$ of collagen from diets based in both ecosystems and that of individuals with mixed sources of food (adapted from Müldner & Richards 2006, 229 Figure 16.1).	55
4.1	Map of Spain indicating the location of Menorca and the site of Sanisera.	61
4.2	Location of Sanisera and Necropolis on the Cap de Cavellaria.	65
4.3	Tomb 13 of Sanisera Necropolis 6 (photo taken by author).	66
4.4	Map of Necropolis 6 (adapted from Hurst & Contreras 2009, Figure 3).	66
4.5	Map of the Iberian Peninsula with the city of Mérida indicated, (adapted from d-maps.com, map of Spain).	68
4.6	Map of Mérida with the three published sites of Nova Romana (1021), Nova Romana III (7017) and Velada (8060) indicated (adapted from Alba Calzado 2005, Delgado 2003 and Barrientos Vera 2004).	70
4.7	Plot of the Roman tombs of Nova Romana (1021) (adapted from Barrientos Vera 2004; 378).	71
4.8	Aerial view and profile of the two types of tombs found at Nova Romana (illustration by author).	72
4.9	Plan of Nova Romana III (7017) (adapted from Alba Calzado 2005; 313).	74
4.10	Roman lanterns with the depictions of the deities Isis, Ceres Hercules and Prosperina (taken from Alba Calzado 2002, Figure 20).	75
4.11	The differences in depth between the Islamic and Roman burials as illustrated by the Roman grave in the foreground and the Islamic grave in the background (taken from Alba Calzado 2005, Figure 21).	76
4.12	Tombs 58 (left) and 6 (right). Illustrating the variation in burial style between Roman (left) and Islamic (right) tombs, as well as the the physical differences between the populations (taken from Alba Calzado 2005, Figure 22).	77
4.13	Plan of site 8060/8065 (Velada) (adapted from Delgado 2003, Figure 2).	78

4.14	Aerial view and profile of the three types of tombs found at Velada (adapted from Delgado 2003, Figure 6).	79
5.1	Brothwell's numerical classification of age based on molar wear (taken from Brothwell 1989 Figure 3.9).	92
5.2	Application of Brothwell's numerical classification of age based on molar wear, using samples from Sanisera (photographs by author).	92
5.3	Scoring system for the mental eminence (adapted from Buikstra and Ubelaker 1987 Figure 4).	93
5.4	Anterior view of the mandible of Individual 248 from the funerary site of Velada in Mérida. This individual was given a score of 4 using the method outlined in Buikstra & Ubelaker 1987, indicating that they were likely male (photograph taken by author).	94
5.5	Depicts the division between the crown and roots of a second molar by the cement-enamel junction (CEJ) as well as where the cut for sampling two sections of the root occurred (at the furication of the root) which divided the root into two sections, now defined as the cervical and apical sections of the root (photograph and annotation by author).	97
5.6	Map of the archaeological sites and the weather stations used in the Meta-analysis (map created by author using R).	105
5.7	Map of the archaeological sites (in red) plotted on the Köppen-Geiger Climate Classification map of Europe (map taken from Peel *et al.* 2007 Figure 8, site of Leptiminus in North Africa excluded).	108
6.1	The number of individuals, from Sanisera, in each age at death category as defined by the methods outlined in Brothwell 1989.	114
6.2	The number of individuals, from each Mérida site, in each age at death category as defined by the methods outlined in Brothwell 1989.	117
6.3	The radiocarbon determination in years BP and the calibrated date for sample 86 from Sanisera, Necropolis 6.	119
6.4	The radiocarbon determination in years BP and the calibrated date for sample 106 from Sanisera, Necropolis 6.	119
6.5	The radiocarbon determination in years BP and the calibrated date for sample NR3-25 from Mérida.	120
6.6	The radiocarbon determination in years BP and the calibrated date for sample V-nn from Mérida.	120
6.7	The $\delta^{13}C$ and $\delta^{15}N$ results on the faunal bone samples and the cow dentine samples from Sanisera. The connected samples are from the same cow.	122
6.8	The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Sanisera's Necropolis 6.	128
6.9	The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Sanisera's Necropolis 6 with the outliers (defined as values >2σ from the population mean) identified with red triangles.	130
6.10	The results of the $\delta^{13}C$ and $\delta^{15}N$ analysis on the human bone samples from Sanisera's Necropolis 6 plotted by Zone.	131

6.11 The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Sanisera's Necropolis 6, plotted by age at death as determined by dental attrition (Brothwell 1989). 132

6.12 The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Sanisera's Necropolis 6 with the outliers (defined as values >2σ from the population mean) identified with red triangles. 134

6.13 The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Sanisera's Necropolis 6, plotted by age at death as determined by dental attrition (Brothwell 1989). 135

6.14 The $\delta^{13}C$ and $\delta^{5}N$ isotopic values of both bone and dentine from Necropolis 6 at Sanisera (excluding outliers). 137

6.15 The $\delta^{13}C$ and $\delta^{15}N$ of human and faunal bone and dentine samples from Mérida. 143

6.16 The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Mérida with the outliers (defined as values >2σ from the population mean) identified with red squares. All outliers are dentine. 144

6.17 The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples of individuals with known sex, from Mérida, plotted by sex. 146

6.18 The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Mérida, plotted by age at death as determined by dental attrition (Brothwell 1989). 148

6.19 The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by tooth. 149

6.20 The $\delta^{13}C$ and $\delta^{15}N$ results of the human bone and dentine samples from Mérida plotted by necropolis, and faceted by material tested. 151

6.21 The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Mérida plotted by time period and faceted by material tested. 152

6.22 The $\delta^{13}C$ and $\delta^{15}N$ of the fauna from the Meta-Data set grouped by faunal category. 155

6.23 Distribution plots of the $\delta^{13}C$ and $\delta^{15}N$ of each faunal category. 157

6.24 The mean $\delta^{13}C$ and $\delta^{15}N$ ±σ of each faunal type from the Meta-Data set (the colored ellipses), overlain with a theoretical plot of isotope values based on Müldner & Richards 2006, 229. 158

6.25 The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard error, of the most common terrestrial species in the Meta-Data set. 160

6.26 The $\delta^{13}C$ and $\delta^{15}N$ of the most common terrestrial species in the Meta-Data set, faceted by time period and species. 163

6.27 The mean $\delta^{13}C$ and $\delta^{15}N$ ± one standard error, of the most common terrestrial species in the Meta-Data set, faceted by time period. 165

6.28 A&B Tukey Boxplot (Tukey 1977) of the $\delta^{13}C$ (A) and $\delta^{15}N$ (B) for each species grouped by time period. 166

6.29 The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by species (coastal means less than 10km from the coast and inland means more than 10km). 167

6.30	The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by species and time period (coastal means less than 10km from the coast and inland means more than 10km).	170
6.31	The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard error of each Köppen-Geiger Climate Classification for each species.	172
6.32 A&B	Tukey Boxplot (Tukey 1977) of $\delta^{13}C$ (A) and $\delta^{15}N$ (B) for each species grouped by Köppen-Geiger Climate Classification.	173
6.33	The $\delta^{13}C$ and $\delta^{15}N$ of every adult human (n=1381) in the Meta-analysis. Points jittered and at 1/2 transparency to make them more visible.	175
6.34	Tukey box-plot (Tukey 1977) showing the distribution of $\delta^{13}C$ by location on the left vertical axis. The box represents the interquartile range, while the lines represents 1.5 times that. The division in the box is the population median, and the dots are the outliers. Locations are colored according to their country (listed in the key on the right) and ordered North to South.	178
6.35	Tukey box-plot (Tukey 1977) showing the distribution of $\delta^{15}N$ by location along the left vertical axis. The box represents the interquartile range, while the lines represents 1.5 times that. The division in the box is the population median, and the dots are the outliers. Locations are colored according to their country (listed in the key on the right) and ordered North to South.	179
6.36	The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard errors, for each location in the Meta-analysis. The points are colored by country as can be seen in the legend. The site of Friuli V.G. is indicated by the red arrow.	180
6.37	The $\delta^{13}C$ and $\delta^{15}N$ of individuals from the Meta-Data set divided by time period.	182
6.38	The $\delta^{13}C$ values found at each latitude, with linear regression line in red and 95% confidence variable in grey. The points are at 3/4 opacity, so darker points indicate more samples.	185
6.39	The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast. Within 5 kilometers of the coast (Coastal) versus farther inland (Inland).	186
6.40	The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast, faceted by Time Period. Within 5 kilometers of the coast (Coastal) versus farther inland (Inland).	188
6.41	Tukey box-plot (Tukey 1977) showing the distributions of $\delta^{13}C$ and $\delta^{15}N$ values by Köppen-Geiger Climate Classification.	195
7.1	The $\Delta^{13}C$ (dentine $\delta^{13}C$ subtracted from the bone $\delta^{13}C$) of each individual from Sanisera Necropolis 6. The dashed red line and shaded area indicates the mean $\Delta^{13}C \pm 2\sigma$ (calculated excluding outliers). Bars colored red indicate individuals whose values fall outside this range. Individuals previously determined to be outliers are indicated with an *.	202

7.2 The $\Delta^{15}N$ (dentine $\delta^{15}N$ subtracted from the bone $\delta^{15}N$) of each individual from Sanisera Necropolis 6. The dashed red line and shaded area indicates the mean $\Delta^{15}N \pm 2\sigma$ (calculated excluding outliers). Red bars indicate individuals whose value falls outside this range. Individuals previously determined to be outliers are indicated with an *. 202

7.3 The mean $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by age at death. 212

7.4 The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by age at death and divided by the molar the sample was taken from. Samples from the same individual are labeled. 212

7.5 The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by longevity (defined by the mean difference between the age of formation of the tooth tested and age at death of the bone sample). 214

7.6 The $\delta^{13}C$ and $\delta^{5}N$ of the bone and dentine samples for each individual. The color and shape denotes the material sampled. Dentine sampled from whole molars are labeled simply as that molar, while bisected samples are labeled by the part of the root they were taken from. The * indicates a missing sample. 215

7.7 The $\delta^{13}C$ and $\delta^{5}N$ of the different materials from individual nn from the Velada necropolis in Mérida. Dentine sampled from whole molars are labeled simply as that molar, while bisected samples are labeled by the part of the root they were taken from. 216

7.8 The mean human $\delta^{13}C$ and $\delta^{15}N \pm$ one standard error for each location as well as the $\delta^{13}C$ and $\delta^{15}N$ for the faunal values from each. Location is identifiable by color and species by shape. 225

7.9 The mean $\delta^{13}C$ and $\delta^{15}N \pm$ one standard error, of each location. The shape of the points is determined by the general area of each location: the Balearic Islands (circle), Mainland Spain (square), Italy (triangle), North Africa (inverted triangle). 229

7.10 The mean $\delta^{13}C$ and $\delta^{15}N \pm$ one standard error, for each location in the Meta-Data set. The points are colored by country as can be seen in the legend. 233

7.11 The $\delta^{13}C$ and $\delta^{15}N$ of the cattle, pigs, and sheep/goats in the Meta-Data set, faceted by time period and species. 235

7.12 The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by whether they are from coastal or inland locations (coastal means less than 10km from the coast and inland means more than 10km) and colored by the Köppen-Geiger Climate Classification. 237

7.13 The $\delta^{13}C$ and $\delta^{15}N$ of the cattle, pigs and sheep/goats in the Meta-Data set, faceted by base climate classifications and species. 239

7.14 The $\delta^{13}C$ and $\delta^{15}N$ of the individuals from the Meta-Data set divided by time period, with the individuals from Leptiminus plotted in black. 240

7.15 The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast. Within 5 kilometers of the coast (Coastal) versus farther inland (Inland). Individuals from the site of Leptiminus are plotted in red 242

7.16 The $\delta^{13}C$ and $\delta^{15}N$ divided by the the first two variables of the Köppen-Geiger Climate Classification. It should be noted that the individuals who make up the cold group are sourced from on e site, and those in the arid group are from two. See Table 5.8 for further details. 248

7.17 The original and climate corrected mean $\delta^{13}C$ and $\delta^{15}N$ values (± two standard errors) for each location in the Meta-analysis. The points are colored by country. 251

7.18 The difference between the original and climate corrected mean $\delta^{13}C$ for each location in the Meta-analysis. The points are colored by country 253

7.19 A&B The difference between the mean $\delta^{13}C$ of a given species and a population, $\Delta^{13}C$ (human-faunal) (A) and the mean $\delta^{15}N$ of a given species and a population, $\Delta^{15}N$ (human-faunal) (B). The shaded area is the expected shift in values of a single trophic level; 0-2‰ for $\delta^{13}C$ and 3-5‰ for $\delta^{15}N$ (Brocherens & Drucker 2003; Brocherens *et al.* 1994; DeNiro & Epstein 1981; Hare *et al.* 1991; Vogel *et al.* 1990) 256

7.20 The human $\delta^{13}C$ and $\delta^{15}N$ results from Mérida without outliers (defined as >2σ from the population mean) as well as the results from the two cattle tested (in red). 258

7.21 The $\delta^{13}C$ and $\delta^{15}N$ of the samples from the restricted Meta-Data set divided by species. Points are plotted at 75% opacity, to compensate for overlapping samples. 261

7.22 The Original and Faunal Corrected $\delta^{13}C$ and $\delta^{15}N$ values of the human samples from the Meta-Data set. The points are colored by country. 263

7.23 Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ divided by Köppen-Geiger Climate Classification. 264

7.24 Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast. Within 5 kilometers of the coast (Coastal) versus farther inland (Inland). 266

7.25 Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ faceted by Time Period. 267

7.26 The Original and Faunal Corrected $\delta^{13}C$ and $\delta^{15}N$ ± two standard errors, for each location in the Meta-analysis, colored by country. 268

List of Tables

3.1	Mean consumer $\delta^{13}C$ based on diet (Chisholm 1989).	42
5.1	An inventory of the faunal samples taken from the city site of Sanisera. All samples date to the Roman Period (3rd-5th century AD). Definitions: M2-Second Molar, M3-Third Molar.	85
5.2	An inventory of the human samples taken from Necropolis 6 of the site of Sanisera including the tomb and zone where they were located. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left.	86
5.3	Inventory of faunal samples taken from the city of Mérida, including the collection site, species and approximate date. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left.	88
5.4	Inventory of the human samples taken from the city of Mérida, including the collection site, tomb and approximate date. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left. An * indicates that a tooth was bisected as described in section 5.2.	88
5.5	Sites included in the meta-analysis, their location, date, number of human and faunal samples and their study of origin.	101
5.6	The weather stations where the climatic data for the meta-data set were sourced. Included is each stations World Meteorological Organization (WMO) code, the time period from when the data was sampled and the number of samples included.	106
5.7	Description and defining criteria of Köppen-Geiger Climate Classifications that apply to this study. Taken from Peel *et al.* 2007 Table 1.	107
5.8	Köppen-Geiger Climate Classifications for each site in the meta-data set.	109
6.1	Number of analyzed faunal samples per age group by species.	113
6.2	Number of analyzed individuals, from Sanisera, per age at death category (as defined by the methods outlined in Brothwell 1989).	114
6.3	The number of individuals and the percent of the analyzed populations, from each Mérida site, in each age at death category (as defined by the methods outlined in Brothwell 1989).	116
6.4	The calibrated and uncalibrated radiocarbon dates of samples from Mérida and Sanisera. The calibrated dates were calibrated using Oxcal version 4.2.3 (Ramsey 2013), and the IntCal 13 atmospheric curve (Reimer *et al*. 2013).	118
6.5	Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of bone and dentine collagen taken from the fauna found at the city site of Sanisera. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), are italicized.	123

6.6 The means of $\delta^{13}C$ and $\delta^{15}N$ (± σ) of each species from the fauna sampled from Sanisera. The means consist of bone collagen, except for the *Bos taurus* mean, which is derived from one bone sample and three dentine samples. 124

6.7 Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of the human bone and dentine collagen from Necropolis 6 at Sanisera. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), and a C:N ratio outside the standard 2.9-3.6 (DeNiro 1985), are italicized. 126

6.8 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the human bone and dentine samples from Necropolis 6 at Sanisera (excluding outliers). 136

6.9 Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of the human and faunal bone and dentine collagen from Mérida, grouped by site. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), and a C:N ratio outside the standard 2.9-3.6 (DeNiro 1985), are italicized. The samples indicated by * only had one acceptable run and should be regarded with caution. 139

6.10 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the human bone and dentine samples from Mérida (excluding outliers). 145

6.12 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the bone samples from Mérida based on their age at death category (as defined by the methods outlined in Brothwell 1989). 147

6.13 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the individuals from Mérida based on tooth tested. The age at which the dentine sampled was developed for each tooth is based on Moorrees *et al* 1963 and Ubelaker 1979. 149

6.14 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) by necropolis. For the dentine samples, if more than one sample was present for an individual, second molars were selected. 150

6.15 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the individuals from Mérida based on the time period in which they were buried. 153

6.16 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each faunal category, and the p-value for the Shapiro-Wilk test of normality. An * indicates a normal distribution. 154

6.17 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for the faunal categories. Species with the same letter ($\delta^{13}C$) or number ($\delta^{15}N$) are not significantly different at the 5% level based on the Dunn's test (1964) for stochastic dominance. 159

6.18 The p-values for the Dunn's test on the faunal $\delta^{13}C$ and $\delta^{15}N$ values. With p-value for carbon being on top and the p-value for nitrogen being on bottom and in grey. Values indicating statistically different groups are indicated with an * . 161

6.19 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each species by time period. 164

6.20 The p-values for the Dunn's test on the difference between time periods of the faunal $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically different groups are indicated with an * . 164

6.21 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the coastal and inland groups of each species. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *. 168

6.22 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the coastal and inland groups of each species, for each time period. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *. 169

6.23 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each of the three main faunal species (cattle, pigs, and sheep/goats), grouped by Köppen-Geiger Climate Classification. 171

6.24 The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classifications of the faunal $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically different groups are indicated with an * . 174

6.25 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of each location. Also included is the p-value of the Shapiro-Wilk test of normality (p>0.05 indicates that a distribution is normal). 176

6.26 The mean for $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each time period. Also included is the p-value for the Shapiro-Wilk test of normality (p>0.05 indicates that a distribution is normal). 181

6.27 The results of uni-variate regression analysis on $\delta^{13}C$ and $\delta^{15}N$ by the location variables of altitude, latitude and longitude. 183

6.28 The results of regressing $\delta^{13}C$ and $\delta^{15}N$ values, individually on the binary indicator variable for coastal and inland locations. 186

6.29 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each time period in the meta-data set. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *. 189

6.30 The results of linear regressions of local climate variables (temperature - monthly, seasonal and annual mean (± σ) and precipitation- monthly, seasonal and annual total (± σ) on both $\delta^{13}C$ and $\delta^{15}N$ values for each location. 192

6.31 The number and mean (± σ) for $\delta^{13}C$ and $\delta^{15}N$ for each of the Köppen-Geiger Climate Classifications. 196

6.32 The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classifications of the $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically different groups are indicated with an * . 197

7.1 The mean of $\delta^{13}C$ and $\delta^{5}N$ values (± σ) of the dentine from Necropolis 6 at Sanisera, (excluding outliers), sorted by age at death category (as defined by the methods outlined in Brothwell 1989). 199

7.2 The mean $\delta^{13}C$ and $\delta^{5}N$ values (± σ) of the bone and dentine sampled from individuals from Necropolis 6 at Sanisera, excluding outliers. 201

7.3 The $\delta^{13}C$ and $\delta^{15}N$ values of the bone outliers. With the mean $\delta^{13}C$ and $\delta^{15}N$ values (± σ) of the bone and dentine, excluding outliers. 207

7.4 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on their age at death (as defined by the methods outlined in Brothwell 1989). 211

7.5 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on their molar and age at death (as defined by the methods outlined in Brothwell 1989). 213

7.6 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on the age at formation of the tooth tested and age at death. In this table "longevity" is defined by the average difference between the age of formation of the tooth tested and age at death of the bone sample. 213

7.7 The $\delta^{13}C$, $\delta^{15}N$, and material sampled of the isotopic outliers from Mérida (based on being greater than two standard deviations from the mean dentine values). 216

7.8 The $\delta^{13}C$, $\delta^{15}N$, and material sampled of the isotopic outliers from Mérida (based on being greater than two standard deviations from the mean dentine values). *V-99 is just under 2σ (1.84); however, since it is below the bone value (NR-140) and over 0.5‰ less than the next highest $\delta^{15}N$ value, it has been included. 220

7.9 The results of regressing $\delta^{13}C$ and $\delta^{15}N$ values, individually on the binary indicator variable for coastal and inland locations, excluding the site of Leptiminus. 243

7.10 Description and defining criteria of Köppen-Geiger Climate Classifications that apply to this study. Taken from Peel *et al.* 2007 Table 1. 246

7.11 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) from the Meta-Data set, divided by the base two variables of the Köppen-Geiger Climate Classifications. 247

7.12 The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classifications of the $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically different groups are indicated with an * . 249

7.13 The original $\delta^{13}C$ and climate corrected $\delta^{13}C_c$ means, of each location in the Meta-Data set, well as the difference between the two. 252

7.14 The mean faunal $\delta^{13}C$ and $\delta^{15}N$ (± σ) from Sanisera, divided by species. The means consist of bone collagen, except for the *Bos taurus* mean, which is derived from two bone samples and two dentine samples. Also included are the Domestic Faunal Mean and outlier free mean of the human samples from Sanisera. 257

7.15 The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each species. 260

Chapter 1: Introduction

1.1 Overview

The time between the fall of the Roman Empire and the Middle Ages, generally understood to be between the 3rd and 7th centuries AD, is commonly referred to as the Late Antique Period or Late Antiquity. This was a tumultuous time across Europe and the Mediterranean, and one that is far less documented than the periods bracketing it. Recently, there has been increased interest and research in this period. More specifically, there is a paucity of isotopic studies of Late Antique Spain as compared to other Mediterranean and European locations and time periods.

The overarching objective of this thesis is to further the understanding of how common people from Late Antique Spain fit in the wider context of the period following the collapse of the Roman Empire in the Western Mediterranean and Continental Europe, as well as to further refine the methods used to isotopically compare populations. This was done in three steps. First, stable carbon and nitrogen isotope analysis was performed on the bone and tooth collagen of individuals from Late Antique Spain with the aim of reconstructing and interpreting their diet. The second step, was to utilize the data from the first step and include it in a meta-data set and directly compare it to data from previously published studies of contemporary sites in the Western Mediterranean and Continental Europe and see what conclusions could be drawn and what extraneous factors might be hindering their comparison. The final step was to take the conclusions reached from the second step and explore methods by which extraneous factors could be eliminated

or compensated for with the aim of allowing more robust comparisons, and see what further conclusions and hypothesis this method generates.

The first objective was accomplished using stable carbon and nitrogen isotope data obtained by the author from individuals from Necropolis 6 of Sanisera in Menorca, Spain and funerary locations within the city of Mérida in west central Spain. Sanisera and Mérida were selected as they represent two drastically different Late Antique Spanish cities. During Late Antiquity, Sanisera was a small port city located on an island off the coast of Spain, and Mérida was a large capitol city in west central Spain situated along one of the most important roads in the peninsula (Kulijowski 2010). Individuals from each city offer a different perspective of life in Late Antique Spain. Also of importance was that neither city has been a part of similar study, and both had sufficient skeletal material that the destructive testing necessary for this study would not be a hinderance to future osteological studies of the sites. The value, in this first step, is the addition of new knowledge pertaining to the carbon and nitrogen isotopes for individuals from Spain as well as individuals during the Late Antique/Migration Period.

The second objective of the thesis was to explore inter-site comparisons among sites contemporary to Sanisera and Mérida. Neither Sanisera nor Mérida existed in isolation. Any interpretation of them would be lacking if it did not include other contemporary sites. With an understanding of the principles of isotope analysis, and the history of the the Late Antique Period (particularly that of the selected sites), it becomes possible to better understand the manner in which the individuals from these sites related not only their immediate surroundings, but also the larger population of the Western Mediterranean and Continental Europe.

The second analysis in this thesis was done by compiling a data set of published

contemporary Mediterranean and European sites and, using different methods of comparison and interpretation, to analyze their human and faunal results. The substantial potential of such a large study is hindered by the multitude of issues that can arise when comparing individuals across such a large geographical region. These concerns were addressed and explored with the result being the development of a standard method by which other such comparisons can be made. The work here contributes to the ongoing discussion of the methods of inter-site comparisons, and how to control for certain, possibly mitigating, variables.

1.2 Reconstructing Diet with Isotopes

Diet is one instance where the cultural world meets the physical world and one of the few instances where evidence of this interaction is left on the human skeleton. More importantly, it is left on every human skeleton through the nutritional components of their diet. While diet is the sum of the food an organism consumes, nutrition is the process by which an organism assimilates the food into their tissues (Whitney 2008). What an individual eats may be defined by their cultural preferences, but their need to eat is universal. Diet is a part of human existence that is unique to the individual and their situation, but at the same time a physiological necessity that is present for every human being despite their culture, where they lived, or even when they lived. An examination of the dietary choices of a society gives us a view not only into its economic state and cultural attitudes but also the relationship with its surroundings, environment, and its place in the larger political, cultural and economic world (Reitsema 2013).

While there are many archaeological methods used to study past cultures, the human skeleton provides a truly unique opportunity, in that it enables the study

of past lives from the remains of the people themselves, and not by what they left behind. Cultures can leave their mark on the human skeleton in many ways, from artificial cranial deformation to occupational stress markers resulting from intensive repetitive activity. However, diet is a factor that is present in every culture and stable carbon and nitrogen isotopes are present in every human skeleton (though preservation may affect our ability to study them). This makes stable carbon and nitrogen isotope analysis an important means by which to study and compare different cultures.

The application of stable carbon and nitrogen isotope analysis to reconstruct past diets of humans as well as of animals has been in practice for nearly 40 years. The principle is that carbon and nitrogen isotopes found in bone collagen and tooth dentine directly reflect the diet of the individual or animal sampled (DeNiro & Epstein 1978, Vogel 1978, Bender *et al.* 1981, Ambrose 1991).

However, Late Antiquity has been sorely neglected over the years, especially Late Antique Spain. There have been a handful of studies conducted for this time period in the Balearics (Garcia *et al.* 2004, Garcia-Guixé *et al.* 2010, Fuller *et al.* 2010, Nehlich *et al.* 2012) and for northwestern Spain (López-Costas & Müldner 2016), but most comparable studies have focused on other geographical locations, such as Italy (Rutgers *et al.* 2009, Iacumin *et al.* 2014, Scoranno *et al.* 2014), Germany (Schutkowski *et al.* 1999, Hakenbeck *et al.* 2010, Knipper *et al.* 2012), and Greece (Garvie-Lok 2001, Bourbou & Richards 2007, Bourbou *et al.* 2011) to name a few, or other time periods such as the during the Roman Empire (Prowse *et al.* 2004, Craig *et al.* 2009, Crowe *et al.* 2010, Killgrove 2010, Killgrove & Tykot 2013) or the Middle Ages (Mundee 2010, Sirignano *et al.* 2014, Alexander *et al.* 2015). This thesis will

help to fill this gap in knowledge and further the understanding of Late Antiquity in general.

1.3 Areas of Study, Format, and Objectives

The gap in the historical and archeological knowledge of the Late Antique period in Spain is one of the primary focuses of this thesis. It is addressed first by considering primary data resulting from the analysis of human and faunal samples from the sites of Sanisera (Menorca) and Mérida (west central Spain) dating from between the 3rd and 9th centuries AD; and then in the manner in which these sites compare to contemporary sites across Europe and North Africa. The sites of Mérida and Sanisera are important as neither has been the subject of palaeodietary reconstruction, and while the material culture of both sites are being studied to various extents, the carbon and nitrogen isotope analysis of skeletal remains has yet to be included. The isotopic analysis of these remains provides unique information on the individual and population level.

With this in mind, this thesis starts with three background chapters, covering history and diet, isotopes and isotopic analysis, as well as the sites of Sanisera and Mérida themselves. The background chapter on history and diet describes those periods, the available food sources, how these varied within each time period, and discusses variables affecting variability in food consumption. Throughout this chapter, the means by which this information can be used as part of a palaeodietary reconstruction incorporating the stable carbon and nitrogen isotope results were discussed. Rounding out this discussion was a description of the effects that all of these variables could have on the individuals included in this study. The isotope chapter outlines the basic principles behind stable isotope analysis, then focuses on

the specific isotopes of carbon and nitrogen and how they were employed in dietary reconstruction. The samples processed and analyzed in this thesis originated from two sites and three distinct time periods in Late Antiquity on the Iberian Peninsula. The final background chapter outlines the relevant background information for the sites from the Late Antique cities of Sanisera (Menorca) and Mérida (west central Spain). The location and size of the cities are described and compared, as well as the similarities and differences among their burial methods.

The fifth chapter covers the materials and methods employed in this thesis. For the sites of Mérida and Sanisera, it describes how individuals were chosen and sampled, how the collagen was extracted, and what standards were used to determine if the results were acceptable for further analysis.

For the first part of this study, bone and dentine samples were taken from Mérida (humans from the sites of Nova Romano, Velada, Nuevo Mérida, YAC and Nova Romano III and fauna from the site of Casa Herrera) and from Sanisera (humans from Necropolis 6 and fauna from the city itself). The Mérida faunal samples originated from the site of Casa Herrera in the form of two *Bos taurus* (cattle), one of which had both bone and dentine sampled and the other had only dentine. The Mérida human samples were taken from 35 individuals from the sites of Nova Romano (n=3), Velada (n=12), YAC (n=3) Nuevo Mérida (n=4) and Nova Romano III (n=13). Dentine from all of the individuals was sampled and 24 of them also had associated bone. From Sanisera, 25 faunal samples were collected. They originated from the city site and came from the bone of two *Bos taurus* (cattle), nine ovicaprids (sheep/goat), ten *Sus domesticus* (pigs), and one *Canis canins* (dog), as well as dentine samples from three *Bos taurus* (one of which had related bone). Of

the 36 individuals from Sanisera Necropolis 6, 21 had dentine and associated bone and materials were both sampled, and 15 consisted of only dentine.

The hypothesis for the first portion of this thesis is as follows: *based on archaeological and literary sources, individuals from the coastal site of Sanisera will have diets reflecting heavier marine influence as compared to the diets of individuals from the inland site of Mérida. A secondary hypothesis is that the more cosmopolitan and populated site of Mérida will have a greater range of isotope values, than the comparatively small and insular site of Sanisera.*

In the first half of the results chapter (Chapter 6), the osteological results for Sanisera and Mérida are presented for faunal then human samples. Additionally, the results of radiocarbon dating are put forward. This is followed by the results of the carbon and nitrogen isotope analysis, as well as how they relate to archaeological variables (site, tomb, etc.) and osteological variables (age at death, sex, etc.). The discussion of these results can be found in Chapter 7. The faunal and human results from Sanisera and Mérida were analyzed and interpreted in terms of intra-site variations for both osteological or archaeological results. Also covered are the interpretation of outliers and a cursory look at how the two sites compare to contemporary sites.

Then, this study will discuss how factors pertaining to location, such as climate and geography, affect these comparisons. In this study, the effects of location (climate and geography) on stable carbon and nitrogen isotope analysis were assessed using a compilation of data from contemporary isotopic studies and the associated geographical and climatological meta-data from each site, followed by a statistical analysis of these data to reveal how a variety of climatic and geographic

variables affect carbon and nitrogen isotope results, and how this, in turn, affects the interpretation of inter-site as well as intra-site variations.

Sanisera and Mérida were cities within a larger world, and as previously stated, it is for this reason that it was important to compare their results to other contemporary sites in the Mediterranean and Continental Europe. For the second portion of this thesis, upwards of a 1,000 individuals and 300 faunal samples from 53 sites (grouped into 34 locations), dating from the Late Roman Era to the Early Medieval Period, were used to create a Meta-Data set. Also included for each location was climatological data, such as temperature and precipitation (obtained from the International Atomic Energy Association's online database of the Global Network for Isotope Precipitation or GNIP), and other geographical data, such as altitude and whether the site was coastal or inland. First, each variable was analyzed individually using univariate linear regression analysis for both $\delta^{13}C$ and $\delta^{15}N$. Primary results were based on the individual significance (regression t-tests) of each predictor variable. Due to the nature of the data set there was concern for possible sample biases, with some sites having considerably more individuals than others. As the univariate analysis does not account for such interactions, there is a possibility for biased results. Therefore, univariate regressions were followed by a multivariate linear regression analysis.

The hypothesis for this portion of the analysis was: *The $\delta^{13}C$ and $\delta^{15}N$ values in this dataset will be considerably influence by climate and geography, to the extent that direct comparisons between individuals from different locations would lack any real interpretive power.*

The sources of the data included in the dataset, the reasoning behind their inclusion and the statistical methods used in the analysis are outlined in the

Materials and Methods chapter. In the Meta-analysis results section of Chapter 7, the Meta-analysis aggregating reports of both human and faunal isotopic findings from the 31 locations are presented. The data was first split into faunal and human remains, and then analyzed based on factors such as time period, longitude, latitude, distance to the coast, climate variables (such as mean temperature and annual precipitation) and Climate Classification. The discussion of the Meta-analysis explores the manner in which the climate and geographical variables affect interpretations and comparisons of of the isotope results.

It is not a novel concept that climate and geography affect isotopic research results, and is why most studies have been conducted on the analysis of single sites, or groups of sites within a single region. However, as the number of studies using carbon and nitrogen isotope analysis grows, comparison and integration of their results are inevitable. Considerably more consideration must be given to climatological and geographical variables, otherwise the conclusions drawn from these analyses are more susceptible to misinterpretation. If smaller scale studies treat variations due to climate and geography as noise, it could lead to climate-driven variation being interpreted as dietary or cultural variation when those studies are included in wider reaching comparisons.

Finally, with this in mind, this thesis explores other methods which have been suggested to negate for the effects of climate and geography and then proposes a new model. The model uses local faunal carbon and nitrogen isotope values to form a base-line by which to compare human values. This is done by creating a faunal standard and to calibrate the individual human results, making them more suitable for inter-site comparisons for sites with varying backgrounds. *It is hypothesized that this will allow for the partitioning of isotopic effects resulting from*

climate and geography from those resulting from cultural effects such as diet and mobility.

This study is providing new data on individuals from sites, which have never been included in isotopic studies before, as well as providing a larger scale analysis of sites from the middle of the first millennia AD, from across Europe and the Mediterranean, and is concluded with a new method by which to compare these sites and others.

Through this thesis, it has become clear that the understanding of carbon and nitrogen isotopic data requires the knowledge of the effects that important environmental variables such as temperature and precipitation, as well as geographic variables like altitude and distance to the coast have in oder to accurately reconstruct the diet of individual sites as well as geocultural regions. These factors must also be taken into account in inter-site comparisons in order for these interpretations to be robust and ultimately lead to a better understanding of the past. This thesis ran the gambit of palaeodietary reconstruction using carbon and nitrogen isotope analysis; starting at the local level, with the osteological analysis of individuals from two Late Antique Spanish sites, and ending with the development of a new standard method of inter-site comparison for sites with variable climatological and geographical influences. Not only does this study expand the knowledge of carbon and nitrogen isotope analysis and further the understanding of life in Late Antique Spain, but the method developed there in lays the groundwork for a new method of inter-site comparison.

Chapter 2: Late Antique Spain - A Literature Review

Late Antiquity is generally defined as the period between the fall of the Roman Empire and the Middle Ages, generally, between the 3rd and 7th centuries AD. However, as is commonly the case, these dates fluctuate based on the location being discussed. For example, in northern Europe, this time is referred to as the Migration Period. With the focus of this thesis being on two sites on the Iberian Peninsula, the period is considered to start with the fall of the Roman Empire in the early 5th century AD, and end with the conquest of Spain by the Muslims in the 8th century AD.

Palaeodietary reconstruction may start with isotopic analysis, but a more complete picture requires an understanding of the likely regional diet for the time period/culture in question. The isotopic profile plus the available foods will suggest a possible or even likely diet. The further addition of cultural influences and possible mobility can explain deviations from the expected diet. In this way, historical and archaeological data can help complete the background necessary for the interpretation of isotopic data. In the most general terms, farming practices and the types of plants consumed are most relevant to $\delta^{13}C$; while animal husbandry practices, manuring of crops, and meat and fish consumption in daily life are more relevant to the understanding $\delta^{15}N$.

This chapter first establishes the historical context of Spain between the decline and fall of the Roman Empire through to the beginning of Muslim rule, the Late Antique Period. This is followed by a description of the available food sources, how they changed throughout Late Antiquity, and how these changes potentially affected variability in food consumption. Throughout this chapter, the implications

these variations have for palaeodietary reconstruction, specifically those which incorporate stable carbon and nitrogen isotope results, are discussed. Rounding out this discussion is the effects that all of these variables could have had on the individuals included in this study.

2.1 Historical Background

2.1.1 Introduction

The individuals analyzed in this thesis date from the 3rd through to the 10th centuries AD (individuals and dates are listed in Tables 5.1-5.4 in Chapter 5). The first millennium AD in Spain was a very tumultuous period in the Iberian Peninsula. It saw the Roman Empire transition from its height to its collapse, the invasion of multiple tribes both from both the North and the South, and finally the rise of the Muslim state. During these dramatic political changes, there were simultaneous changes in climate which also played a role during the time period.

2.1.1.1 Climate Changes

The Late Antique Period is defined by changes in the government, but there were simultaneous changes in climate, which also contributed to changes in the available foods. The height of the Roman Empire benefitted from wet and warm summers with only slight annual variations (Büntgen *et al.* 2011). The stable and advantageous weather conditions between the 1st century BC and the 3rd century AD eased the expansion of the empire as a whole (McCormick *et al.* 2012). Then, in the later half to the 3rd century to the 7th century AD, precipitation become extremely variable with an initial increase in dry conditions until 300 AD (Holzhauser *et al.* 2005). In addition, a volcanic eruption near the equator in 536 AD (Larsen *et al.* 2008) contributed to increased variability of precipitation,

hemispheric cooling, and falling lake levels, during the 5th century AD. The 6th century AD saw an increase in precipitation followed by an abrupt decline (Büntgen *et al.* 2011). Finally, this more variable and generally less hospitable period was followed by a return to the more favorable conditions (wet summers) that persisted for the next century and the end of the Late Antique Period (Büntgen *et al.* 2011).

2.1.1.2 Discussion of the Political and Economic Changes

The sections below cover the basic historical background of the Iberian Peninsula, with particularly on the Balearic Island of Menorca and the city of Mérida, in central mainland Spain. The Late Antique period is first divided it into three shorter time periods, defined by two major events in the history of the Iberian Peninsula, the fall of the Roman Empire in 409 AD, and the rise of Islamic Empire in 711 AD (Collins 1998). Using these two events as delimiters, the resulting three time periods, Roman Spain (3rd-5th century AD) in Section 2.1.2, Gothic Spain (5th - 8th century AD) in Section 2.1.3, and Islamic Spain (8th - 10th century AD) in Section 2.1.4, the agricultural, demographic, economic and social trends of the three periods are discussed below.

2.1.2 Roman Spain from the 3rd to 5th Centuries AD

2.1.2.1 Government

Roman rule began on the Iberian Peninsula in the 2nd century BC (Kulikowski 2004). *Hispania* was the name given to the region, and it remained under Roman control until the fall of the Western Roman Empire in the 5th century AD. *Hispania* was initially divided into two provinces (*Citerior* and *Ulterior*), in 27 BC. Augustus further divided *Ulterior* into *Baetica* and *Lusitania.* It was also around this time that the province of *Citerior* was renamed to *Tarraconensis.* In 293 AD,

Diocletian's Tetrarchy saw *Hispania* become one of the four new diocese with Emerita Augusta as its capitol. It was also divided into the new provinces of Baetica, Carthaginesis, Gallatia, Lusitania, and Tarraconensis, on the peninsula, Mauritania Tingitana, in North Africa and Insulae Baleares (Keay 1988). See Figure 2.1 for a map of this division. By the 3rd century AD, the Iberian Peninsula was incorporated culturally, militarily, and linguistically into the Roman Empire. Nearly all Hispanic towns had the rights of Roman law and citizenship and *Hispania* was essential to the Roman economy.



Figure 2.1: Map of Spain in the Late Roman Empire (taken from O'Callaghan 2013; 29, Map 1).

2.1.2.2 Economy

The Iberian Peninsula, over the course of the 3rd to 5th centuries AD, saw an economic boon followed by a steep decline. The 3rd century AD saw high volumes of wool and metals (most notably gold) exported, as well as large amounts of food

staples, such as wine, olive oil and grain (Keay 2003, Kulikowski 2007). The 3rd and 4th centuries saw a "great deal" of new land cultivation in the area as well as a population boom that has been estimated at between five and ten million at its peak (Kulikowski 2007; 154). Grain was exported from *Hispania* at such a volume during the 4th century AD that it began to rival Egypt in prominence (Payne 1973). The peninsula was sufficiently prosperous to support a strong middle class, though the majority of the population consisted of small farmers and shepherds and as was common in the rest of the Empire, the population was predominately Christian.

One of the largest industries along the coast of the peninsula during this time was centered around the production and trade of fermented fish sauces such as *garum* and salted fish products like *salsamenta* (Curtis 1991, Trakadas 2005). There had be an increase in production and exports that had started from the 1st century BC, but the increasing addition to the market of goods from African sites in the late 3rd century AD lead to many fish processing sites limiting their production, or closing all together.

2.1.3 Gothic Spain: 409 to 711 AD

2.1.3.1 Government

With the dissolution of Roman authority in Spain the Visigothic Kingdom officially ruled in the Iberian Peninsula from AD 409 to 711 (Collins 1998; 19). The spread of their control from the north was slow, as there were other groups, including the Alans, the Sueves, and the Byzantine Empire vying for dominance in the region. While the Visigoths were militarily superior, the *Hispani* (or native population) were more advanced economically, culturally, and substantially larger in number. One estimate had only three hundred thousand Visigoths entering the

peninsula as compared to the four million[1] *Hispani* in residence (Payne 1973). The Visigoths were more Romanized than the other invading Germanic tribes; they were Christian, and had a similar political structure with the King being selected and ratified by the aristocracy. As a result, the overall culture of the Iberian Peninsula remained relatively consistent under Visigothic rule. Unlike other Roman territories, the Iberian Peninsula did not suffer a total societal collapse. Despite being thrown into a tumultuous political period, the Iberian Peninsula retained much of its culture, in no small part because the new leaders saw themselves as a continuation of the Roman tradition, rather than as conquerors (Payne 1973, O'Callaghan 2013, Jiménez Garnica 1999). The institutional roots left by the Romans were upheld by the Visigothic rulers (Kulikowski 2004). Using a similar system as their predecessors, the Visigoths had a centralized administration that oversaw the cities, aqueducts, bridges, roads, waterworks and coinage (Orlandis 2011). After the mid-seventh century AD, the wealthy started to leave the declining cities in favor of the countryside. Large agricultural estates were formed with a combination of land seizures, reallocations, and marriages between landed families. Poorer land owners were often forced to sell their land to these estates, which lead to a seigniorial system in which those who owned the land had little invested in its up keep (Ruggles 2000). This led to a decline in the strength in the political system which was further hindered by the oppression of the Jewish population (which had been a formerly prosperous section of society) and an unremitting struggle for succession of the throne (Orlandis 2011).

[1] These numbers are highly contested due to the lack of statistical data for this period. Valdeavellano estimates that the population was three hundred thousand to nine million, while Vicen Vives estimates two hundred thousand to six million (O'Callaghan 2013; 70-71)

2.1.3.2 Economy

The economic decline that accompanied the fall of the Roman Empire had less impact on the population of *Hispania* in comparison to those living in other parts of the Empire, though it was not untouched by "inflation, taxes, warfare and [a] drop in commerce" (Payne 1973; 8). Economically, Gothic Spain was less prosperous than the preceding Roman period. The decline in the general population led to a labour shortage that is reflected by the increase in laws regulating rural and servile labour in the mid-seventh century (Kulikowski 2007). Previous trade routes were no longer as stable, and economic opportunities were reduced. An example of this is the noticeable absence of African fineware in Spain from the 560's on (Reynolds 1993). The drastic decrease in imported goods to the peninsula could also be linked to the port cities being those first inundated with the Justinian plague (discussed below), thus hindering the work force and the ability to move goods.

This economic decline is also evident in the re-use and construction of buildings. During this period, it was commonplace for building materials and buildings to be repurposed, rather than rebuilt. When new materials were produced, it is clear that the level of craftsmanship was inferior to that typical of the Roman Period. In addition, many larger buildings were divided into smaller domestic spaces using scavenged or inferior materials. An example of this is at the Morerís Archaeological Zone in Mérida (Alba Calzado 2001).

2.1.3.3 Plagues

Between the years of 541 and 750 AD, the Justinian Plague swept through the Mediterranean, drastically reducing the population (Little 2007). The literary evidence[2] states that Spain first fell victim to the plague some time between 542 AD

[2] References to this literary evidence can be found in García Moreno 1975; 52-53 & 112-115.

and 543 AD, then in the 580s[3], and again during the reign of King Erica (687-702 AD)[4]. There are also references to the plague in the 7th century; the *Akbar Majumu'a* states that between 707 and 709 half of the population of Spain was struck down by plague and famine (Ruggles 2000, Kulikowski 2007), though this text dates to the eleventh century and there is question as to whether the population density at the time was sufficient to support the spread of an endemic plague (Sallares 1991).

Archaeologically, the evidence is more circumstantial. There are a few instances of mass graves dating to the sixth century, two in Valencia and one in Carthage Nova (modern day Cartagena), which have been suggested were a result of the high mortality caused by the plague (Kulikowski 2007). Another possible reason for the perceived increase in deaths during this period was a shift in burial customs. The sixth century saw an increase in deliberate multiple inhumations, be they consecutive or simultaneous, as well as what Kulikowski refers to as "an increased tolerance for the physical intrusion of the dead upon the living", with above ground tombs going unsealed and exposed ossuaries appearing in churches (Kulikowski 2007; 159). In any case, the combined climatological and demographic instability lead to a disruption in food production in the Iberian Peninsula (Kulikowski 2007).

The general decline of the population and cities during the Visigothic rule, as well as strife in the ruling class and a weakening of the Church, made the peninsula ripe for take-over by the time the Berber and Arab armies crossed the straights of Gibraltar at the beginning of the 8th century AD (Kennedy 1996).

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[3] discussed in Gregory of Tours, *Historia Francorum*

[4] *Cronica Mozárabe de 754* 41, p. 58

2.1.4 Rise of Muslim Spain: 711 to 10th Century AD

2.1.4.1 Government

The Islamic conquest of the Iberian Peninsula was relatively expeditious due to the weakened state of the Visigothic Kingdom. The deciding battle occurred in 711 AD when the Visigothic King Rodrigo was defeated by the Arab and Berber armies with the help of Visigothic dissidents at the Lake of La Janda (Collins 1983; 152-154). The complete conquest took only three more years. Mérida, specifically, fell under Islamic rule, after the Visigothic nobility surrendered the city on the 30th of June in 713 AD (O'Callaghan 2013; 93). Thus, with the exception of the northernmost portions, the peninsula became a minor province of the Islamic Empire (ruled by the Umayyad caliphs in Damascus) known as *al-Andalus.* In 755, Umayyad prince Abd al-Rahmān I established *al-Andalus* as an independent kingdom and began his Hispano-Umayyad dynasty. While the borders of *al-Andalus* shifted frequently, the Umayyads had long reigns and brought overall stability to the region (Ruggles 2000).

2.1.4.2 Economy

The new Islamic rulers, for the most part, respected the rights of the native population including land ownership and religion. Though there was a tax levied against non-muslim citizens (the majority were Christian and Jewish). The conversion to Islam started off slowly, but quickly gained momentum with the majority of the population being converted by the 10th century AD (Glick 2005, Kennedy 1996 and Boone & Benco 1999). The system of large agricultural estates diminished, and in its place arose a system by which a percentage of the harvest was paid as rent by land workers to the owners they were renting the land from. As

opposed to the previous system, this new arrangement saw the upkeep of the land in the best interest of both parties, thus stimulating agricultural production (Vives 1969). There was also an increase in cultivars and improvements in agricultural techniques and hydraulic engineering (Ruggles 2000). Coupled with the return of climatological stability (Büntgen *et al.* 2011), there was an overall increase in agricultural production and quality leading to increased trade and population growth.

2.2 Food Sources

There is a noticeable scarcity of literary sources in reference to diet during these time periods in Spain. What is available includes social and historical commentaries, regulations for the sale and taxing of food, cookbooks, historical records of traveler's tales, supply records from ships and armies, the dietary regimes of monasteries, and comments made by physicians concerning diet (Bourbou & Richards 2007; 64). Literary sources have to be considered with care though, as they are taken through the "mediation of a rather narrow range of literary spokesmen, drawn from the social and political elite of the cities" (Garnsey 1999; 79). Fortunately, archaeological sources can be used to counter the inherent bias of literary sources. Some methods for determining diet archaeologically include botanical and faunal remains, depictions in artworks, lipid remains left in ceramics, and stable isotope analysis (Bakels & Jacomet 2003, Dunbabin 2003, Evershed *et al.* 2001, Sealy 2001). Using these methods in concert with literary sources can create a clearer, more complete picture, which considers the population as a whole, rather than simply the elite.

Diets in Late Antiquity were based mostly on what Braudel referred to as the "eternal (or essential) trinity"; cereals, vines and olives (Braudel 1995; 236). To this base diet meat, fish, legumes and other foodstuffs were added. This coincides with the nature of the Late Antique society being primarily agricultural. The majority of the population was part of the agricultural economy and most homes had their own small gardens. While there were regional variations in diet across Europe and North Africa, it remains the case that the general population consumed a diet heavily based on grains and vegetables, with animal proteins, such as meat and cheese, being added only sporadically (Chabrán 2002).

2.2.1 Agricultural Based Food Sources

With the Late Antique diet consisting mainly of plant foods, it is important to note that the range of vegetation consumed was as varied as the manner of preparation. The literature on what was available for consumption in Late Antiquity is diverse and prolific (Aguilera 1991, Bourbou and Richards 2007, Bradley 1998, Braudel 1995, Curtis 1983, Donahue 2015, Garnsey 1999 and Garnsey & Humphries 2001). For this reason, this chapter focuses only on the major dietary components specific to Spain.

The primary component of the typical diet throughout Late Antiquity was grain. In fact, three quarters of the caloric intake of the average Roman diet came from grains (Rickman 1980, Garnsey 1983, White 1988, Killgrove 2010). There were many grains being cultivated in Late Antiquity, and numerous ways in which they were prepared. Most recipes for cereals and pulses fall under the umbrella of breads (leavened or unleavened, soft or dark), flat-cakes, porridge, pastries and soups and stews (Adkins & Adkins 2014, Alcock 2001, Garnsey 1999, Medina 2005b, Mundee 2010). The most common grains consumed in Late Antique Spain were wheat and

barley, with millet, oats, rye, and sorghum being considered secondary crops (Garcia Sanchez 1994; 257).

Wheat was the most desirable grain, with barley considered to be substandard (Garnsey 1999), though it was often used in place of wheat especially by soldiers (Adamson 2013; 7). Differences in socio-economic status were often reflected in grain consumption, particularly in the type of bread, with higher status individuals preferring white bread made of wheat and lower status individuals consuming breads consisting of mixed, less refined grains (Mundee 2010; 56-57). This was so widely accepted that it was even described in medical texts (Waines 1992, Adamson 2013). The lack of recipes involving less desirable grains is likely a consequence of the bias mentioned above which results from cookbooks having been written for the elite (García Sánchez 2002; 280).

The most common secondary cereals in Late Antique Spain were rye, millet, and sorghum. Rye grows in colder climates, so was mostly limited to the northern areas of the peninsula (Montanari & Ipsen 1994; 31). Millet and sorghum, though, would have been present in both central Spain and the Balearics. They are particularly of interest to palaeodietary reconstruction using isotope analysis as they are C_4 grains, which, will be discussed in Chapter 3, greatly affect the carbon isotope values.

The broomcorn or common millet (*Panicum miliaceum*), and the Italian foxtail (*Setaria italica*) were the two species of millet present in Spain during Late Antiquity (Buxó 1992, Marnival 1992). Millet has been commonly considered "the grain of poor backwards people" (Semple 1935; 343), though this notion is starting to change (Murphy 2016). As well as being a dietary resources, millet is referenced as being used as animal fodder and having medicinal uses (Murphy 2016). While

millet may have not been as preferred as wheat, barely or rye, it does have many attributes that would make it an advantageous crop. Agriculturally, it fairs well in heat and in drought conditions as well as in areas with less fertile soil. Additionally, millet has a short vegetation cycle of 3-4 months (Zohary *et al.* 2012) and most notably, can be stored for extended periods of time (Spurr 1983). With millet having a longer shelf life than the more common grains, it made a good dietary supplement when autumn crops failed (Spurr 1986; 89). There are a few city sites in which the archaeobotanical remains of millet have been found (Alonso 2008, Alòs *et al.* 2006), but it is always in relatively small quantities in comparison to other grains. However, its scarcity in the archaeological record may be due to its physically small size (Murphy 2016). While the assertion that the regular consumption of millet was only done by the rural poor (Braudel and Reynolds 1972; 595) and that it was "synonymous with poverty and famine" (Adamson 2013; 8) may hold some weight, millet was clearly present in Late Antique Spain.

Sorghum was introduced to mainland Spain during the Muslim period and likely replaced millet as the grain of the lower class (Mundee 2010). It is well suited to a hot, dry climate (Glick 2005) and is a rapid-growing grain, which means that it would be available earlier in the spring when other grains were in short supply (Mundee 2010; 57). It would have been used in a similar manner to millet, such as being mixed with wheat during times of 'famine' or for animal fodder.

Legumes are an important dietary component for isotope studies. The legumes common to Late Antique Spain were chickpeas, fava beans, kidney beans, broad beans, lupins, lentils, and peas (Mundee 2010). With the consumption of legumes being tied to the lower classes as a meat substitute (Garnsey 1998), it is not surprising that they are not as prominent in literary sources. Their use as a

replacement for meat is of particular relevance in isotopic analysis as consumption of legumes leads to lower $\delta^{15}N$ values in consumers (DeNiro & Epstein 1981) and the lack of animal protein would only further decrease $\delta^{15}N$ values.

Acorns were another dietary staple in Spain, commonly being made into bread or gruel. The Greek naturalist Strabo, estimated that for two-thirds of the year individuals from the more mountainous regions of the peninsula subsisted on acorn bread (Strabo III.3.7, referenced in Alcock 2006). Acorns were able to be stored for long periods of time and were often consumed during the winter months, or times of famine (Alcock 2006). Acorns were also commonly used as feed for animals, most famously to fatten pigs (Parsons 1962).

Olives were and still are one of the main defining features of the Mediterranean diet. Olive trees have been referred to as the "Queen of all the trees" in Latin agricultural manuals (Forbes & Foxhall 1978; 38). The olive only does well in the "regions of true Mediterranean climate" (Garnsey 1999; 14) needing a dry growing season, and a cool winter. Finally, olives do not fair well at altitudes above 800 meters. As can be seen in Figure 2.2, olives were grown throughout much of Spain. Olive oil was produced extensively in Spain (Greene 1986) and was a major export (Casson 1994; 129). The provinces of Bética and Tarragona became important suppliers of olive oil to Rome. Olive oil was used in making sauces, for frying and for cooking vegetables and cakes (Medina 2005b; 6).

Fruits that were common in Spain were dates, figs, pomegranates, pears, grapes, peaches, plums, apples and cherries. They were typically left to dry in the sun making them easier to package and export. Also prepared in this manner were sweet olives, which had a richer taste than raisins. Other fruits known to be in Spain at this time were lemons, melons, and apricots, though these were considered



Figure 2.2: Map of olive distribution across the Mediterranean Region (taken from Renfrew 1973; 132, Figure. 82).

novelties. Wine was an important product of the peninsula. It was made in many different varieties; red, white, sweet, young, mixed with honey and spices, or cooked. During the Roman period wine was rarely consumed undiluted (Renfrew 1973).

While the specifics of the Late Antique diet are hard to pinpoint, it is clear that it was centered heavily in agriculturally-based foodstuffs. The people of the time were agriculturalists and their focus was on the production of cereals, oils, and wines. Diets varied regionally, but the staples where ubiquitous. The most common limiting factor in Spain during this time period was social status. The lower classes could not afford more expensive supplements to their diet, such as meat and fish, and cheaper less desirable types of grains were consumed in greater quantities than by their upper-class counterparts.

2.2.2 Animal Husbandry

While the Late Antique diet consisted mainly of plant foodstuffs, meat and cheese consumption was also practiced in moderation. Land was mainly used for crops, as animals produce less food per unit than plants (Garnsey 1999; 16). Only

larger landowners could afford to keep livestock. Animals were primarily kept for their secondary uses, such as work (oxen), wool (sheep and goats) cheese (sheep, goats, cows) and skins (Alcock 2001; 64). Pigs were the only animals whose sole purpose was meat (Garnsey 1999; 17). That is not to say that meat was not consumed, but only that it did not have the same prominence that it holds in modern Western diets. Also, those that consumed meat on a regular basis were likely to be members of the upper echelons of society.

The most frequently consumed meat came from animals such as goats, sheep, and pigs. Beef was also consumed, but cows were more expensive to keep, as they required more room. Because animals were often used for their secondary products over their meat, consumption of younger animals would be considered a delicacy. Another animal commonly referenced in the classical literature is chickens (Faas 1994 and Alcock 2006). Chickens could be kept to produce eggs, and were themselves a good source of protein. Due to the nature of chicken remains, and the lack of sieving at Spanish sites, there is very little zooarchaeological evidence for chickens, or any other type of poultry. The study of zooarchaeological remains from Late Antique sites in Spain is lacking compared to contemporary sites in the rest of Europe, but the study by King 1999, gives a good background as to the trends in the prominence of pig, sheep/goat and ox in the Roman world. The first century AD saw an increase in pig and ox percentages, and a decline in sheep/goats (King 1999). *Hispania* became well known for its ham during the Roman Period. The intensification of cash-crops during this period (olives, etc.) is one explanation of the decline in sheep/goats as they would have to graze farther away. Conversely, pigs were well suited to the shady conditions provided by new cash crops. They were fed wild fruits and acorns, a practice still common today (Parsons 1962 and Medina

2005a). With the decline of the economy after the fall of the Roman Empire, Spanish agriculture became less focused on cash-crops and grain crops that were more sympathetic to animal husbandry returned. This led to sheep/goats becoming the more dominant domestic fauna (King 1999). Pigs continued to decline for a time as the Islamic period saw pork consumption decline drastically (Benito 1989).

Game is often referenced in contemporary literature, particularly in cook books. Wild game available in central Spain would have been rabbit, deer, and game birds such as pheasant, partridge, and quail (Adamson 2004). Game in Menorca would have included rabbit, the origin of which was attributed to the Balearic Islands by Greek naturalist Strabo, and which Pliny described as "bringing famine to the Balearic Islands by ravaging the crops" (Toussaint-Samat 2009; 74).

Preservation of meat was often a concern during Late Antiquity. While smaller animals, like chickens, were readily consumed in a single sitting, meat from larger animals would have needed preservation. The most effective and common means of preserving meat was drying and salting. This made the butchering of larger animals more practical, as the practice would allow for more time to consume the large quantity of meat such an animal would have yielded.

It was through the consumption of secondary animal products that most individuals consumed animal protein. Dairy production is the most frequently mentioned animal protein source. Milk was taken from cows, sheep and goats. As there were few means of preserving milk in Spain (with its high temperatures), it was often processed into cheese, yogurt, or butter.

The manner in which animal husbandry practices affected the diets of individuals in Late Antiquity is clear. While meat was sometimes consumed, the secondary products produced by these animals (eggs, milk, cheese, etc.) would have

been more frequently consumed. For the lower classes, eating the meat of an animal was likely done only when that animal was no longer useful. Only those in the upper classes could afford to consume animals more frequently. What this means for an isotopic analysis is that those in the upper class should present with higher $\delta^{15}N$ values, since they were likely consuming more animal protein. However, the $\delta^{15}N$ values of individuals from the lower classes should still indicate the presence of animal protein in their diet, since they likely consumed some secondary animal products.

2.2.3 Fishing

Late Antique, coastal Spain was one of the most prominent areas of large-scale fish processing (Curtis 2005). The Straights of Gibraltar, connecting the Atlantic Ocean to the Mediterranean Sea, is used by many marine species as a major migratory route (Ponsich 1976, Ponish 1988, Coracoran 1963) and this was well understood in Late Antiquity. Spain being the source of the largest surmullets and murry is mentioned by Strabo (III.2.7)(Trakadas 2005). The production and trade of salted fish (*salsamenta*) and fermented fish sauces (*garum*) are well documented during Late Antiquity (van Neer & Ervynck 2004). Amphora and fish processing sites are two of the main archaeological sources of information on this topic (Curtis 1991). While amphora were commonly reused, the presence of fish remains have been found associated with some amphora. Fish processing sites[5] along the southern coast of Spain date from the 1st century BC through to the 6th century AD (Curtis 1991, Trakadas 2005). The most common species of fish found are Spanish mackerel (*Scomber japonicus*) and sardines (*Sardina pilchardus*), other taxa that

[5] For a list of fish processing sites in Spain see Ponsich & Taradells 1965 as well as the 1988 update by Ponsich.

have been identified are amberjack (*Seriola dumerilii*), horse mackerel (Trachurus), mullets (Mugilidae), picarel (*Spicara smaris*), seabreams (Sparidae), tuna (*Thynnus thunnes*), and wrasses (Labridae) (Delussu & Wilkens 2000). Amphora containing *salsamenta* has been found on ship wrecks Corsica (Desse-Berset 1993), Italy and Sardinia (Delussu & Wilkens 2000) as well as at sites in the Neatherlands (Lauwerier 1993), England (Yule 1989, Locker 1994) and Germany (Ehmig 2003). The bones of Spanish mackerel have also been found in multiple sites in Belgium, Britian, Germany, the Netherlands, and Switzerland (van Neer & Ervynck 2004), demonstrating just how far reaching the trade in salted fish was.

More important than salted fish were the fermented fish sauces known as g*arum, allec, liquiamen,* and *muria.* These sauces were used as a table seasoning similar to the way salt is used today. They were made by adding salt to fish and leaving them to ferment anywhere from one and three months (Curtis 1983). The liquid that formed on top of the fermented fish was what made up the sauces. There were many recipes for making *garum,* as each manufacturer had their own recipe. *Garum,* across the Mediterranean was made using a variety of fish and products such as olive oil, spices and wine were added, and different names were given to each combination (Grimal & Monod 1952, Corcoran 1963, Curtis 1991, Martínez Maganto 1992). One such example is *garum sociorum,* also known as the '*garum* of the allies'. Originating from Gades (modern day Cádiz) and Carthagena in Spain (Toussaint-Samat 2009) and made with tuna (*Thunnus*), it was one the most desired and widely traded varieties of *garum*.

The production and sale of fish sauces would have constituted a substantial part of the economy of *Hispania* during Late Antiquity (Curtis 2005). Fishing and fish processing would have been done on a large scale to supply the demand for the

salted fish and their sauces. It was reputed that the people who made the *garum* ate inferior fish and reserved the tuna for the production of *garum sociorum* for export (Corcoran 1963). Even with that in mind, the isotope values of individuals working and living near a fish processing site would still be expected to reflect marine diets. Also important to note is that work at fish processing sites would have been seasonal, and many workmen would only have lived in the area temporarily (Ponish & Tarradell 1965). Seasonal workmen would have dispersed throughout the Iberian Peninsula and may have unusually high nitrogen isotope values for their region, due to marine fish consumed during their time working at the processing site.

As with salted fish, the archaeological evidence of fish sauces is mainly limited to amphora, the fish processing sites, and zooarchaeological remains of the fish themselves. Amphora containing fish bones have been found in Austria, Spain, Greece, Elba, Sardinia, Sicily, mainland Italy and even as far as Masada, Israel (Williams 1978, von den Driesch 1980, Wheeler & Locker 1985, Lepiksaar 1986, Morales Muñíz & Roselló 1989, Curtis 1991, Cotton & Goren 1996, Desse-Berset & Desse 2000, Delussu & Wilkens 2000). The interpretation of classical authors such as Horacius, Martialis, and Plinius that fish sauces were highly valued and expensive is now thought to possibly be an exaggeration, as excavations in Pompeii and Herculaneum have found evidence of the sauces in both poor and wealthy households (Curtis 1991). The ingredients used to make a fish sauce, as well as how far it had to be transported were likely the driving factors in dictating its value.

With the ubiquitous use of fish sauces during much of Late Antiquity, it is expected that there should be some evidence of its consumption in the isotopic record with $\delta^{13}C$ and especially $\delta^{15}N$ values reflecting higher marine values. While many isotope studies of the time period look for evidence of fish in the diets of

people in from this period (Prowse *et al.* 2004, Craig *et al.* 2009), it is difficult definitively pinpoint due to the issue of low protein diets and subsequent nutrient scrambling (as will be further discussed in Chapter 3). The 'typical' diet in Late Antiquity in the Mediterranean was mainly composed of foodstuffs with little to no protein (cereals and olive oil) which would lead to lower $\delta^{15}N$ values, and an increase in the effect that the $\delta^{13}C$ derived from carbohydrates and lipids. Generally, diets have been found to be terrestrially based, with supplemental input from marine resources. This fits well with the concept that the general public rarely consumed fish as a main dish, and instead used fish sauces, such as *garum*, as an additive to their food. Individuals who lived near fish processing sites would probably have consumed fish on a regular basis (Trakadas 2005), as has been found at the site of A Lanzada in Northwest Spain (López-Costas & Müldner 2016). The coastal site of Sanisera (discussed further in Chapter 4) has no evidence of fish processing, though a small number of fish bones have been found at the site, making it safe to assume that marine fish were consumed to some extent.

The other site included in this study, Mérida (discussed further in Chapter 4), sits on the Río Guadiana and its citizens would have had access to freshwater fish. The consumption of fish was not limited to marine fish during this period. Fish were caught from lakes and rivers and there was also an industry of farming, both marine and freshwater fish (Kron 2014). The classical writer Strabo (III.3.1) praised the Tagos River in Portugal as being rich in fish (Trakadas 2005). The two main freshwater species consumed in Spain were trout and sturgeon (de Castro Martínez 1996). Freshwater fish were consumed on a more local scale compared to marine fish making their importance difficult to discern archaeologically. The methods used to recover fish bones are not as well practiced in Spain, leaving little in the way of

zooarchaeolgical evidence. As will be discussed in Chapter 3, the consumption of freshwater fish would be identifiable isotopically.

2.3 Variations in Diet

2.3.1 Chronology

The fall of the Roman Empire in the 5th century AD would have had far more than political repercussions. The collapse of the government was also accompanied by an upheaval to the economic infrastructure. One of the main consequences of this upheaval was the disruption of many trade routes. As Spain was one of the main agricultural producers in the Mediterranean at the time, the disruption of trade routes mainly effected exports. Their diets would have remained relatively unchanged as they were not reliant on imported foods. The introduction of a new ruling class of Germanic origin introduced new dishes and new methods of preparing old staples. An increase in C_4 plant consumption (likely millet) has been identified isotonically in studies from Central and South-eastern Europe (Hakenbeck *et al.* 2010, Lightfoot *et al.* 2012). This find has been mirrored in the recent study of A Lanzada in Northwest Spain, that also saw an increase in fish consumption (López-Costas and Müldner 2016). The rise in millet consumption could also be attributed to the climatological changes occurring at the time. The warm temperate climate of the Roman Empire saw a substantial increase in humidity (and consequently precipitation) in the 4th century (Martínes Cortizas *et al.* 1999, Martínez Cortizas *et al.* 2005, Mighall *et al*. 2006, Martín-Fuertas *et al.* 2009). The shift in climate would have made millet more prominent as other crops failed.

The rise of the Islamic state brought a deluge of new foodstuffs and preparation methods that would have had a substantial effect on the diet of the

general population. While few cookbooks or recipes survive from Arab Spain (Adamson 2004) those that do indicate a fusion of Arab, Visigothic, and Roman cooking styles. In spite of all the changes, the core of the common diet during the Islamic period was still based on "bread, cheese, olives, olive oil, wine and some roast meat" (Adamson 2004). However, there are some notable changes in diet that would affect isotopic results. *Garum* fell out of favor during this time, while lamb and mutton became the preferred meat over pork (Adamson 2004). Fruits also became more fashionable. Most importantly, isotopically, the C_4 grain sorghum was introduced (Braudel and Reynolds 1972, Glick 1982, Buxó 1992, Marnival 1992), though it was thought of as food for the poor (Semple 1935).

Islamic dietary laws prohibited the consumption of spilt blood, carrion, pork and technically, alcohol (Insoll 1999, Adamson 2004). The month of Ramadan consisted of fasting during the daylight hours and a meal once the sun went down (Insoll 1999). The exclusion of pig from the Islamic diet would have had the most noticeable affect on carbon and nitrogen isotope values, as the omnivorous diet of pigs means that they generally had higher $\delta^{15}N$ values than their herbivorous counterparts. With this in mind, Islamic individuals might be distinguishable isotopically from the rest of the population.

While there is no doubt that the Islamic period came with a wider variety of foods and increased dietary taboos, it remains to be seen if this is discernible through carbon and nitrogen isotope analysis of the individuals from Sanisera and Mérida.

2.3.2 Impact of Social Status

The main social variables that would have had an effect on diet were social status, gender and age. As always, those in the upper echelons of society had access

to more and often higher quality food stuffs. This includes not only meat, but meat from younger animals (including those who might still have been nursing). Those in the lower classes would have consumed meat on a much less regular basis (mostly only at feasts), and it was often legumes that replaced meat as the principal source of protein in their diet. Also, the animals consumed by the lower classes would have been older, and those that were no longer useful for other purposes (Garcia Sanchez 1983, Marsilla 1993). Regular consumption of meat generally leads to an increase in the consumer's $\delta^{15}N$ values. Add to that the preference for younger animals who may not have yet been weaned would have led to an even larger increase in $\delta^{15}N$. The use of legumes by the poor, as a source of protein over meat, would also create a noticeable difference in nitrogen isotope values between the wealthy and the poor, as eating legumes leads to a decrease in $\delta^{15}N$. This suggests that there should be a very distinct difference in $\delta^{15}N$ values between those of higher and lower social status. Social status would also have had an effect on the grains an individual was likely to consume. More desirable grains such as wheat and barley would have gone to the wealthy, while grains such as millet and sorghum were more easily afforded by the poor. The majority of the grains present during Late Antiquity were from C_3 plants. The main exceptions to this were millet and sorghum, which are C_4 plants. If millet or sorghum were routinely part of an individual's diet, their $\delta^{13}C$ values would be higher than the probably more affluent individual who only ate C_3 plants. Overall then, the dietary variations that accompanied extreme differences in social status should be clearly indicated isotopically.

Status is not only determined in terms of social hierarchy based on birth and wealth, but also by an individual's status within their own family unit. It falls to reason that the most prominent member in the household would have had

preferential access to dietary resources. Since society during this time was patriarchal, the male household heads would mostly have this preferential access. It is commonly assumed that women and children were consuming "more frugal" foods than men (Bradley 1998), with a 'frugal' diet identified as containing less meat and more of the less desirable grains. In terms of a household, this would most likely be applied only in terms of meat consumption. Rufus of Ephesus wrote that women should "moderate their intake of food, […] not touch meat at all, or other foods that are very nourishing" (Oribasius, *Liber Incertus* 18.10 in Garnsey 1999; 101). It was also suggested that elders should avoid foods like beef, that were too coarse and instead eat softer foods such as milk, chicks, eggs, goat and sheep meat, as well as other foods such as figs, which had laxative effects (Adamson 2004, Salas-Salvadó *et al.* 2006).

To determine whether females did indeed consume less meat, an isotopic comparison would be needed. To date, isotope studies of the Late Antique and Medieval periods have been mixed as to whether there is a correlation between sex and diet, with some finding that there is a difference (Garcia *et al.* 2004, Reitsema & Vercellotti 2012) and others finding little to no relation between diet and sex (Prowse *et al.* 2004, Craig *et al.* 2009, Keenleyside *et al.* 2009, McGlynn 2007, Mundee 2010).

The presence of isotopically visible age related variations in diet has also been mixed. With some studies finding no evidence for it other than nursing infants (Prowse et al 2004; Craig et al 2009), others finding that children aged 5-6 years old and younger having higher $\delta^{15}N$ values (Prowse *et al.* 2005, Keenelyside *et al.* 2009) and one study finding the exact opposite (Fuller *et al.* 2012). Apparently, this is a case of the historical literature representing an ideal, rather than an actual practice.

While there may have been variations in diet based on sex and age, they were probably not substantial or consistent enough to be identified isotopically.

2.4 Conclusion

The standard diet during the Late Antique period was primarily a grain-based diet with meats, fish, and vegetables commonly being included in small quantities. Isotopically, this would be reflected as a mostly terrestrial C_3-based diet supplemented with marine resources and C_4 grains. Variations in diet would have been based on a plethora of variables ranging from social status to geographic location. Many variations to the Late Antique diet would have very little noticeable effect on an individual's carbon and nitrogen isotope values; for example, bread made with wheat or barley (unless one grain was fertilized with manure, and the other not). However, some variations would have had a substantial effect, such as bread made with wheat versus that made of millet.

Based on the classical literature, individuals from Sanisera could be expected to have a mainly grain-based diet (since Menorca possessed ideal land from which to farm wheat and grapes (for wine), and grazing for sheep and goats (Hurst *et al.* 2011) with fish only supplementing their diet. To what extent fish were consumed at Sanisera is unknown. The individuals from Necropolis 6 seem to all be of the same social class, and consequently would have had access to generally the same food stuffs.

Individuals from Mérida exhibit more diverse burial practices and a wider range of grave goods, suggesting a wider range of cultural practices. This, in turn, suggests that there might also have been a greater variety of foods present in these individuals' diets. Being from a major city both physically and in terms of trade could

also suggest access to a wider range of foods than those found at Sanisera; though Sanisera's status as a port city would mean that it should have had an ample variety of foods, as well as a greater access to marine resources. The presence of Islamic individuals in the Mérida population, may highlight any effects that religious practices might have on stable carbon and nitrogen isotope values of an individual.

Chapter 3: Isotope Analysis

Stable isotope analysis is widely used in the field of archaeology for multiple applications such as reconstruction of past diets and environments as well as studies of materials and mobility. Some of the most commonly studied stable isotopes are from the elements carbon, nitrogen, hydrogen, oxygen, and sulphur. This study used carbon and nitrogen isotopes to reconstruct past diets, which are reviewed in this chapter. First, an outline of the basic principles behind stable isotope analysis is presented, then the focus moves specifically to the isotopes of carbon and nitrogen used in dietary reconstruction. This is followed by a discussion of bone collagen and paleodietary reconstruction. This final section highlights the history and details the relation of carbon and nitrogen isotopes in this practice.

3.1 Basics and Principles

Isotopes are different atomic forms of the same chemical element that have different numbers of neutrons (DeNiro 1987). The variation in the number of neutrons gives each isotope a different atomic mass. This difference in mass results in the isotopes having different bond energies and reaction kinetics; which is why they may react at different rates in chemical reactions (Schoeller 1999). Stable isotopes, unlike radiogenic isotopes, are so slow to break down over time that they are considered constant, in terms of geological time (Hoefs 1997). This means the relative amount of two isotopes of a given element will be stable for long periods of time, until a chemical reaction which interacts more readily with one of the isotopes changes the relative amounts of the two isotopes in the reaction products. The relative amounts of stable isotopes resulting from these reactions can yield information about the environment and mechanisms of the reaction that produced

them, as well as give information as to their source. Thus, the analysis of the corresponding content of different stable isotopes in a sample is useful to archeological research, including dietary reconstruction and questions of origin.

The process, called isotope fractionation, is the relative separation of lighter and heavier isotopes of the same element by means of physical, chemical, and biochemical reactions, resulting in a shift in the proportional concentration of the isotopes in the reaction (Chisholm 1989). Photosynthesis is one of the reactions producing fractionation. Depending on the mechanism used by the plant to convert carbon dioxide into organic matter, the ratio of ^{13}C to ^{12}C will differ. Another cause of fractionation, which is meaningful to archaeology is referred to as the "trophic level" effect. This is relevant to the fractionation of nitrogen isotopes as organic matter is passed up the food web. The influence of these two processes, photosynthesis and the "trophic level" effect, on carbon and nitrogen isotopes is discussed below, both in general terms, and as to how they can be used in dietary reconstruction.

Understanding the fractionation process is essential to isotopic studies as it reveals information about the relationships between the different species sampled. Fractionation is expressed as a relative change in relation to established standards, which are available through the International Atomic Energy Agency, Vienna and the National Bureau of Standards (Katzenberg 2011). The equation which describes this relationship is shown below (Schoeninger 1985).

$$\delta(‰) = \left[\frac{\text{Sample}}{\text{Standard}} - 1 \right] \text{x } 1000‰$$

The two most commonly used elements in palaeodietary reconstruction are carbon and nitrogen. The standard for $\delta^{13}C$ is the Vienna Peedee belemnite (VPDB) and for $\delta^{15}N$, the standard is the Ambient Inhalable Reservoir (AIR). First, the information that each element holds as it pertains to diet is outlined, followed by a more in-depth review of how they are used in concert to help reconstruct diet.

3.2 Carbon

3.2.1 Basics

Carbon has two stable isotopes, ^{12}C and ^{13}C that are used in palaeodietary reconstruction. The ratio of ^{13}C to ^{12}C, written as $\delta^{13}C$, is mainly affected by variations in plants at the bottom of the food web.

Plants can be divided into three types based on how each processes atmospheric CO_2: C_3 plants, C_4 plants, and Crassulacean Acid Metabolism (CAM) plants. CAM plants mainly consist of tropical succulents such as cacti, agaves, and bromeliads (e.g., pineapple) (Ambrose & Norr 1993). Since they do not play an important role on the European continent, CAM plants are generally excluded from European studies of diet, including this one.

C_3 plants use the C_3 photosynthesis pathways which produce a molecule that has three carbon atoms as its initial intermediate product (Chisholm 1989). Between 80% and 90% of plants are C_3 plants, this includes temperate grasses (e.g. rice, wheat, oats, barely, and rye), trees, herbs, and most shrubs. The glucose found in the leaves of a C_3 plant has a $\delta^{13}C$ value of between -22 to -34‰ (parts per mil)(Sealy 2001).

C_4 plants, often referred to as Hatch-Slack plants, produce molecules with four carbon atoms (oxaloacetate). C_4 plants have adapted to hot and arid climates

making use of different pathways to increase the rate of glucose production and reduce water loss due to air exposure (Papathanasiou 2003). This leads to C_4 plants being more discriminating towards the ^{13}C of the CO_2 than C_3 plants. As a results C_4 plants have $\delta^{13}C$ values closer to that of the atmosphere than C_3 plants. The general $\delta^{13}C$ of C_4 plants ranges between -10‰ and -4‰ (Smith & Epstein 1971). Examples of C_4 plants include maize, millet, sorghum, sugar cane, tropical grasses, some chenopods, and some amaranths (Papathanasiou 2003). While C_4 plants did not feature prominently in most Late Antique diets, millet and sorghum were present, as they were easy to grow in areas of poor fertility and could be stored longer than wheat (Spurr 1983).

Marine plants are also C_3 plants, but they differ from terrestrial plants in that they get their carbon from dissolved oceanic bicarbonates (0‰) rather than the CO_2 atmosphere (-7‰) (Fry & Sherr 1989). The carbon ratios in marine plants can vary

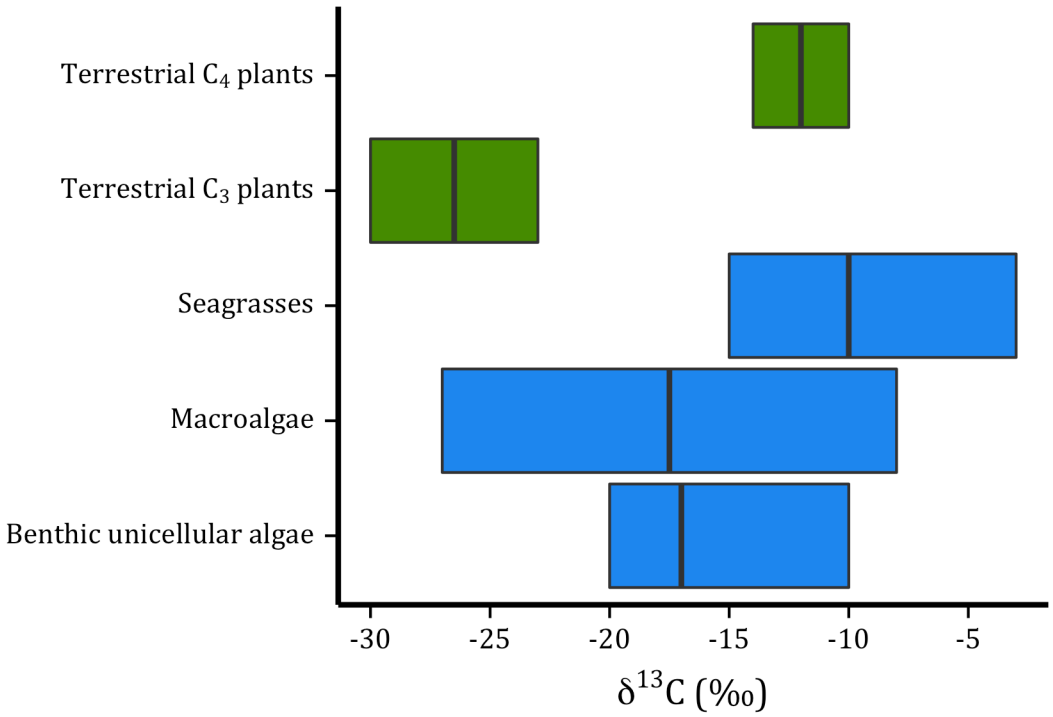


Figure 3.1: Theoretical plot with the range of $\delta^{13}C$ values from different plant sources as well as the average used in mixing models (data taken from Fry & Sherr 1989, Table 12.1)

greatly, but generally lie between that of terrestrial C_3 and C_4 plants. As can be seen in Figure 3.1, C_3 plants have more negative $\delta^{13}C$ values than C_4 plants while marine plants and lower level fauna, are situated in between.

3.2.2 Trophic Level

The unidirectional shift in isotope ratios between food consumed and the consumer is referred to the "trophic level effect" (Schoeninger 1985). A multitude of studies have been conducted to ascertain the difference in $\delta^{13}C$ between different animal tissues and their diet (DeNiro & Epstein 1978, Bender *et al.* 1981, Tieszen *et al.* 1983, Schoeninger & DeNiro 1984, Schoeninger 1985, Lee-Thorp *et al.* 1989, Bocherens *et al.* 1994a, Fizet *et al.* 1995, to name a few). It becomes more complex when variation among different tissues of the same animal is taken into account. For example, Hübner (1985) reported as large as an 8‰ difference between hair and subcutaneous fat, as well as differences between other tissues such as brain tissue, collagen, pancreas, and milk. This suggests that the part of the animal that is consumed may lead to different $\delta^{13}C$ values being passed up the food chain. With studies varying so widely, this thesis used the range from Bocherens and Drucker (2003), of 0-2‰ between the $\delta^{13}C$ of a consumer and its diet. Keeping in mind that the $\delta^{13}C$ of a consumer is more a reflection of the type of plant at the bottom of the food chain, than it is of the consumers level on said food chain (see Table 3.1).

Table 3.1: Mean consumer $\delta^{13}C$ based on diet (Chisholm 1989)

Diet	Mean consumer $\delta^{13}C$
C_3 plants only	-21.5‰
C_3 herbivore meat	-20.5‰
C_4 plants only	-7.5‰
C_4 herbivore meat	-6.5‰
Marine plankton only	-14.5‰
Marine herbivores meat	-13.5‰
Marine carnivores meat	-12.5‰

3.2.3 Variations in Carbon Isotope Values

Variability in $\delta^{13}C$ values is more easily discussed when divided into factors that influence the plants at the base of the food web, and those that influence consumers (faunal and human) of said plants. As previously stated, this study was mainly concerned with C_3 plants, so the influences affecting the carbon isotope values of plants discussed below are mainly in reference to C_3 plants.

3.2.3.1 Variation in C_3 Plants

Some of the most influential factors affecting the $\delta^{13}C$ values of C_3 plants are those associated photosynthesis: light, nutrients, water availability, and climate (Farquhar *et al.* 1989, Tiesszen 1991, O'Leary 1995, Heaton 1999). As one of the main elements in photosynthesis, light and the amount of it, have a large effect on the $\delta^{13}C$ of a plant. An increase in the amount of light leads to an increase in $\delta^{13}C$ values. Studies conducted by O'Leary (1995), and Yakir and Israeli (1995) found that if light intensity was doubled, wheat and banana leaves would have around a 1‰ increase in the $\delta^{13}C$ of their leaves (O'Leary 1995, Yakir & Israeli 1995). On the other hand, the effect of a lack of light leads to the depletion of ^{13}C in forested areas. This effect has been extensively studied, and is referred to as the 'canopy effect' (van der Merwe & Medina 1991). The exact reasons behind this occurrence are not completely understood, so while light intensity may be the apparent cause, lower $\delta^{13}C$ values could also be influenced by the greater recycling of CO_2 of the detritus found on the forest floor (France 1996).

This variation is not only found between ecosystems (forested versus open), but also within the forested ecosystem. Plants lower to the ground have been found to be more depleted in ^{13}C than those found closer to the canopy (van der Merwe &

Medina 1989). Again, whether this is due to the comparative lack of light at the forest floor, or to the increase in CO_2 recycling near the forest floor, or a combination of both, has yet to be definitively determined.

Also of interest, is that depleted $\delta^{13}C$ values can also be found in vegetation surrounding forests (up to 100 meters measured in van der Merwe & Medina 1989; 1092). In temperate forests, this translates to approximately 1-2‰ depletion for all leaves, an additional 2.5‰ depletion for vegetation found at the forest floor (van der Merwe & Medina 1989), and a depletion of ~5‰ from grasses grown in a forest versus those grown in the open (Bonafini *et al.* 2013). There is a gradient effect for the $\delta^{13}C$ values in between.

This variation in plant $\delta^{13}C$ values is assumed to be passed up the food chain. A study on modern monkeys in Brazil and Costa Rica found that the $\delta^{13}C$ values from the hair of closed-forest species was significantly lower than those of the open-forest (Schoeninger *et al.* 1997). The 'canopy effect' has been employed in many archaeological studies as the explanation for the depleted $\delta^{13}C$ values in some faunal remains (Bocherens *et al.* 1995, Fizet *et al.* 1995, Rodière *et al.* 1996, Cerling & Harris 1999, Bocherens *et al.* 1999;, Iacumin *et al.* 2000, Stewart & Lister 2001, Krigbaum 2003, Drucker *et al.* 2008). Though, the 2013 study conducted by Bonafini *et al*. suggests that there is a more complex pattern, as animal feeding behaviors are not as cut and dried as only consuming materials grown in a forest or not (Bonafini *et al.* 2013).

Soil nutrition is another factor that influences photosynthesis and has also been found to affect the $\delta^{13}C$ values in plants. The nitrogen content of the soil a plant is in has been shown to positively correlate to $\delta^{13}C$ values in that plant (Hill *et al.* 1996, Sparks & Ehleringer 1997). Soils with a higher nitrogen content, such as those

rich with organic matter, result in an increase in plant $\delta^{13}C$ values. Another element of soil nutrition that affects plant $\delta^{13}C$ values is salinity. For plants that are not salt-tolerant, or glycophytic (as the majority of plants are), an increase in the salinity in the soil commonly leads to an rise in $\delta^{13}C$ values (Guy *et al.* 1986, Farquhar *et al.* 1989, Alpha *et al.* 1996, Poss *et al.* 2000).

The $\delta^{13}C$ values of a plant are influenced by the amount of water available to it. Water availability has been shown to negatively correlate to plant $\delta^{13}C$ values (O'Leary 1995, Scheleser 1995, Stewart *et al.* 1995). Water availability is subject to multiple factors. Humidity, for instance, has a marked effect on plant $\delta^{13}C$ values. Drier air leads to plants trying to minimize water loss by closing their stomata. This leads to a reduction of CO_2 intake, which in turn results in increased $\delta^{13}C$ values (Francey & Farquhar 1982, Tieszen 1991). There is only a certain amount that this can fluctuate before the affected plant species is replaced by a different species that is more suited to the area. It has been suggested that the process of more tolerant species replacing less tolerant species leads to a reduction in the overall range of $\delta^{13}C$ values for a given area (Schulze *et al.* 1996, 1998). It is also important to keep in mind that there are other factors that can affect water availability for plants, such as rooting depth, the movement of water within the plant (Waring & Silvester 1994, Panek & Warring 1995), the physical soil structure (which affects drainage), and even the evaporation rate of water from the leaf surface (Heaton 1999).

This is all without considering human interference such as farming practices like irrigation. When crops are irrigated, it can lead to lower $\delta^{13}C$ values which would then pass up the food chain (Araus *et al.* 1997). Rotating crops to improve the nutrients in the soil is another manner in which agricultural practices can affect isotope levels in plants.

An additional environmental component that affects $\delta^{13}C$ variation is climate (temperature and humidity). van Klinken *et al*. 2002 outlined the effect that climate has on the photosynthetic process of plants.

> *"This influence acts in two ways: i) on the diffusion of gases into and from the plant leaves through the stomata; ii) on the biochemical (enzymatic) step, the actual fixation of carbon, which is affected by temperature and partial pressure of the CO_2" (van Klinken et al. 2002, 42)*

There are many tabulated studies in which temperature has been found to have a positive correlation with a plant's, specifically trees, $\delta^{13}C$ values (Stuiver & Braziunas 1987, Lipp *et al.* 1991, van Klinken *et al*. 1994, 2002, Switsur *et al.* 1994, Hemming *et al.* 1998). Temperature is a difficult variable to observe in action, as it is often associated with other climatological factors. However, it is one of the more commonly measured climatological variables, and can be used as an overall indicator of climatological variation.

Altitude has been found to have a positive correlation on the $\delta^{13}C$ values of plants by a number of studies (Friend *et al.* 1989, Vitousek *et al.* 1990, Körner *et al.* 1991, Marshall & Zhang 1993, Sparks & Ehleringer 1997).

The continental biosphere influences the difference between continental air and marine air (Keeling *et al.* 1989, 1980), and to add complexity, these differences can vary with latitude and season (van Klinken *et al.* 2002).

The enrichment of $\delta^{13}C$ values latitudinally across Europe has been found to be between 2-4‰ due to the accompanying climactic shifts from North to South (van Klinken *et al.* 2002). With this in mind, van Klinken *et al.* created a formula to compensate for climate in an attempt to better compare $\delta^{13}C$ across Europe (van

Klinken *et al*. 1994). The formula and its effect on inter-site comparisons will be discussed more fully in Chapter 7.

3.2.3.2 Temporal

While temporal variations are slightly more far reaching than this study (pre-holocene compared to modern samples), the effect that fossil fuel usage has had on atmospheric CO_2 needs to be noted, as the steady decrease in atmospheric ratio of ^{13}C /^{12}C means that 1.5‰ needs to be added to modern $\delta^{13}C$ results to accurately compare them to pre-industrial samples (van Klinken *et al.* 2002).

3.3 Nitrogen

3.3.1 Basics

Similar to carbon, nitrogen has two stable isotopes ^{14}N and ^{15}N. Nitrogen bound as N_2 in the atmosphere and in ocean water, makes up over 99% of the nitrogen on the planet (Schoeninger & Moore 1992). Two processes are responsible for most of the nitrogen transferred through the biological realm. The first is bacterial N_2 fixation; in which N_2-fixing organisms (bacteria terrestrially and blue/ green algae aquatically) convert atmospheric nitrogen into soluble nitrates. This leads to $\delta^{15}N$ values close to atmospheric levels (approximately 0‰). The second process occurs when vascular plants obtain nitrates directly from the soil. Nitrates in the soil are a product of the decomposition of organic matter by bacteria in the soil, or atmospheric precipitation transferring nitrate and ammonia to the soil solution (Pate 1994). Overall, the $\delta^{15}N$ range for plants is generally between -2 to +6‰. Nitrogen-fixing plants (i.e., legumes) have a $\delta^{15}N$ closer to the lower end of that range, averaging around +1‰, while plants that obtain their nitrogen from the soil

have a $\delta^{15}N$ throughout the range, averaging around +3‰ (Delwiche *et al.* 1979, DeNiro & Hastorf 1985, Shearer & Kohl 1986, Pate 1994).

The nitrogen available in the marine environment is mostly present through bacterial denitrification with greater quantities of ^{15}N from dissolved N_2 (Schoeninger & Moore 1992). This means that in terms of $\delta^{15}N$, marine plants will generally have more positive values than their terrestrial counterparts (Wada 1980).

3.3.2 Trophic Level

The "trophic level effect" is the shift in isotope values between consumers and their food. This is never more evident than with nitrogen isotope values. As animals lack the ability to metabolized N_2, their nitrogen is obtained from the amino acids in the protein they consume (Schoeninger 1985). The effect occurs when amnio acids are metabolized. Amnio acids with ^{14}N have bonds that are more readily broken down than those containing ^{15}N. This results in greater frequency of amnio acids with ^{14}N being broken down and excreted. Consequently, ^{15}N is relatively more available for tissue synthesis (Schoeninger & Moore 1992) and ultimately translates to higher $\delta^{15}N$ values. Therefore, with each additional organism in the food chain, the more positive a $\delta^{15}N$ value, and the higher the trophic level of an individual (Sealy 2001).

In considering which increase between food and consumer to utilize in this study, many other studies were examined (Wada 1980, DeNiro & Epstein 1981, Schoeninger *et al.* 1983, Vogel *et al.* 1990, Hare *et al.* 1991, Schwarcz & Schoeninger 1991, Bocherens & Drucker 2003, O'Connell *et al.* 2012). This study used the increase of 3-5‰ between food and consumer, as it is the most commonly agreed upon value (DeNiro & Epstein 1981, Vogel *et al.* 1990, Hare *et al.* 1991, Bocherens & Drucker 2003).

With the increased $\delta^{15}N$ values of aquatic plants relative to terrestrial plants (of approximately 4‰), as well as the longer length of the marine food chain (i.e. more steps of ^{15}N enrichment), $\delta^{15}N$ values from marine ecosystems are substantially higher than those from terrestrial ecosystems. Interestingly, these two ranges do not overlap in most instances, which is important to consider when reconstructing diet.

3.3.3 Variations in Nitrogen Isotope Values

While there are many factors that can affect $\delta^{15}N$ levels in an ecosystem, this section will cover those most relevant to palaeodietary reconstruction in European populations. First, environmental factors will be addressed, then factors affected by human agency. Environmental factors that cause $\delta^{15}N$ levels to fluctuate are more the result of adaptations, which organisms use to better survive, than a direct effect of an environmental factor. For example, cool forested environments have lower $\delta^{15}N$ values than arid or saline enriched environments. The lower $\delta^{15}N$ values of these forests can be attributed to higher mineralization and N_2-fixing rates (Ambrose 1991). Organisms from more arid environments have more positive $\delta^{15}N$ values due to physiological adaptations for water-stress. A similar increase in $\delta^{15}N$ can be found in saline enriched or coastal environment (Ambrose 1991). As $\delta^{15}N$ in plants and some animals is affected by hot arid environments, it has been reported that higher $\delta^{15}N$ values are passed on to humans in some of these desert settings (Ambrose & DeNiro 1986a and 1986b, Heaton *et al*. 1986). It has also been found that increasing precipitation and decreasing temperature can lead to a decrease in soil and plant $\delta^{15}N$ (Amundson *et al.* 2013)

Human agencies that can affect $\delta^{15}N$ levels are mostly the result of farming and animal husbandry practices. Soils that have been enriched with organic material

(such as guano or manure) have increased $\delta^{15}N$, which can in turn be passed up the food chain (Fraser *et al.* 2013, Szpak 2014). While soils that have been leached of N_2 will have lower $\delta^{15}N$. This translates to fertilized crops have higher $\delta^{15}N$ values. Sometimes this occurs inadvertently when animals are kept in pens, and consume plants grown in those pens (Bogaard *et al.* 2007, Szpak 2014).

3.4 Palaeodietary Reconstruction

The dietary habits of past populations is a major focus of archaeological study, and, as such, there are many methods by which it has been examined. Some of the more common methods include faunal analysis, dental studies, pathology, osteological analysis, palaeoethnobotany, ethnographic analogy, and, in the case of historical populations, literary resources. While these are all good methods for general reconstruction, there are strengths and weaknesses to each. Conditions at some sites can lead to poor preservation of organic remains, which, in turn, leads to an inherent bias towards the more durable foodstuffs in the archaeological record. Dental studies can give evidence as to the physical aspects of diet and the amount of sugar present, but give very little information beyond that. Pathology is more apt at indicating dietary deficiencies or excess, and may only be present with long-term sufferers or those suffering at the time of death (Roberts & Manchester 2007). This means that pathology is more representative of dietary extremes rather than the norm. Stature can give information as to the nutritional quality of childhood diet, but not its composition. Predictive models, which look at certain characteristics of food sources such as density, mobility, and weight to estimate their importance, are based on a considerable number of assumptions which might not necessarily hold in every circumstance (Price 1989).

Given these standards for analyzing remains, isotopic analysis becomes an invaluable tool in reconstructing past diets. It provides a quantitative measure that can complement the qualitative methods employed in the field. Nevertheless, due to the limitations discussed above, isotopic analysis is best used in concert with qualitative techniques such as analysis of material remains and the use of literary sources.

3.4.1 Collagen

Analysis of stable isotopes in collagen extracted from bone and dentition is a commonly employed method for reconstructing past diets from human remains. It was first used in the late 1970s by Vogel and van der Merwe in their study of maize cultivation in America (Vogel & van der Merwe 1977), but it was not fully used as a tool for palaeodietary reconstruction until the early 1990s (Rutgers *et al.* 2009). The method of stable light isotope analysis is predicated on the assumption that the composition of an individual's tissues is a "direct and constant function" of their diet (Ambrose & Norr 1993). In essence, this concept is captured by the seemingly ever-present colloquialism 'you are what you eat'. However, what makes isotopic analysis so invaluable in dietary reconstruction is that it can offer insights into the individual as well as the population taken over time when multiple individuals from different time periods are considered. It is particularly useful in instances where dietary habits might otherwise remain archaeologically invisible or ambiguous.

3.4.1.1 Bone

Bone is composed of inorganic minerals, bound to an organic matrix. The protein collagen makes up more than 90% of the organic material with the remaining material being comprised of non-collagenous proteins, carbohydrates and

lipids (Schwarcz & Schoeninger 1991). The majority of collagen in bone is initially formed during adolescence, after which it is continuously remodeled or turned over over the course of an individual's life (Hedges 2004). The rate of bone collagen turnover is complex and difficult to define (Smith & Rennie 2007). Due to growth, children have much higher bone deposition and turnover rates than adults. As a result isotope values of adult bone collagen may be weighted in favor of earlier life stages (Hedges *et al.* 2007). The bone element and type of bone can also have an effect on turnover rates. Trabecular bone, for example rib, has a large number of blood vessels and thin bone structure, leading to a higher rate of remodeling (Sealy *et al.* 1995) when compared to the compact bone like that found in the femur, which Hedges *et al.* estimated as having a turnover rate of roughly 10 or more to 20 years (Hedges *et al.* 2007).

3.4.1.2 Teeth

Enamel, dentine, and cementum are the three tissues that make up a tooth. Enamel is mostly inorganic in its composition and covers the crown of the tooth. Enamel is not a living tissue; therefore, once it is formed it does not change in composition. This makes enamel useful for reconstructing diet and location at the time in childhood when the enamel was being formed. Dentine and cementum are just over a quarter organic in composition (Hillson 1996). The organic portion of dentine is mainly collagen, while the composition of cementum is similar to that of bone (Mays 2010). Dentine does not readily turnover and subsequently reflects the diet of the individuals at the time it was laid down (Hillson 2005). The growth rates of teeth are well understood, making it possible to be very precise as to the age when the enamel and dentine were laid down (Moorrees *et al.* 1963).

3.4.1.3 Preservation

Diagenisis is the alteration biological material after burial. It is affected by extrinsic variables, such as temperature, moisture, and soil pH, as well as the intrinsic variables of the material itself such as structure (chemical and molecular), porosity, density, and size (Lynman 1994). The preservation of collagen is important to paleaodietary research, as poor preservation can lead to variation in the isotopic values. Increased soil acidity and variable moisture conditions can cause considerable amounts of bone destruction and lead to the loss of biological information (Lee-Thorp 2002). Conversely, humid environments when ambient temperatures promote microbial growth, which can also lead to information loss (Urzi & Krumbein 1994). Microbial attack has also been shown to be influenced by the taphonomic process in recent studies (Nielsen-March *et al.* 2007, Smith *et al.* 2007). Articulated remains (or burials that occur before decomposition of the soft tissue) are more at risk than processed bone (e.g. faunal bones stripped of meat). These two extremes are demonstrative of the need for quantifiable levels of preservation to be determined before inferences can be made based on the chemical analysis of collagen. The most two most commonly used standards are the percent of collagen, 5% is best, but 1% is acceptable (Dobberstein *et al.* 2009, Van Klinken 1999); the ratio of C:N established by DeNiro in 1985. The acceptable range is between 2.9 and 3.6 (Deniro 1985).

3.4.1.4 Composition

The macronutrients from which collagen is formed are critical to the interpretation of of isotope values in paleaodietary reconstruction. Collagen $\delta^{15}N$ values are derived from dietary protein. Consequently, foods that are higher in protein (such as meat, fish or legumes, tend to be over-emphasized compared to

foods with little to no protein (such as cereals). The carbon in collagen, while mainly sourced from protein, can also be derived from carbohydrates and lipids. This is dependent on the overall amount of protein in an individual's diet (Ambrose & Norr 1993; Tiezen & Fagre 1993, Howland *et al.* 2003, Jim *et al.* 2004, Jim *et al.* 2006, Craig *et al*. 2013). Carbon sourced from protein (termed "direct routing") can differ drastically in $\delta^{13}C$ values from carbon taken from the whole diet (referred to as "scrambling"). This is especially relevant if the protein source is marine and the source of the carbohydrates is terrestrial (Craig *et al*. 2013). The quality of the overall diet, is the determining factor for the ratio of carbon in collagen which is a product of routing or scrambling.

3.4.2 Stable Carbon and Nitrogen Analysis

The use of stable carbon isotopes in palaeodietary reconstruction is focused on plant consumption, and the distinction of terrestrial versus marine diets. As previously mentioned, terrestrial C_3 plants and terrestrial C_4 plants have different $\delta^{13}C$ values, due to the manner in which they photosynthesize. As these isotopic differences are passed up the food chain, it becomes possible to determine the plants consumed both if an individual consumed the plant directly, or if they consumed an animal that ate that plant.

The primary focus of stable nitrogen isotope analysis in palaeodietary reconstruction is to determine trophic level; and it is mainly employed in differentiating marine versus terrestrial resource consumption. By using both carbon and nitrogen together, it is possible to determine the trophic level of an individual as well as the type of plants they consumed. Figure 3.2 depicts the typical manner in which carbon and nitrogen isotopes are graphed. This figure details theoretical values for the marine and terrestrial C_3 ecosystems, some of the animals

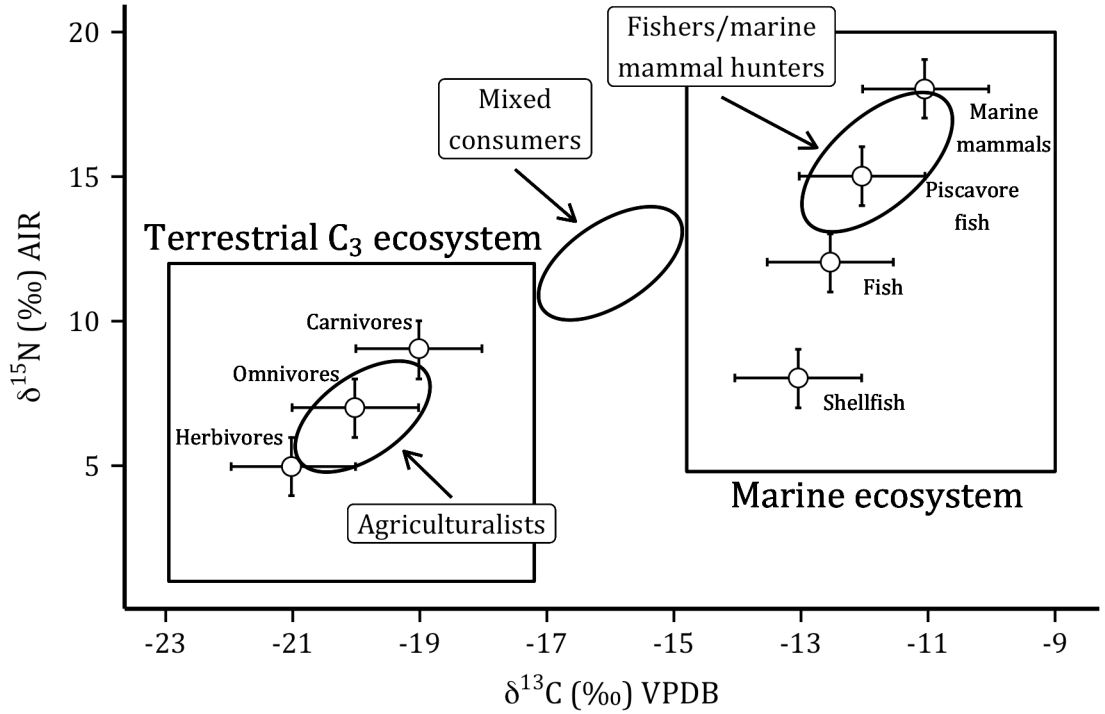


Figure 3.2: Theoretical $\delta^{13}C$ and $\delta^{15}N$ plot with terrestrial C_3 and marine ecosystems outlined. Points and error bars indicate the typical range for different animals, while ellipses indicated average $\delta^{13}C$ and $\delta^{15}N$ of collagen from diets based in both ecosystems and that of individuals with mixed sources of food (adapted from Müldner & Richards 2006; 229, Figure 16.1).

in each, and the predicted $\delta^{13}C$ and $\delta^{15}N$ values of those consuming resources solely from the terrestrial C_3 ecosystem (agriculturalists), exclusively from the marine ecosystem (fishermen), and individuals who consumed food from both (mixed consumers) .

For example, if a hypothetical individual consumed almost exclusively marine foods, their expected $\delta^{13}C$ and $\delta^{15}N$ values would place them in the upper right quadrant of the graph in Figure 3.2. In contrast, if this individual's diet was mainly terrestrial C_3 plants, their expected $\delta^{13}C$ and $\delta^{15}N$ values would find them plotted in the lower left portion of the graph in Figure 3.2 (Richards *et al.* 1998, Müldner & Richards 2006). Individuals with a mixture of marine and terrestrial resources would be expected to have isotope values between these two. It has been found that

historic populations with a mainly marine diet had collagen with $\delta^{15}N$ values ranging between 17‰ and 20‰, while agricultural populations had collagen with $\delta^{15}N$ values ranging from 6 to 12‰. For both historic and prehistoric societies, depending on whether they subsisted on C_3 or C_4 plants, populations were found to have more negative (C_3) or more positive (C_4) $\delta^{13}C$ values, respectively (Schoeninger *et al.* 1983).

Freshwater ecosystems provide another source of food, and identifying diets that include freshwater resources, is not as straight forward as the difference between terrestrial C_3 and C_4 plants or as between marine and terrestrial resources. The carbon and nitrogen isotopic values of freshwater ecosystems have been found to be rather heterogenous (Fry & Sherr 1989, Fry 1991, Hoefs & Hoefs 1997, Dufour *et al.* 1999). Carbon in freshwater environments can originate from both the atmosphere as well as from geological sources. This is important to note, as organic material with carbon derived from atmospheric CO_2 (with a $\delta^{13}C$ of -7‰) will have lower $\delta^{13}C$ values than organic material derived from geological sources, or dissolved inorganic carbon (with a $\delta^{13}C$ of 0‰)(Fry & Sherr 1989). The amount that each source contributes to the ecosystem is dependent on a number of variables. Size, turbidity, and amount of sunlight are just three variables affecting fluvial (Finlay & Kendall 2007) and lacustrine ecosystems (Dufour *et al.* 1999).

The variability in organic matter can affect $\delta^{15}N$ values as well. Also of importance is the larger size of aquatic food webs as compared to terrestrial food webs. A fish consuming detritus materials originating from the terrestrial ecosystem, will have a lower $\delta^{15}N$ than that of one consuming pelagic materials. Foodstuffs sourced from freshwater ecosystems will generally have a higher trophic level, as aquatic ecosystems have longer food chains. Van Klinken *et al.* 2002

suggested that while the $\delta^{15}N$ would be comparable to that of marine fish, $\delta^{13}C$ would be markedly more negative, though this is highly variable (van Klinken *et al.* 2002).

3.4.2.1 Human/Faunal Comparison

While there is a general understanding of what carbon and nitrogen isotope values mean in terms of palaeodietary reconstruction for European populations, analyses are always more accurate and precise when the local fauna is taken into account. Rather than compare a population to fauna from different sites or time periods, the faunal remains from where and when the individuals themselves lived give a more appropriate description. This happens by controlling for the effects of variables related to time period and geography including variables such as climate, variation in agricultural, or animal husbandry practices.

With the expanse of studies using carbon and nitrogen stable isotope analysis in reconstructing past diets comes the opportunity for inter-population comparison. It is common for studies to be published as single case studies, rather than as studies that analyze populations from a diverse array of geographical and temporal origins. As discussed above, plant carbon and nitrogen isotope values can vary significantly due to factors associated with time and space, such as climate, or shifts in agricultural practices (Heaton 1999, van Klinken *et al.* 2000, Hedges & Reynard 2004, Hamilton *et al.* 2009).

It has become common practice to include faunal samples in studies as a baseline in an attempt to identify if inter-population variation is actually due to dietary variation or instead due to extrinsic factors, such as climate (Jay & Richards 2007, Stevens *et al.* 2012). Herbivores that are commonly consumed as part of a typical diet (such as cattle and sheep/goats), are normally preferred as their diet is

assumed to be an accurate reflection of the local vegetation (Hedges *et al.* 2004, Jay & Richards 2007, Hedges & Reynard 2007, Müldner 2013).

There are studies in which the variations between human and herbivore isotope values were quantified. In one study (Müldner 2013), this was done by taking the difference between the average $\delta^{13}C$ or $\delta^{15}N$ values of the human samples and the contemporary faunal samples. Average isotope values for the herbivores were taken from no less than ten cattle and sheep/goat (which were averaged separately, then combined). The $\Delta_{\text{Human-Faunal}}$ has the advantage of normalizing not only for inter-laboratory variability (assuming both human and faunal samples were analyzed at the same laboratory), but also for counteracting any baseline variations that occur due to differences in environment or animal husbandry practices. Variance in $\Delta^{13}C$ and $\Delta^{15}N$ values found between populations is consequently a stronger indication of dietary differences than would be found by simply comparing the $\delta^{13}C$ and $\delta^{15}N$ values of the different populations directly.

Where this method lacks interpretive power is in the clarity with which variations between populations can be explained. The scale of $\Delta_{\text{Human-Faunal}}$ variation is inherently limited as it only allows comparing the differences, while establishing a baseline for location in attempting to control for variability outside of human diet. Diets are more complex than the difference between what an individual consumed and what the average herbivore value for their current location consumed. This issue will be addressed further in the coming chapters.

Palaeodietary studies employing carbon and nitrogen isotope analysis have been conducted on a wide range of populations from a variety of geographical areas and from multiple time periods. Studies pertaining to the period following the fall of the Roman Empire (c. 3rd century AD) in Europe have been mainly limited to single

populations, as well as being focused on a select few geographic regions (England, Italy, Germany, Denmark, etc.). Populations originating from Spain have only been the focus of a few previous studies (Alexander *et al.* 2015, Fuller *et al.* 2010, Mundee 2010, Nehlich *et al.* 2012, Sirignano 2014, López-Costas *et al.* 2016). Unfortunately, the majority of the data from these studies relates to historic populations rather than those from Late Antiquity.

In addition to palaeodietary reconstruction, isotopic studies of Late Antique populations have also had the aim of elucidating intra-population variability based on physical characteristics such as sex (Alt et al. 2014, Reitsema *et al.* 2010, Reitsema & Vercellotti 2012), age (Fuller et al. 2006, Fuller *et al.* 2010, Herrscher *et al.* 2001, Keenleyside *et al.* 2009, Prowse *et al.* 2005, 2007), disease (Scorrano *et al.* 2014), and social characteristics such as status (Keenleyside *et al.* 2009, Linderholm *et al.* 2008, Reitsema & Vercellotti 2012, Schutkowski *et al.* 1999) or occupation (Crowe *et al.* 2010).

Sex has been found both to be a determining factor in past diets (Alt *et al.* 2014, Hakenbeck *et al.* 2010, Reitsema *et al.* 2010, Reitsema & Vercellotti 2012) and also to have no apparent effect (Alexander *et al.* 2015, Bourbou & Richards 2007, Garcia *et al.* 2004, Keenleyside *et al.* 2009, McGlynn 2007). With studies that find a significant difference between the two sexes often finding that females diets are less enriched isotopically, indicating that they consumed less animal protein (Alt *et al.* 2004, Hakenbeck *et al.* 2010, Reitsema *et al.* 2010, Reitsema & Vercellotti 2012).

Studies where age has been found to be a dietary determinant were often examining the difference between childhood and adult diets, particularly when it comes to breastfeeding and weaning. Childhood and infant diets are commonly found to be higher in $\delta^{15}N$ when compared to adult diets (Fuller *et al.* 2010,

Keenleyside *et al.* 2009, Prowse *et al.* 2005) and this can most often be attributed to the effect that breastfeeding and weaning are known to have (Schurr 1998).

Another commonly studied aspect of stable carbon and nitrogen isotope ratios and how they pertain to diet is how common marine food consumption was within a population. The increased $\delta^{13}C$ and $\delta^{15}N$ values found in marine ecosystems are passed on to humans when consumed. In studies such as the one conducted by Garvie-Lok in 2001, it has been commonly found that coastal populations had higher $\delta^{13}C$ and $\delta^{15}N$ values than comparable inland populations (Bourbou & Richards 2007, Garvie-Lok 2001).

The present study aimed to use stable carbon and nitrogen isotope analysis to reconstruct the diet of human and faunal individuals from two different sites (Sanisera and Mérida), and to integrate the different approaches to understanding dietary variation similar to those described above. Furthermore, the analysis of these individuals were used in a larger comparison of multiple contemporary sites spanning continental Europe and Northern Africa. By understanding the manner in which carbon and nitrogen ratios were affected, inter-site comparisons can be used to further illuminate the manner in which past peoples subsisted and how that might have varied geographically and chronologically.

Chapter 4: Site Backgrounds

4.1 Sanisera

4.1.1 The City

The Balearic islands are an archipelago in the Mediterranean Sea located off the Eastern coast of the Iberian Peninsula. Menorca, the second largest of the Balearic Islands, is located just over 200 kilometers off the eastern coast of Spain (see Figure 4.1). Greek and Roman writers divided the archipelago into two groups, the *Baliares* consisting of Mallorca and Menorca, and the *Pityussa* made up of Ibiza and Formenterra (Blanes *et al.* 1990, Zucca 1998, Riaza & León 2000, Guerrero 2004). During the Iron Age, the *Baliares* hosted to the Talyotic culture, famous for the cyclopean constructions and slingers (Cau 2012). In Antiquity, it was one of the islands along the North-West Mediterranean coast that formed part of the trade

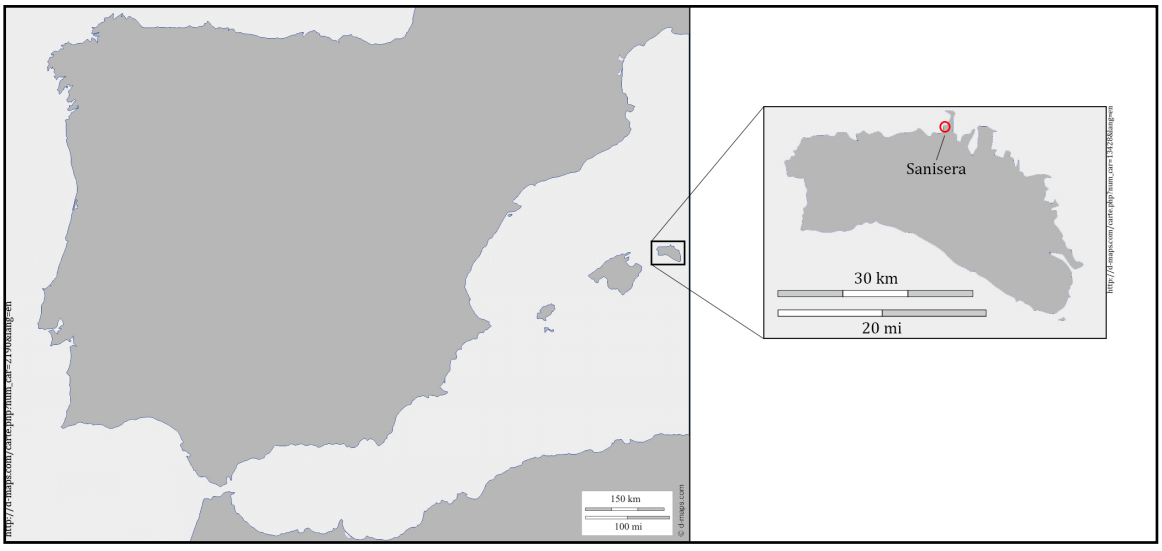


Figure 4.1: Map of Spain indicating the location of Menorca and the site of Sanisera.

routes, not only between Spain and Italy, but also between Spain and North Africa. In 123 BC Roman forces conquered the *Baliares* under Q.C. Metellus (Hurst *et al.* 2011,

Cau 2012). The strategic conquest of the island was pivotal in providing safe passage for ships, in suppressing the rampant piracy in the Mediterranean, and for expanding the Roman agricultural economy. The islands along the southern coast of Europe were used mainly as 'way stations': places to find refuge in a bad storm, or to repair boats, as well as places for trading opportunities (Rauh 2003). A sea route was necessary between *Hispania* and Italy due to the hostilities with the Gauls and several Germanic tribes, making land trade unstable. The only other option was a sea route, even though the Mediterranean Sea was also dangerous due to pirates. The route between Italy and Spain required ships to sail along the coast on the way to Spain and then return by following an island hopping route from the Balearic Islands to Sardinia and Sicily back to Italy. Travel from Italy to ports along the North African coast followed a similar pattern of easy and direct travel assisted by the winds and currents; the return trip being rather more circuitous with ships hopping from port to port (Rauh 2003).

The island of Menorca had three main urban centres during the Roman Period, *Mago*, *Iamo* and *Sanisera*. *Mago* and *Iamo* were referred to as *castella* by Mela (Chorographia II.124), as *póleis* by Ptolomy (*Geografia* II 6, 73). Pliny (Nat.Hist. III, 78) describes all three urban centres (including *Sanisera)* as *civitates* (Riaza & León 2000, Orifla & Riera 2004, Cau 2012). The island itself was initially part of the province of *Hispania Citerior*; then part of *Tarraconensis* after the reforms of Augustus. Finally, in the later part of the fourth century AD the Balearic Islands became an independent province *Baleares Insulae* (O'Callaghan 1975, Amengual 1991-92, Riaza & León 2000). The letters of Consentius, from the early fifth century AD mention how well connected Menorca was with Mallorca, the Iberian Peninsula, Gaul and Africa (Amengual 1991-92). The fifth century AD also saw the Vandals

raiding (425 AD) and subsequently conquering (455 AD) the island (Cau 2012). Less than a century later, in 534 AD, Justinian's troops conquered the island, incorporating it into the Byzantine Empire. The island was technically under Byzantine rule until the Muslim conquest at the start of the 10th century AD. However, in 625 AD the Byzantines were forced out of Southern Spain leaving the Balearic Islands in a marginal position (O'Callaghan 1975, Buxeda i Garrigós *et al.* 2005).

The site of Sanisera can be found at the northern most tip of Menorca, near the modern town of Es Mercedal. The Roman city of Sanisera was located on the bay of Cap de Cavellera, and built on limestone bedrock. It is not very well known historically, and unlike the other two Roman cities on Menorca, Mago and Iamo, Sanisera is rarely mentioned in Roman texts, it is noted briefly by Pliny the Elder in his "Naturalis Historia" (III; 77-78). The location of Sanisera remains a mystery until the late 18th century when it was hypothesized that it was located at the Port of Sanitja due to the similarities in their names (Ramis i Ramis 1989, Ramis y Ramis 1819, Oleo y Quadrado 1876, Ponce 2017,). This theory persisted until the 1970's (García y Bellido 1947, Muñoz 1974), when the first data-based evidence of material culture was published (Nicolas 1985). The study found a wide variety and quantity of ceramic materials as well as the remains of cyclopean walls, foundations of Roman buildings and evidence of a necropolis. It was concluded that, based on the ceramic evidence, the site dated from at least the second century BC through to the 4th century AD (Nicolas 1985).

The first excavation of the site began in 1979 and continued until 1984 (Rita *et al.* 1988). The excavation found the foundation of a building, referred to as Building C, and 21 inhumations. The earliest Roman structures on the site are part of

the fort of Sanitja, constructed during the initial military occupation in 123 BC. Though the fort at Sanisera was only occupied for 70 years (abandoned in 45 BC) (Contreras *et al.* 2006). The city that rose out of its *cannabae*[1] was continuously inhabited through the 6th century AD (Hurst *et al.* 2011).

During the initial field survey of the site it was found that the majority (57.5%) of finds were African in origin, and were mainly coarse cookware (Contreras 1997). This is congruent with the overall prevalence of African coarse ware in the Balearic Islands in the 5th and 6th centuries (Buxeda i Garrigós *et al.* 2005). While the dominance of coarse ware on the site could be due to preservation bias, the fact remains that it was present in substantial quantity. This raises the question of the relation between Menorca and North Africa, and whether incomers were more likely to be from mainland Spain, due to its proximity, or from North Africa, as the ceramic finds suggest.

4.1.2 Necropolis 6

Sanisera is encircled by seven necropoles. This study focuses on Necropolis 6, which is located northwest of the city (Figure 4.2) and is estimated to date from between the 5th and 6th centuries AD (Hurst *et al.* 2011). The tombs are aligned in neat rows generally running North to South, with the tombs themselves being oriented East-West. The majority of the tombs are rectangular cists, cut into the bedrock and lined with locally sourced stone (limestone, slate or sandstone) or re-used, rudimentary building materials (Hurst *et al.* 2011). There was evidence that the tombs once had capstones, though the majority of them have since been removed, possibly as materials to build the nearby 18th century wall. Most tombs

[1] "Settlements often grew up for the purposes of supplying goods and services to the legions" (Adkins and Adkins 1994; 143)

are oriented on an East-West axis with individuals lying in a supine-extended position, indicating a Christian burial rite (Hurst *et al.* 2011). There were a few exceptions to the standard burials; there was one pit tomb, one amphora burial, and five tombs oriented along a more North-South axis (though these were part of a separate section of the site and are discussed further below).



Figure 4.2: Location of Sanisera and Necropolis on the Cap de Cavellaria.

To date, forty-four tombs have been excavated, yielding remains of a minimum of 240 individuals. Each tomb contained multiple inhumations, ranging from two to sixteen individuals per tomb (see Figure 4.3) The majority of individuals were disarticulated and co-mingled, with only the most recent inhumation in each tomb being fully articulated, or in the normal anatomical order (Sprague 2005). This suggests that there was repeated use of each tomb over an extended period, with older remains being moved aside to make room for each new individual, as opposed to multiple individuals being buried at once. Though grave goods were relatively scarce (due to looting, both during Late Antiquity and in modern times), the most common goods were hairpins, bracelets, rings, pendants, earrings and paste beads (Hurst *et al.* 2011). Every tomb had a relatively equal proportion of the sexes and ages, which combined with the use of the tombs over long time periods could be



Figure 4.3: Tomb 13 of Sanisera Necropolis 6 (photo taken by author).

indicative of family tombs, though DNA tests would be needed to confirm this hypothesis as none of the tombs had grave markers.

Tombs in Necropolis 6 were grouped into three distinct areas, referred to as Zones 1, 2, and 3 (Figure 4.4). Zone 1 sits at the most northern most point of the necropolis and consists of 12 tombs. Of the three zones, Zone 2 is the largest, with the most uniform alignment. It consists of 27 tombs, including one unfinished tomb and three smaller tombs that contained almost exclusively infants. Zone 3 stands out as having five tombs oriented North-South as well as being at a slightly higher elevation. The separation of this group and the

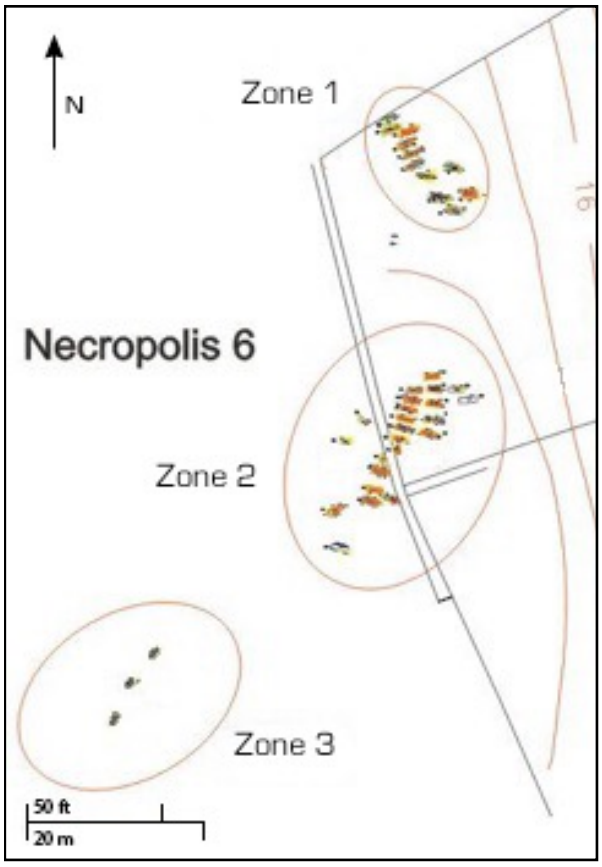


Figure 4.4: Map of Necropolis 6 (adapted from Hurst *et al.* 2011, Figure 3).

different orientation sets the individuals inhumed here apart. While there could be many reasons for the distinction (religion, time period, etc.), it is also possible that they are incomers to the city.

While the final osteological report has yet to be published, the initial findings from (Hurst *et al.* 2011) paint a picture of a lower class rural population. Children under twelve made up 34.3% of the total population, which fits well with comparable populations of the time period, normally between 30-50% (Brothwell 1987, Angel 1969, Bennike *et al.* 2005). The mortality rate was similar for both males and females, though the small percentage of older adults in the populations (5%) indicates that overall life expectancy was relatively low (Hurst *et al.* 2011). The three most common pathologies were dental calculus, joint disease, and non-specific infection (Hurst *et al.* 2011). What is of note is the relatively low instances of dental caries, present in less than 2% of the population. With higher instances of caries being linked to higher consumption of carbohydrates, this would suggest lower amounts of grain consumption as compared to a typical Roman population, which had a rate of caries closer to 6-7% (Roberts and Manchester 2007). This will be explored later in Chapter 6. Overall, the population from Sanisera's Necropolis 6 present an opportunity to further the understanding of the rural lower class, during the tumultuous 5th and 6th centuries AD, a group that is commonly overlooked historically.

4.2 Mérida

4.2.1 The City

Mérida, or *Emerita Augusta*, as it was called in the Roman period, was located in the west of central Spain (see Figure 4.5) and was the capital of the Roman province of Lusitania, as well as the capital of the Diocese of Spain. As such, it was one of the most important cities in Spain during Late Antiquity. It was founded by Augustus in 25 BC, for his soldiers after the conquest of Galicia to the West (Curchin 2014). The city was under Roman rule until the start of the 5th century, which saw *Emerita Augustus* come under the control of the Vandals in AD 411, then the Sueves in AD 439, and finally the Visigoths in AD 456. The city remained in the control of the Visigoths until AD 713, when it then came under Islamic rule (Kulikowski 2010).



Figure 4.5: Map of the Iberian Peninsula with the city of Mérida indicated, (adapted from d-maps.com, map of Spain).

Mérida was an important city for many reasons, not the least of which was its location. By modern standards, the city is hardly at the centre of the Iberian Peninsula; however, if the diocese of northern Africa is taken into account, Mérida sits at the very centre of the Late Roman territories in the West. The capitol city was situated along the main road that connected the northern capitals with the city of Seville and the port of Iulia Traducta. It was also at the start of the only road to diagonally traverse the peninsula ending in Zaragoza (Kulikowski 2010).

Further evidence as to the importance of Mérida to trade was the relative abundance of African coarse ware as compared to other inland cities. Additional evidence of North African influences is seen in architecture and a number of funerary epitaphs with North African names. It has been argued that the North African influence found in Spain was attributed to ties in trade and not to the presence of individuals of North African origin (Arce 2005). Further arguing that non-African traders transported African goods and influences to the region, but there is little evidence of African people residing in the area.

The city is of great importance archaeologically and historically and the "Archaeological Ensemble of Mérida" has been classified as a UNESCO world heritage site since 1993 (http://whc.unesco.org/en/list/664/). Much of the monumental architecture from the Roman period such as the theatre, the amphitheater, the circus, the Puente Romano (or Roman Bridge) spanning the Guadiana River, and the Temple of Diana still stand today. On average, "Roman Spain" sits just two meters below the current occupation level (Menéndez-Pidal 1988).

4.2.2 The Necropoles

As a major city, Mérida has many necropoles. This study includes five sites from the southeastern portion of Mérida, just beyond the Roman city wall (Figure

4.6). The sites were chosen to be included in this study based on their date, Late Antique (5th - 9th centuries AD) and burial style (cist tombs with minimal grave goods), with the aim of having the population from Mérida be as similar as possible to the population from Sanisera's Necropolis 6. This was done with the goal of eliminating social status as a variable when comparing the two populations.

The sites are Nova Romana (site no. 1021), Nova Romana III (site no. 7017), Nuevo Mérida (site no.7034), Velada (site no. 8060) and Y.A.C (site no. 83925)[2]. All sites were excavated as part of rescue excavations conducted by the Consortia de la

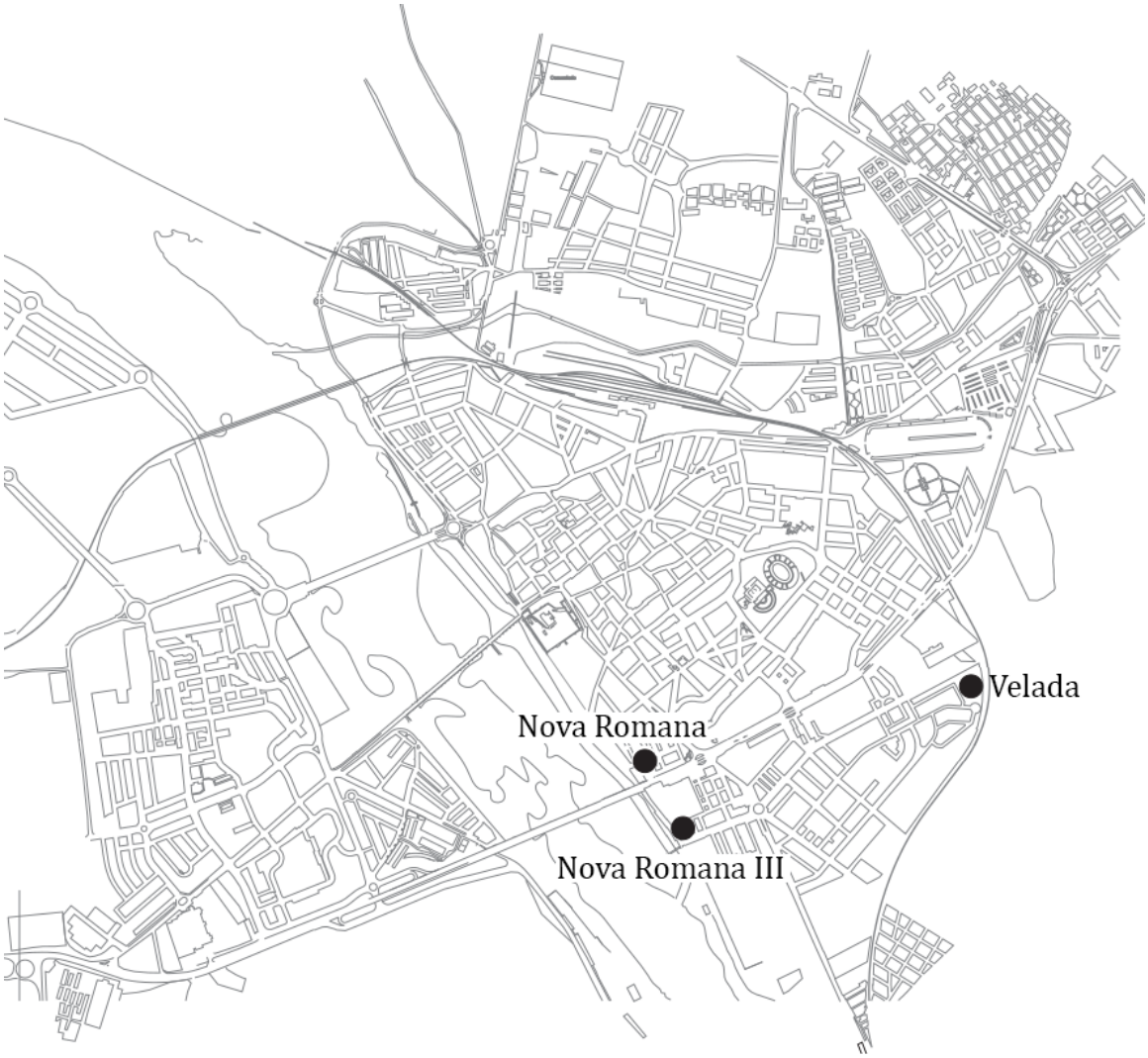


Figure 4.6: Map of Mérida with the three published sites of Nova Romana (1021), Nova Romana III (7017) and Velada (8060) indicated, (adapted from Alba Calzado 2005, Delgado 2003, and Barrientos Vera 2004).

[2] Site numbers are designated by the Consortio de la Ciudad Monumental de Mérida.

Ciudad Monumental de Mérida. While site reports for Y.A.C. and Nuevo Mérida have yet to be published they are similar to the other three sites described below, both in composition, location and date.

4.2.2.1 Site 1021 - Nova Romana

Site 1021, here in after referred to as, Nova Romana (1021) sits on the western side of the hill of San Albín sloping down to the Río Guadiana, just south of the Roman city wall. A plot of 146.8 meters squared was excavated between September 2002 and March 2003. The site report and inventory can be found in the 2004 edition of the *Mérida Excavaciones Arqueológicas* (Barrientos Vera 2004).

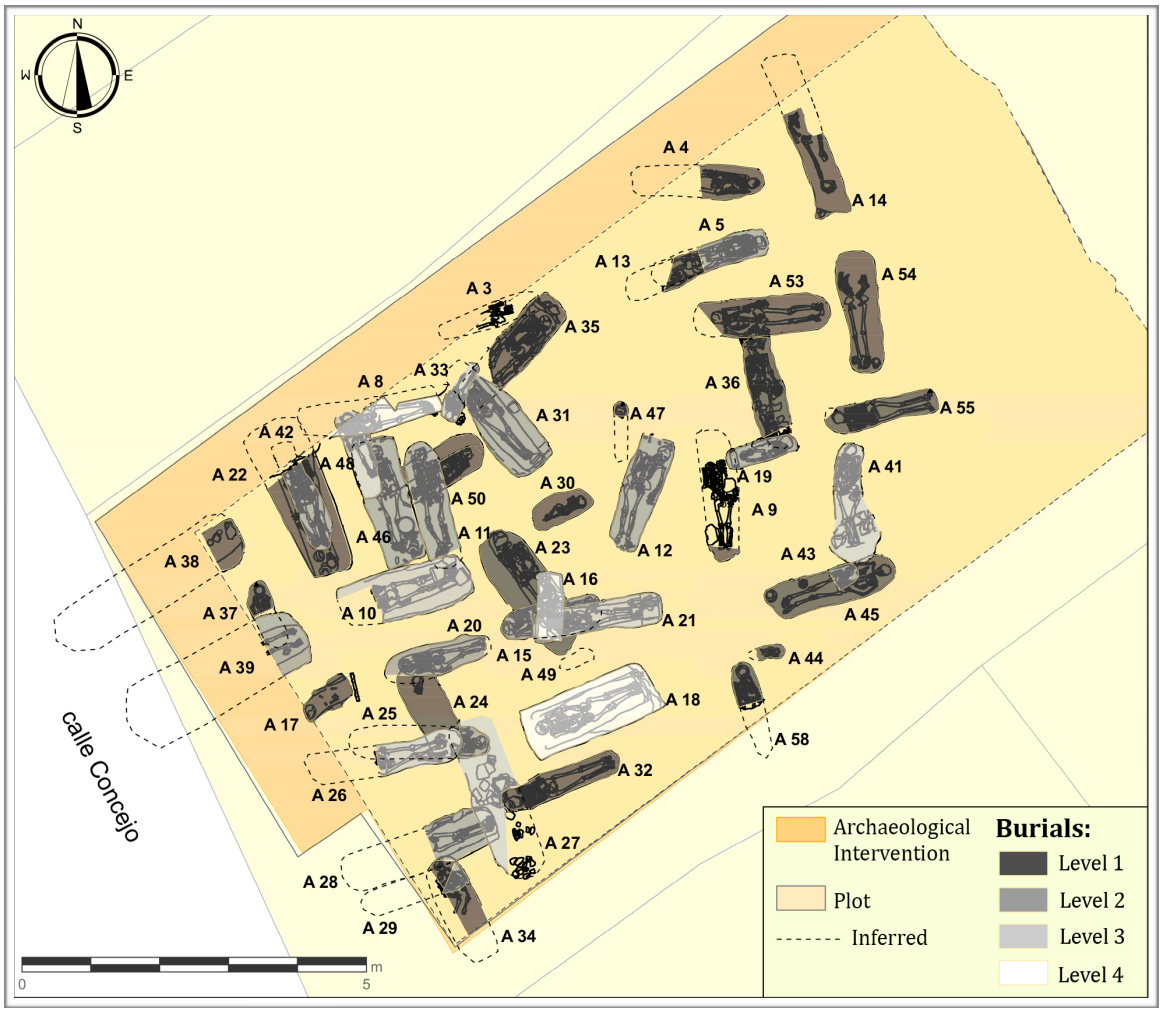


Figure 4.7: Plot of the Roman tombs of Nova Romana (1021) (adapted from Barrientos Vera 2004; 378).

Initially, the area was the site of a 1st century AD *figlina*, or potters workshop, then became a landfill during the 2nd century AD. From the 3rd through the 4th centuries AD, the site was used as a funerary space consisting of 48 tombs. As can be seen in Figure 4.7 there is no discernible pattern to the placement of the graves, though they are relatively uniform in structure (discussed more below). The 5th century AD saw the site abandoned again until the Islamic Period (around the 8th to 9th centuries AD), when it was again used as a funerary space for a final five graves.

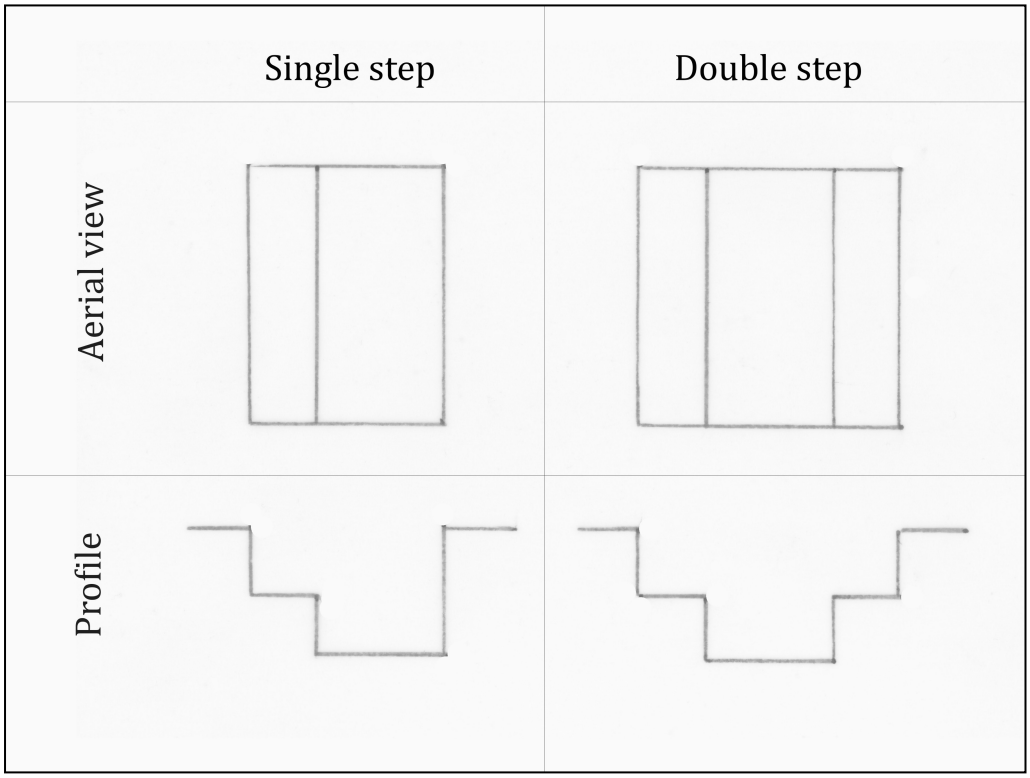


Figure 4.8: Aerial view and profile of the two types of tombs found at Nova Romana (illustration by author).

The Late Roman tombs are generally simple rectangular pits, sized to fit the individual being interred and on average one meter deep. Of the original 48 graves, most were pits, cut straight down, but eight of them have a step halfway up one of the longer sides and five have a similar step on both of the longer sides (see Figure

4.8). Three of the graves have been lined, two with small brick fragments and one with *tegulae*. Some tombs had coverings of brick or *tegulae,* but none of them had any form of identifying markers, which might be why they were arranged so haphazardly (Barrientos 2004).

Twelve graves have what was referred to as "caches" associated with the skeletal remains. These caches consisted mainly of ceramics and glass, and were at the same height as the remains, sometimes even in contact with them. The grave goods were dated to between the 3rd and 4th centuries AD. Eight graves had grave goods that can be defined as personal adornment (rings, bronze bracelets, a glass paste necklace and the remains of sandals). Iron nails were also found in seven graves, indicating the presence of coffins or stretchers. There is also evidence of a shroud found in one grave.

There were five sets of remains buried on top of previously interred remains. The initial burials were not otherwise disturbed, so it has been suggested that there is a certain "chronological proximity" with these burials and that the initial burial might not even have decomposed at the time of the second inhumation (Barrientos 2004).

Of the 53 individuals buried at the site, 19 were subadults. All individuals were found in the supine position with their legs extended. The only variation in burial position at this site was found in the placement of the arms.

4.2.2.2 Site 7017 - Nova Romana III

Site 7017, referred to as Nova Romana III, was excavated from late 2002 to early 2003; the site report and inventory can be found in the 2005 edition of the *Mérida Excavaciones Arqueológicas*. It is in the southern portion of the city, near the

Río Guadiana and outside the Roman city walls (by about 420 meters) at the intersection of Calla de Albuhera and Agenda de Lusitania (see Figure 4.9). It

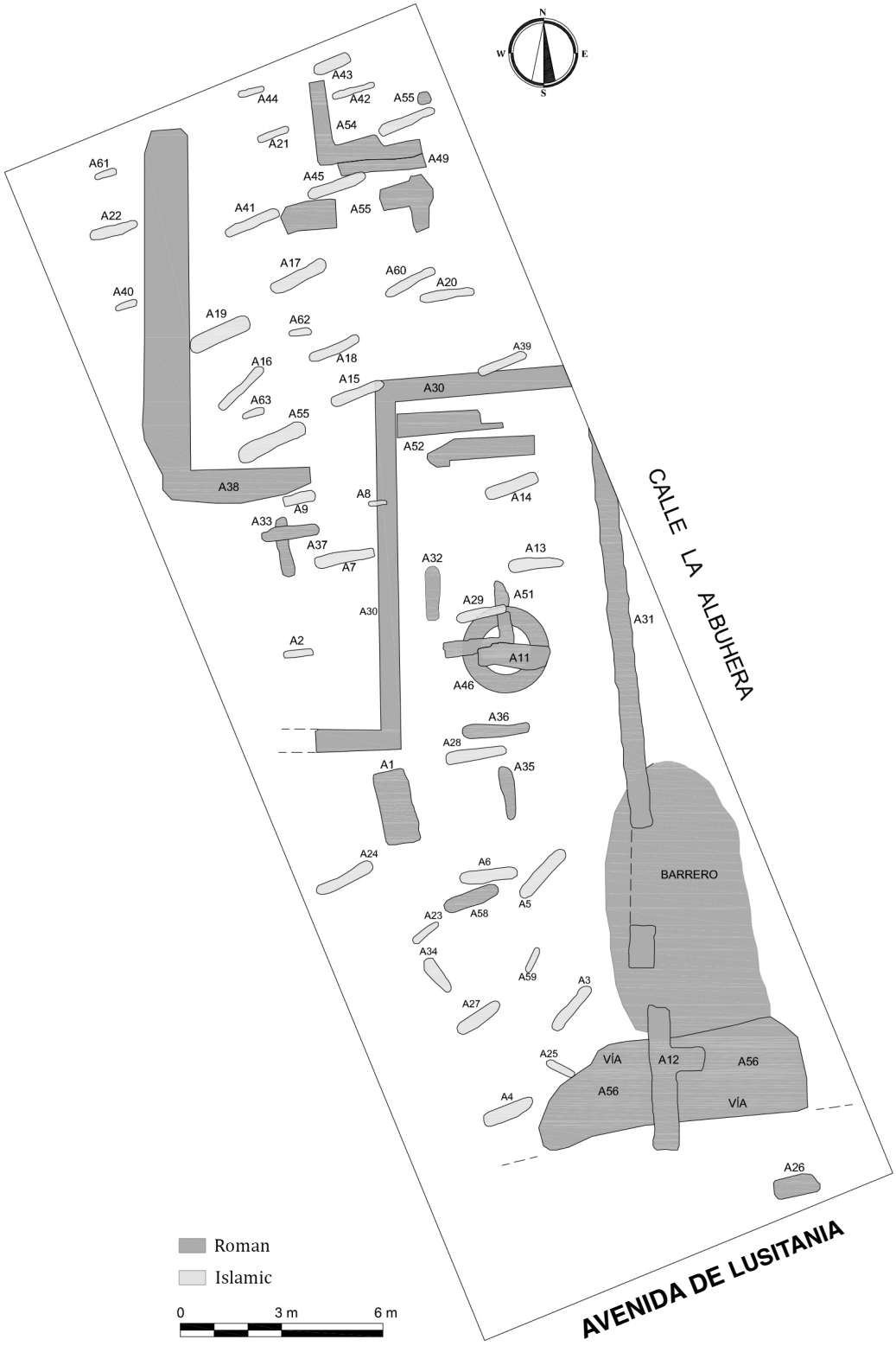


Figure 4.9: Plan of Nova Romana III (7017) (adapted from Alba Calzado 2005; 313).

occupies roughly 530 square meters and was in use from the 1st century AD through to the 9th century AD. During the 1st and 2nd centuries AD the land was part of an industrial complex known for its pottery production (Alba *et al*. 1994, Sanchez and Sanchez 1996 a and b). At the start of the 3rd century the land began to be used as a funerary site. Three burials sites have been discovered, consisting of eleven Roman graves and a possible mausoleum. Two of the eleven burials were cremation burials. While the graves all have the same orientation there is no clear plan. One of the more common grave goods was a lantern of Spanish production (Figure 4.10). Additionally, three of the eleven burials had coins associated with them. Coins found



Figure 4.10: Roman lanterns with the depictions of the deities Isis, Ceres Hercules and Prosperina (taken from Alba Calzado 2002, Figure 20).

with the dead during this period are referred to as "Charon's obols" (Morris 1992). The coins help to date the burials to the 3rd century. The grave goods were modest in nature and suggest a more humble social status of the individuals.

The site also contained 39 burials dating to the Islamic Period (8th and 9th centuries AD). The Islamic Period graves can be differentiated from the earlier Roman Period graves based on four factors: the greater depth of the burials (see Figure 4.11), the orientation (Southeast or South), the positioning of the remains



Figure 4.11: The differences in depth between the Islamic and Roman burials as illustrated by the Roman grave in the foreground and the Islamic grave in the background (taken from Alba Calzado 2005, Figure 21).

inside the graves (right lateral decubitus), and the use of flat covers made of reused Roman material. While there are more than twenty Islamic Period burial sites in Mérida, there have only been three instances of Islamic Period burials being in the same funerary space as Roman burials.

In terms of skeletal structure, the individuals dated to the Roman Period were short in stature (between 1.6 and 1.7 meters) and described as more robust in the site report (Alba Calzado 2005). The individuals dating to the Islamic Period were



Figure 4.12: Tombs 58 (left) and 6 (right). Illustrating the variation in burial style between Roman (left) and Islamic (right) tombs, as well as the physical differences between the populations (taken from Alba Calzado 2005, Figure 22).

comparatively tall, exceeding 1.7 meters in stature, and reportedly possessing quite gracile skeletons. Figure 4.12 shows the marked differences in their skeletal structure as well as the variation in burial positions between the two time periods.



Figure 4.13: Plan of site 8060/8065 (Velada) (adapted from Delgado 2003, Figure 2).

4.2.2.3 Site 8060 - Velada

Site 8060, here after referred to as Velada, is situated at the top of a small hill in the neighborhood of Bodegones in the southeast of Mèrida, outside the walls of the ancient Roman city. The site was excavated in two phases over the course of 2003 by the Consortia de la Ciudad Monumental de Mérida. The site report and inventory can be found in the 2003 edition of the *Mérida Excavaciones Arqueológicas.* The first phase of the site was given the identifier of site 8060 and the second phase is identified as 8065 (see Figure 4.13). While there were remains found during both phases of excavation, only those from the first phase (8060) were used in this thesis.

There were three types of burials at this site, referred to as 'simple burials', 'double grave burials,' or 'concealed burials' (Delgado 2003). The 'simple burials' were pit burials that were rectangular in shape. 'Double grave burials' are defined as

a smaller pit being dug within a larger pit. The remains are found within the smaller pit and were covered horizontally with terra-cotta *tegulae*. The third type of burial, the 'concealed pit burials', are similar to the double grave burials in that they involved two pits. However, in the case of the concealed burials, the lower second pit is dug laterally into and under the wall of the upper pit, partially concealing the remains. The *tegulae* in the concealed burials were then placed diagonally, leaning against the wall of the upper pit, to cover the lower pit and the remains (see Figure 4.14).

Though these graves lacked grave goods, they were dated to the 8th-9th centuries AD using the associated *tegulae*. The individuals buried at this site were oriented Northwest-Southeast and were supine in position. Ten of the simple burials were placed within the structure of an older hydraulic feature, though this has been deemed as coincidental by the archaeologists, as the burials are at the same level as the others at the site. Also found during the excavation of Velada were seven

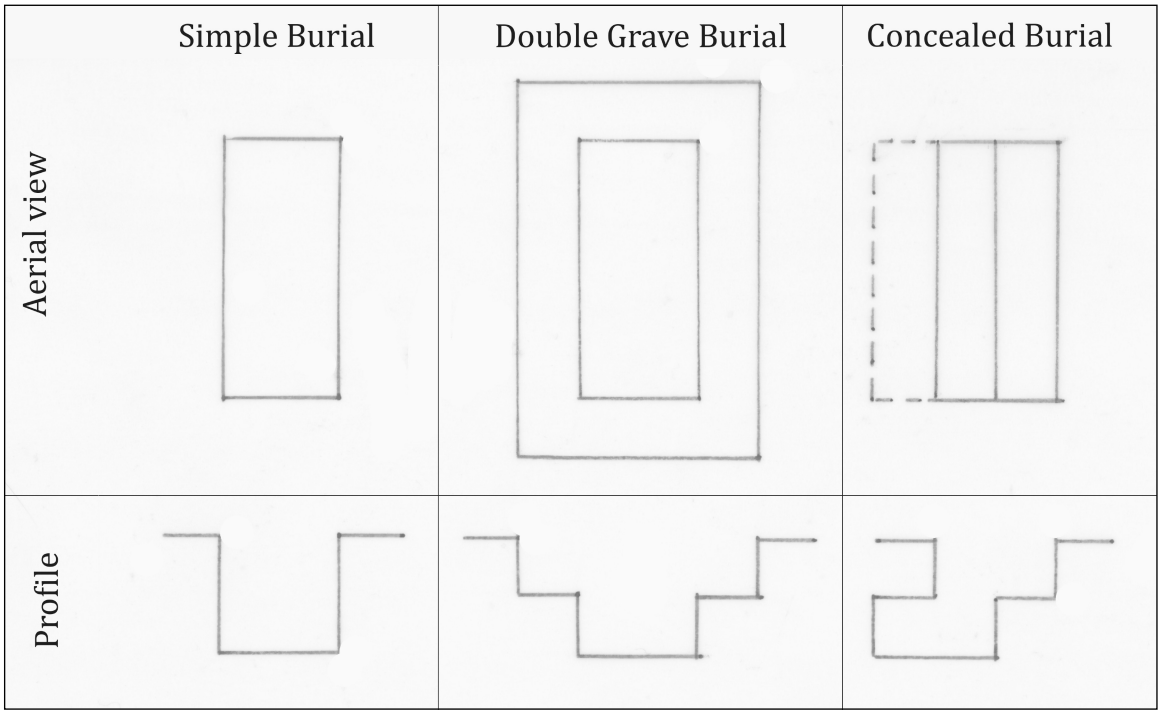


Figure 4.14: Aerial view and profile of the three types of tombs found at Velada (adapted from Delgado 2003, Figure 6).

cremation burials with fragmentary remains that date to the second half of the first century AD.

4.3 Comparisons

4.3.1 Cities

The cities of Mérida and Sanisera, though very different in size and location, have a number of similarities that make the study of their respective populations important. As with many cities founded under the auspices of the Roman Empire, both cities originally served military purposes, then later became civilian centres as the Empire expanded. Both cities were along important trade routes in Spain: Sanisera, on the sea route through the Mediterranean and Mérida along the land route through the Iberian Peninsula.

The differences between the cities are as important as their commonalities when it comes to studying populations and their diets. With the populations being studied dating to the same period in history, it becomes possible to study the affects of coastal versus inland locations in Late Antique diet as well as the effect that the size of the city might have on its population. Both of the cities played important roles in the history of Late Antique Spain and by studying individuals from both of them it becomes possible to see how the characteristics that define each of them during the time period affected the individuals inhabiting them.

4.3.2. Burials

The sampled necropoles were selected with the aim of controlling for time period and social status. The sites are Late Antique, some with origins in the Late Roman period, and some continuing on into the Islamic Era. The burials themselves were simple for the time period, consisting of variations of simple pit burials. While

there was some variation in the manner in which the burials were covered, it was consistently done with recycled material and there were no grave markers associated with any of the graves. The burials are also considered humble for the time period, containing few if any grave goods. Also consistent with the time period was the manner in which most graves were laid out in linear rows (though this was not always the case).

In terms of the individuals themselves, the majority were buried in the supine position, with their hands placed in some manner on or beside their torso. There was a good representation of both sexes and all age groups in each necropolis, indicating that the population included within was not some special group such as soldiers or priests. With all of these similarities in mind, it becomes possible to study the effects that the location in which these individuals lived affected them.

Chapter 5: Materials and Methods

5.1 Osteological Analysis

Due to the destructive nature of isotopic analysis, ethical considerations had to be given before the process began. The proper methods were followed for both sites to obtain permission to conduct destructive analysis of samples. As suggested by the Advisory Panel of the Archaeology of Burials in England (APABE), where possible, samples were taken from material that was already damaged, fragmentary, or incomplete (Mays *et al.* 2013).

Each side of every sample was scanned using an Epson Perfection 4870 Photo scanner at a resolution of 1200 dpi. In some cases, the bone fragment was too large to be scanned, and, in these instances, the sample was photographed using a Canon XTi[1]. The images were then compiled with a scale using Photoshop C6. This was done to create a digital archive of the appearance of the bones and teeth before they were sampled (a destructive process). The images can be seen in Appendix A.

5.1.1 Osteological Materials

This study focused on the bone and dentition of individuals from the Late Antique Spanish settlements Sanisera (Menorca) and Eméritus Agustus (Extramérida), more commonly referred to by its contemporary name Mérida (Central Spain). These sites introduced several challenges for obtaining relevant osteological materials. The relatively high temperatures of the southwest Mediterranean can lead to poor collagen preservation in bone (Smith *et al.* 2003). Another issue with preservation of the samples was the fragmentary nature of the

[1]A 10.1 megapixel camera. The photos were taken at the resolution of 3456 x 2304.

skeletal material from Sanisera (see Chapter 4). With materials being disarticulated and commingled, the ability to differentiate between individuals was very low. This was not the case with individuals from Mérida, as they were interred individually. However, the soil conditions there were even less conducive to good bone preservation than at Sanisera, leading to much of the material being incredibly fragmented.

Given the state of the bone samples, dentine became the primary focus when selecting samples, as dentine was more likely to have collagen still present. Fortunately, dentine is more robust and receives protection from the surrounding bone of the mandible or maxilla (Hillson 1996, Hollund *et al.* 2015, Masters 1987, Schulting *et al.* 2012). Bone samples were only taken when the teeth were still attached, and as a result, bone samples in this study consist solely of mandibular or maxillary bone. While it is more common to take bone samples from long bones or ribs, the fragmentary nature of both collections made it difficult to associate bone and dentine samples unless the two were still attached. When compared to long bones, the maxilla and the mandible both have a larger amount of collagen (Matsuura *et al.* 2014) and a turnover rate three to six times higher (Huja *et al.* 2006) than that of a femur. This is advantageous both in terms of collagen extraction and when comparing bone to dentine, as there is less of a chance of overlap between the formation of the two materials.

The sample collection strategy for both sites was to identify and collect second or third molars as well as any attached bone and transport them back to the Research Laboratory for Archaeology and History of Art at the University of Oxford for analysis. This meant that the samples ranged from large mandibular fragments with multiple teeth *in situ*, to single molars. To avoid taking duplicate samples, (i.e. a

sample from both the left and right side of an individual), only the most common dental element was targeted in each tomb, for example, lower left second molars. Second and third molars were targeted over other teeth as they are the last to develop, avoiding the effects of weaning that may be present in teeth formed earlier in life as much as possible. Dentine in second molars is formed between 8 and 15 years of age, and dentine in third molars is formed between the ages of 13 and 21 (Moorrees *et al.* 1963, Ubelaker 1979), both well past the age at which children are typically weaned. Dentine with associated bone samples were possible for 21 out of 36 of Sanisera samples and 24 out of 35 of Mérida samples. The implications of employing dentine samples as well as bone means that not only will this study be able to examine $\delta^{13}C$ and $\delta^{15}N$ values in the years before death (from bone samples), but also values from childhood (from dentine); and, in comparison to simply taking samples from juvenile remains, the samples associated with childhood taken from dentine are from individuals who survived into adulthood.

Faunal samples were used as controls based on the assumption that all were raised and consumed locally and are therefore the most appropriate comparative material available. They were selected using the same methodology as the human samples.

5.1.1.1 Sanisera

Faunal samples, dating from the 3rd-5th centuries AD, were taken from twenty-four different animals including four *Bos taurus*, ten S*us domesticus*, nine *Ovis/Caprids* and one *Canis familiaris* (Table 5.1).

A total of thirty-six individuals from Sanisera Necropolis 6 were sampled in this study. Bone samples were obtained from twenty-one of these individuals consisting of sixteen mandibular and five maxillary fragments. For fifteen individuals

only dentine was available to sample. In total, thirty-four second molars and two third molars were sampled. The samples originated from nineteen different tombs in Zones 1 and 2 of Necropolis 6 (Table 5.2). The majority of the remains from Necropolis 6 were disarticulated and commingled, making sex estimation unreliable.

Table 5.1: An inventory of the faunal samples taken from the city site of Sanisera. All samples date to the Roman Period (3rd-5th century AD). Definitions: M2-Second Molar, M3-Third Molar

Sample	Species	Common Name	Period	Materials
F1	*Bos taurus*	Cattle	Roman	Maxilla
F2	*Bos taurus*	Cattle	Roman	Maxilla
				M2
F4	*Bos taurus*	Cattle	Roman	M3
F5	*Bos taurus*	Cattle	Roman	M2
F8	*Canis familiaris*	Dog	Roman	Mandible
F9	*Sus domesticus*	Pig	Roman	Mandible
F10	*Sus domesticus*	Pig	Roman	Mandible
F11	*Sus domesticus*	Pig	Roman	Mandible
F12	*Sus domesticus*	Pig	Roman	Mandible
F13	*Sus domesticus*	Pig	Roman	Mandible
F14	*Sus domesticus*	Pig	Roman	Maxilla
F15	*Sus domesticus*	Pig	Roman	Mandible
F16	*Sus domesticus*	Pig	Roman	Mandible
F17	*Sus domesticus*	Pig	Roman	Mandible
F18	*Sus domesticus*	Pig	Roman	Maxilla
F19	Ovicaprid	Sheep/Goat	Roman	Mandible
F20	Ovicaprid	Sheep/Goat	Roman	Mandible
F21	Ovicaprid	Sheep/Goat	Roman	Mandible
F22	Ovicaprid	Sheep/Goat	Roman	Mandible
F23	Ovicaprid	Sheep/Goat	Roman	Maxilla
F25	Ovicaprid	Sheep/Goat	Roman	Mandible
F26	Ovicaprid	Sheep/Goat	Roman	Mandible
F27	Ovicaprid	Sheep/Goat	Roman	Mandible
F28	Ovicaprid	Sheep/Goat	Roman	Mandible

Table 5.2: An inventory of the human samples taken from Sanisera Necropolis 6 including the tomb and zone where the same originated, the approximate date of the sample and the materials sampled. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left.

Individual	Tomb	Zone	Date	Material
7	12	2	5th-6th cen. AD	Mandible
				LRM2
9	12	2	5th-6th cen. AD	Mandible
				LRM2
10	12	2	5th-6th cen. AD	LRM2
11	12	2	5th-6th cen. AD	LRM2
15	28	2	5th-6th cen. AD	LLM2
16	28	2	5th-6th cen. AD	LLM2
18	28	2	5th-6th cen. AD	Mandible
				LLM2
21B	28	2	5th-6th cen. AD	LLM2
26	13	2	5th-6th cen. AD	LLM2
29	33	1	5th-6th cen. AD	Mandible
				LLM2
31	23	2	5th-6th cen. AD	URM2
32	30	2	5th-6th cen. AD	Mandible
				LLM2
35	31	1	5th-6th cen. AD	LLM2
38	31	1	5th-6th cen. AD	Mandible
				LLM2
40	26	1	5th-6th cen. AD	Maxilla
				URM2
43	26	1	5th-6th cen. AD	Maxilla
				URM2
52	16	2	5th-6th cen. AD	LLM2
58	15	2	5th-6th cen. AD	LRM2
60	15	2	5th-6th cen. AD	Mandible
				LRM2
61	15	2	5th-6th cen. AD	Mandible
				LRM2
62	15	2	5th-6th cen. AD	Mandible
				LRM2
63	17	2	5th-6th cen. AD	Mandible
				LRM2

Table 5.2 continued

Individual	Tomb	Zone	Date	Material
64	17	2	5th-6th cen. AD	Mandible
				LRM2
70	10	2	5th-6th cen. AD	Mandible
				LRM2
71	10	2	5th-6th cen. AD	Mandible
				LRM2
80	8	2	5th-6th cen. AD	Maxilla
				ULM3
81	11	2	5th-6th cen. AD	Mandible
				LRM2
86	9	2	5th-6th cen. AD	Mandible
				LRM2
98	6	1	5th-6th cen. AD	LRM2
103	3	1	5th-6th cen. AD	LRM3
106	5	1	5th-6th cen. AD	Maxilla
				URM2
107	5	1	5th-6th cen. AD	Maxilla
				URM2
114A	1	1	5th-6th cen. AD	LLM2
114B	1	1	5th-6th cen. AD	LLM2
115	1	1	5th-6th cen. AD	LLM2
119	6	1	5th-6th cen. AD	Mandible
				LRM2

5.1.1.2 Mérida

Samples from Mérida were taken from thirty-five human individuals, interred in five different necropoles as well as three cattle (*Bos taurus*) from the site of Casa Hererra, just outside the city (see Table 5.3 for the faunal samples and Table 5.4 for the human samples). The samples consisted of twenty-three mandibular and two maxillary bones and dentine from ten first molars, thirty second molars, and thirteen third molars.

Table 5.3: Inventory of faunal samples taken from the city of Mérida, including the collection site, species and approximate date. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left.

Site (no.)	Sample No.	Species	Period	Material
Casa Herrera (8265)				
	A	*Bos taurus*	Islamic (8th-10th cen. AD)	LLM2
				Mandible
	B	*Bos taurus*	Islamic (8th-10th cen. AD)	LLM2
				Mandible
	C	*Bos taurus*	Islamic (8th-10th cen. AD)	LLM2
				Mandible

Table 5.4: Inventory of the human samples taken from the city of Mérida, including the collection site, tomb and approximate date. Definitions: M2-Second Molar, M3-Third Molar, LL-Lower Left, LR-Lower Right, UR-Upper Right, and UL-Upper Left. An * indicates that a

Site (no.)	Sample No.	Tomb	Period	Material
Nova Romana (1021)				
	140	32	Roman (3rd-5th cen. AD)	LLM1
				LLM2
				LLM3
				Mandible
	141	33	Roman (3rd-5th cen. AD)	ULM2
				Maxilla
	149	35	Roman (3rd-5th cen. AD)	LLM1
				LLM2
				Mandible

Table 5.4 continued

Site (No.)	Sample No.	Tomb	Period	Material
Nova Romana III (7017) continued				
	69	20	Islamic (8th-10th cen. AD)	LRM2
	84	58	Roman (3rd-5th cen. AD)	LLM3
				Mandible
	96	28	Islamic (8th-10th cen. AD)	LRM1*
				LRM2
	103	32	Roman (3rd-5th cen. AD)	ULM2*
	107	33	Roman (3rd-5th cen. AD)	LLM2*
	140	36	Roman (3rd-5th cen. AD)	LRM3*
	153	39	Islamic (8th-10th cen. AD)	Mandible
				LRM2
	162	42	Islamic (8th-10th cen. AD)	LLM3*
	174	45	Islamic (8th-10th cen. AD)	LLM2*
Nuevo Mérida (7034)				
	17	-	Visigothic (7th-8th cen. AD)	LLM1*
				LLM2*
				Mandible
	23	-	Visigothic (7th-8th cen. AD)	LLM1
				LLM2
				Mandible
	26	-	Visigothic (7th-8th cen. AD)	LLM2
				Mandible
	67	-	Visigothic (7th-8th cen. AD)	ULM1
				ULM2
				Maxilla
Velada (8060)				
	73	4	Visigothic (7th-8th cen. AD)	LRM2
				Mandible
	96	17	Visigothic (7th-8th cen. AD)	LLM1*
				LLM2
				LLM3*
				Mandible
	99	21	Visigothic (7th-8th cen. AD)	LLM3
				Mandible
	115	28	Visigothic (7th-8th cen. AD)	LLM2
				Mandible
	162	47	Visigothic (7th-8th cen. AD)	LRM3
				Mandible

Table 5.4 continued

Site (no.)	Sample No.	Tomb	Date	Material
Velada (8060) continued				
	207	54	Visigothic (7th-8th cen. AD)	LRM2
				Mandible
	208	33	Visigothic (7th-8th cen. AD)	LLM2
				Mandible
	216	19	Visigothic (7th-8th cen. AD)	LLM1
				LLM2
				LLM3
				Mandible
	232	13	Visigothic (7th-8th cen. AD)	LLM1
				LLM2
				Mandible
	248	56	Visigothic (7th-8th cen. AD)	LLM1
				LLM2
				Mandible
	nn	-	Visigothic (7th-8th cen. AD)	LRM2
				LRM3
				Mandible
	Tomb 17	17	Visigothic (7th-8th cen. AD)	LLM2
				LLM3
				Mandible
YAC (83925)				
	16	-	Visigothic (7th-8th cen. AD)	LLM2
				Mandible
	27	-	Visigothic (7th-8th cen. AD)	LLM3
				Mandible
	31	-	Visigothic (7th-8th cen. AD)	LRM3
				Mandible

5.1.2 Osteological Methods

5.1.2.1 Faunal

After the faunal samples were photographed, the age at death for each individual was estimated using the method outlined in Grant (1982). This method, similar to the one used to estimate age at death in the human samples, is based on tooth wear. It was selected as it was the method being used in the zooarchaological analysis of the site. In the Grant (1982) method for faunal aging, tooth wear stages (T.W.S.) and eruption stages are given letter values which have number equivalents. The mandible wear stage (M.W.S.) is calculated by "totaling the values of all permanent molars in the jaw" (Grant 1982; 96). If teeth are missing from the sample, or there is only a fragment of the jaw, the M.W.S. can still be estimated if the wear of the remaining teeth can be used to estimate wear stages for the missing teeth. Using the M.W.S values, the faunal samples are assigned an age category of either Juvenile, Older Juvenile or Adult.

5.1.2.2 Human

The next step in the human osteological analysis was to estimate the age-at-death of each individual. Samples were aged using methods based on dental attrition. The human samples were analyzed using the method outlined in Brothwell (1989). The general theory behind age-at-death estimation, based on dental attrition or wear, is that the longer a tooth has been in use the more wear it will incur and that this wear will occur, on average, at the same rate both within an individual and across a population. In the method outlined by Brothwell (1989), the wear on each tooth is given a numerical classification on a scale from 1 to 7 (including + and -). Then based on whether the sample tooth is the first, second, or third molar and

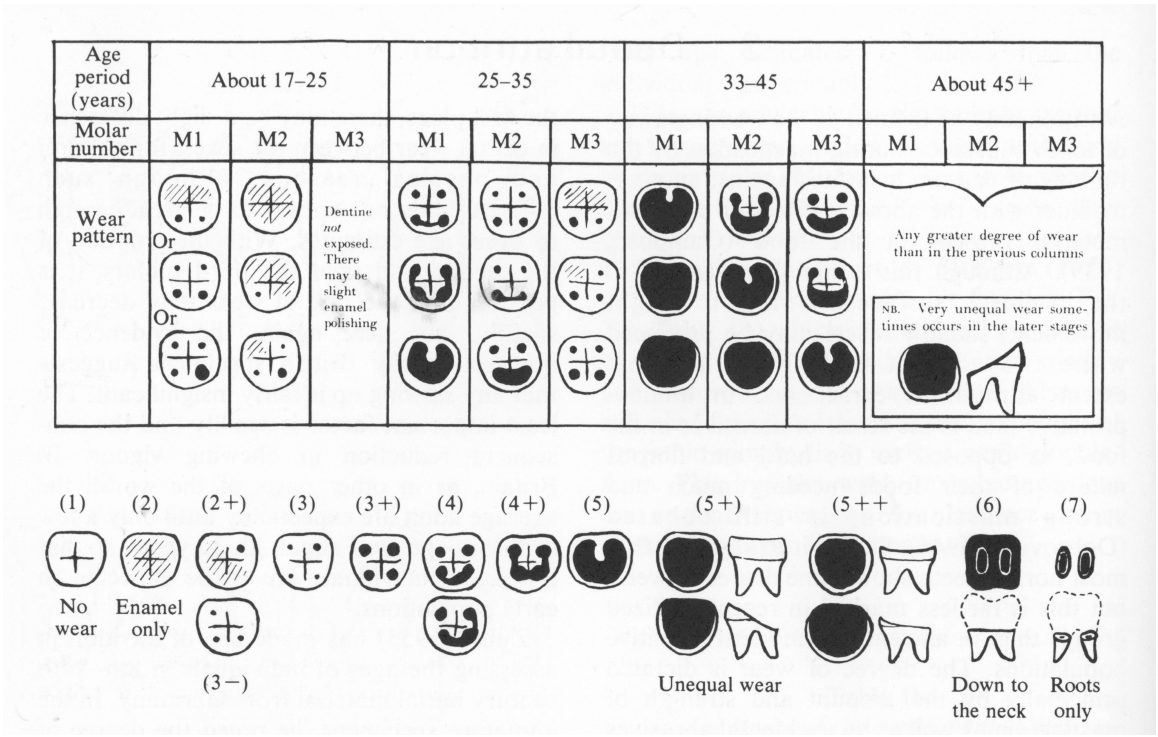


Figure 5.1: Brothwell's numerical classification of age based on molar wear (taken from Brothwell 1989 Figure 3.9).

what classification is given to the other two molars, the individual is given an age-at-death range/category. The five age ranges/categories used in the Brothwell method are <17, 17-25, 25-35, 33-45 and 45+ years (see Figures 5.1 and 5.2 for more

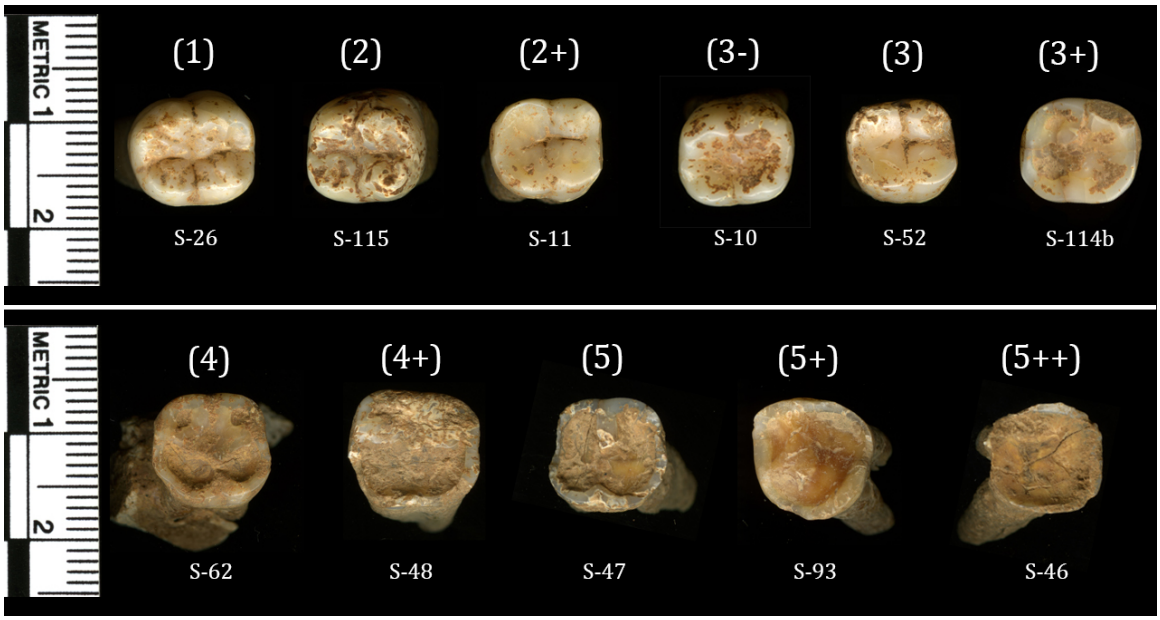


Figure 5.2: Application of Brothwell's numerical classification of age based on molar wear, using samples from Sanisera (photographs by author).

details) The population used to develop this method of classification consisted of British individuals dating from the Neolithic through to the Medieval Period. While the difference between this population and the Spanish populations in this study are large enough for Brothwell's method to be unable to provide absolute age-at-death estimations, the relative order will remain the same. Individuals with more dental wear were older at death than those with less. For the purposes of this study, this is sufficient .

After age-at-death was estimated, any pathologies were noted. These mainly consisted of alveolar resorption, dental calculus, and caries. For some of the individuals from Mérida, sex had previously been estimated by the site's original osteologist as documented in their published reports (Alba 2002). For most of the remaining individuals estimation of sex was impossible, due to the disarticulation of the remains, and the fragmentary nature of the samples taken. However, it was possible to estimate the sex of four additional individuals based on the prominence of their mental eminence/protuberance. While this is by no means the best osteological method of estimating the sex of an individual, it was the only one available. With that in mind, sex was estimated, but the results should be regarded with caution.

The mental eminence/protuberance is the triangular feature at the anterior base of the mandible. Estimating the sex of an individual using this part of their

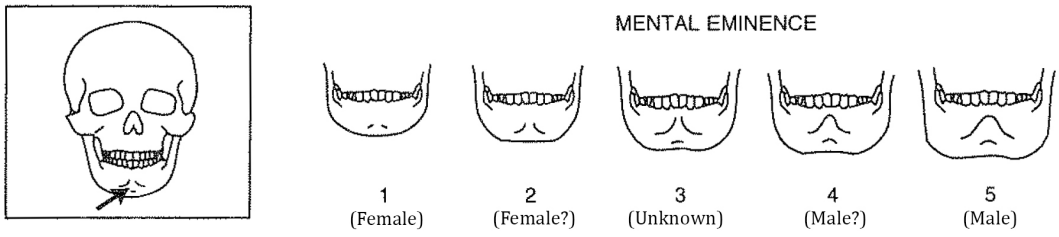


Figure 5.3: Scoring system for the mental eminence (adapted from Buikstra and Ubelaker 1987 Figure 4).

anatomy was accomplished using the method described in Buikstra and Ubelaker (1994), and seen in Figure 5.3. In this method, the expression of the mental eminence is ranked on a scale from 1 to 5 based on its relative size and projection from the surrounding bone. Ranks 1 and 2 are female and likely female, ranks 4 and 5 are likely male and male, while rank 3 is undetermined. A sample to which this method was applied, can be seen in Figure 5.4. The results of this assessment for all of the applicable samples can be seen in Appendix B. While it is less than ideal to rely solely on this method, it was the only method available given the nature of the collection and the samples. With this in mind, sex will be discussed, but any conclusions reached should be regarded with caution.

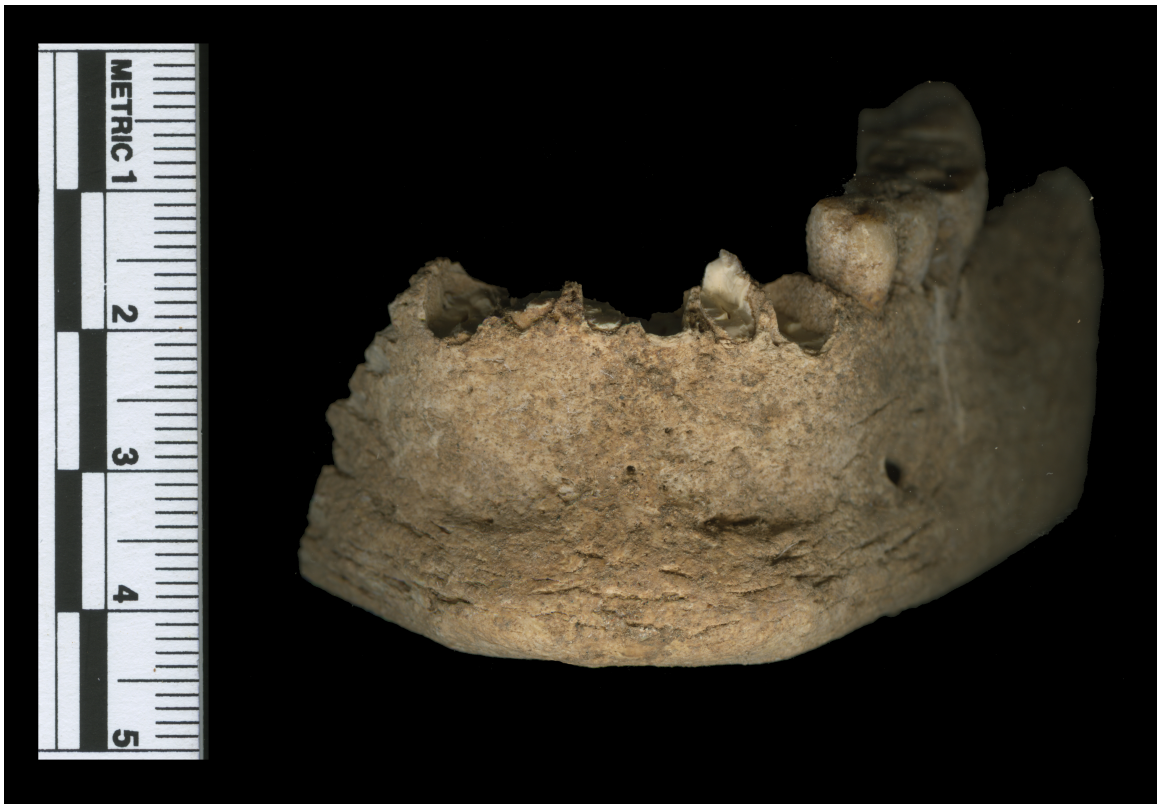


Figure 5.4 : Anterior view of the mandible of Individual 248 from the funerary site of Velada in Mérida. This individual was given a score of 4 using the method outlined in Buikstra & Ubelaker 1994, indicating that they were likely male. (Photograph taken by author).

5.2 Stable Carbon and Nitrogen Isotope Analysis

Collagen was extracted from the bone and dentine samples using a modified version of the method described by Privat *et al.* (2002). First, the surface of the bone or tooth was shot-blasted to remove any adhering soil and as much of any surface contaminants as possible. Next, samples between 0.1 to 1 gram in weight were taken from the bone or dentine using a Dremel™ multi-tool and ground using a mortar and pestle.

Once the samples were weighed and crushed, they were demineralized in 10 ml of 0.5M HCl. This dissociates the carbonates, solubilizes the structural mineral material, and removes any acid soluble contaminates. The initial demineralization process (used on the samples from Sanisera) lasted a week, during which the samples were agitated daily and the acid was replaced every two days.

Next, the samples were rinsed three times in distilled water and filtered to remove the acid. Each sample was then gelatinized by adding 10 ml of pH 3.0 water (made with HCl) and heating the sample at 75°C for 48 hours. This denatured and solubilized the collagen. Finally, the supernant liquid was filtered through Eezee filters into pre-weighed tubes and lyophilized in a freeze-dryer for two to three days.

This process was used to extract collagen from all of the Sanisera bone and dentine samples. Dentine samples were taken from below the cemento-enamel junction and were taken from the entire length of the root of the tooth. Due to the fragile condition of the material from Mérida, initially only larger sections of bone were processed using this method. Unfortunately, due to their fragile condition the initial samples from Mérida processed using this method produced insufficient collagen for isotopic analysis to proceed. Luckily, there was enough remaining

material to try a second, gentler method. These new Mérida samples, after being similarly cleaned and weighed, were powdered using the mortar and pestle, and were placed in 10 ml of 0.5M HCl for between 2 and 6 hours with the samples being observed and agitated every hour until they were fully demineralized.

Another means by which to increase the sample size from Mérida was to taking multiple samples per tooth, and included associated molars. Extracting multiple samples horizontally from the same tooth allowed for an examination of the variation in $\delta^{13}C$ and $\delta^{15}N$ values as a function of an individual's age. With better preserved material, it is becoming common (Beaumont & Montgomery 2015, Eerkens *et al.* 2011, Henderson *et al.* 2014) to undertake high resolution sampling of dentine with as many as 10 sections from the crown to root. However, due to the poor preservation of the bone samples from Mérida, it was decided that smaller-sized samples of dentine would have produced an insufficient amount of collagen for measurement. With preservation in mind, samples from Mérida had their roots halved horizontally, at the furication (where the root splits). This created two samples from each tooth, one from the CEJ to the furication (the cervical sample) and one from the furication to the apex of the root (the apical sample). The sampling process can be seen in Figure 5.5, and an asterisk next to a material in Table 5.3 indicates which teeth were bisected. Unfortunately, it was not possible to return to the Sanisera material to replicate the process, leading to a slight variation in sampling methods between the two sites.

The resulting collagen samples were measured in duplicate and analyzed by a Carlo Erba EA coupled to a Europa Geo 20-20 isotope ratio mass spectrometer at the Research Laboratory for Archaeology and the History of Art, University of Oxford. The carbon and nitrogen samples were measured against purified alanine and

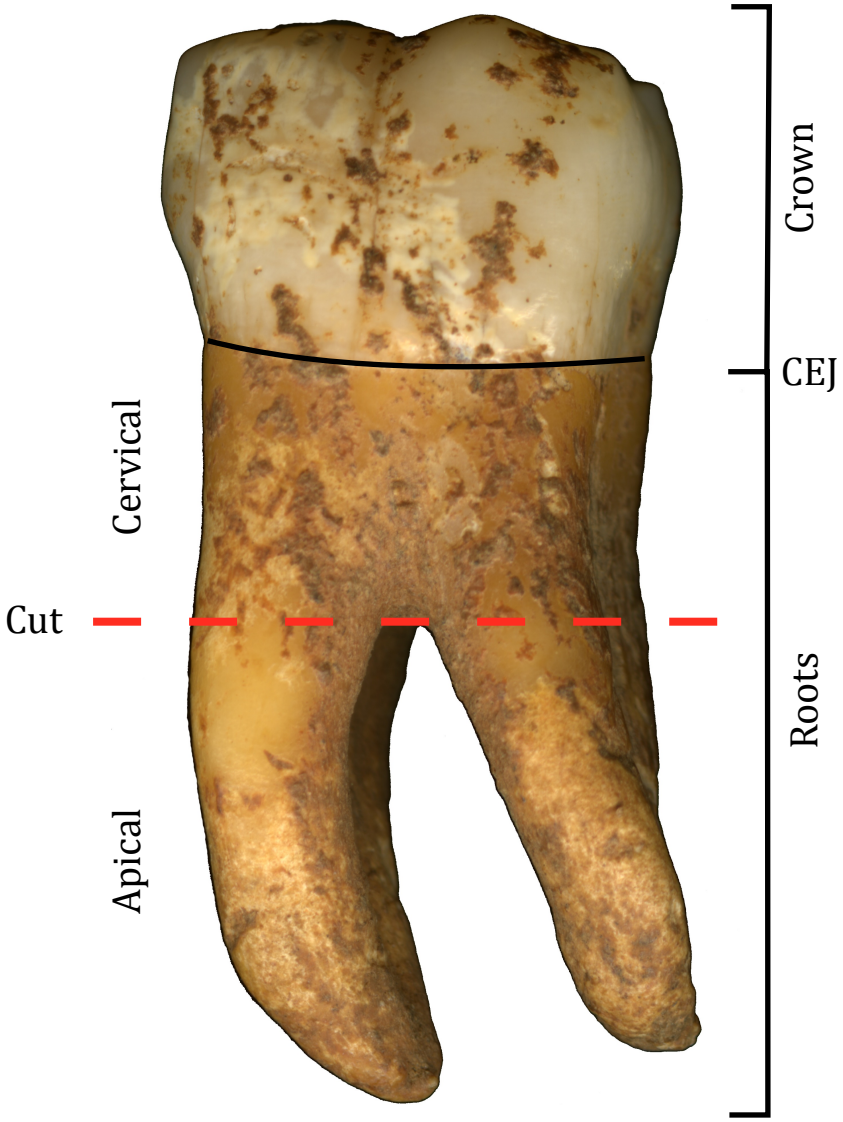


Figure 5.5: Depicts the division between the crown and roots of a second molar by the cement-enamel junction (CEJ) as well as where the cut for sampling two sections of the root occurred (at the furication of the root) which divided the root into two sections, now defined as the cervical and apical sections of the root. (Photograph and annotation by author).

internal laboratory standards (of bovine liver and seal bone) which were calibrated to the internationally certified reference materials, of AIR for nitrogen and VPDB for carbon. For good collagen preservation in archaeological samples the acceptable range of C:N is 2.9 to 3.6 (DeNiro 1985). If the C:N of the one of two samples from the same individual was outside the acceptable range of 2.9-3.6 and the other was within this range, then a third sample was analyzed.

The other indicator of good collagen preservation is the percentage of collagen in the sample; over 5% is preferred, though many studies include samples with as little as 1%, if they do not significantly differ from the other samples (Dobberstein *et al.* 2009, Van Klinken 1999).

Analytical error was calculated from the pooled means of the standard deviation of multiple measurements of the internal references run along with the samples (Jasper 2001). The internal standards used where Alanine ($\delta^{13}C$ -26.9‰ and $\delta^{15}N$ -1.63‰) and Bovine Liver ($\delta^{13}C$ -21.1‰ and $\delta^{15}N$ -7.6‰). The analytical error was found to be ±0.2‰ for $\delta^{13}C$ and ±0.1‰ $\delta^{15}N$.

The statistical analysis of data from Sanisera and Mérida was done using non-parametric Mann-Whitney U and Kruskal-Wallis tests due to the results not being normally distributed.

5.3 Radiocarbon Dating

The collagen from five individuals was AMS radiocarbon dated, two from Mérida (V-nn and NR3-25) and three from Sanisera (S-86, S-106 and S-F2). These samples were selected after the stable isotope analysis had been done. The aim was to compare an isotopic outlier from each site, with a sample representing the site mean. The collagen used was excess collagen extracted during the process outlined above. The samples were submitted to the University of Oxford Radiocarbon Accelerator Unit (ORAU) for radiocarbon dating. The samples were run as part of larger batch from another project limiting the number of samples that could be run to five. The AMS measurements followed the procedures outlined in Ramsey *et al.* (2002, 2004a, 2004b). The results of this analysis are described in Section 6.2

5.4 Meta-Analysis of Related Isotopic Data

The individuals from Sanisera and Mérida did not exist in isolation, the populations from both cities were heavily involved in trade and the political upheaval that followed the collapse of the Roman Empire. While it is possible to draw some conclusions from looking at their isotopic results, a study of the two populations would be better suited if reviewed in the context of other similar sites.

The nature of $\delta^{13}C$ and $\delta^{15}N$ analysis means that individuals and sites can be compared very easily by plotting their results on a graph and drawing conclusions from there. However, in making these comparisons the effects of the factors outside of diet which can affect $\delta^{13}C$ and $\delta^{15}N$ values needs to be considered as these effects can drastically skew any conclusions.

With this in mind a data set was created from sites comparable to Sanisera and Mérida. This data set not only included $\delta^{13}C$ and $\delta^{15}N$ results, but also variables such as weather, location and time period that could affect those results. Faunal samples were also included to help establish a base line for each site. The Meta-analysis is not simply an accumulation of data, but also the exploration of the means to analyze such data.

5.4.1 Materials

To put the results from Sanisera and Mérida into a broader context, a Meta-analysis was undertaken using studies with published $\delta^{13}C$ and $\delta^{15}N$ data for humans and fauna from sites in continental Europe and North Africa. Data were selected from the previously discussed Sanisera and Mérida samples to match the methodology of the published studies as closely as possible. This meant that only one result per individual was used, and since the studies included in the Meta-

analysis all use bone collagen, the results of the $\delta^{13}C$ and $\delta^{15}N$ analysis run on bone was taken over dentine for each individual. If the individual did not have a bone sample available, the dentine sample that was formed latest in life/closest to the time of death was used (e.g. the apical section of an third molar over a first molar).

The Meta-Data set includes $\delta^{13}C$ and $\delta^{15}N$ data for 1534 human samples and 536 faunal samples taken from 27 different studies. These studies were also chosen based on their relation to Sanisera and Mérida, by location and time period. The locations included in this data set were mainly in the Western Mediterranean and Continental Europe. There was also a North African site included, because North Africa played a major role in economy of both Sanisera (Contreras 1997) and Mérida (Arce 2005). Unfortunately, at the time that this data set was assembled there was only one suitable North African site, although more would have been desirable.

With the comparison of so many studies, it was important to consider inter-laboratory variability. The differences in methodology used to extract collagen and the machinery used to analyze it may well contribute to the variations found in the $\delta^{13}C$ and $\delta^{15}N$ results. In their 2014 study, Pestle *et al.* determined that the Minimum Meaningful Difference (MMD) for $\delta^{13}C$ to be 0.6‰ and 0.9‰ for $\delta^{15}N$ (Pestle *et al.* 2014). This means that differences exceeding these values were highly likely to be due to biological factors rather than a result of a difference between treatments. This is important to keep in mind during the following analysis of the Meta-Data.

Table 5.5: Sites included in the Meta-analysis, their location, date, number of human and faunal samples and their study of origin.

Location	Site	Date	Human Samples	Faunal Samples	Study
Austria					
Volders					
	Volders	6th-7th	100	21	McGlynn 2007
Belgium					
Antwerp					
	Antwerp	8th-11th	2	-	Ervynck *et al.* 2014
Namur					
	Namur	7th-13th	5	-	Ervynck *et al.* 2014
Tongeren					
	Tongeren	7th-11th	2	-	Ervynck *et al.* 2014
Czech Republic					
Mikulčice					
	Mikulčice–Kostelisko	9th-10th	33	18	Halffman & Velemínskỳ 2015
France					
Grenoble					
	Grenoble	13th-15th	34	12	Herrscher *et al.* 2001
Germany					
Munich					
	Altenerding	5th-6th	68	3	Hakenbeck *et al.* 2010
	Aschheim-Bajuwarenring	6th-7th	-	4	Hakenbeck *et al.* 2010
	Eching-Kleiststrasse	7th	-	30	Hakenbeck *et al.* 2010
	Freising-Attaching	7th	-	10	Hakenbeck *et al.* 2010
	Klettham	4th	11	26	Hakenbeck *et al.* 2010
Naumburg					
	Naumburg	5th-6th	-	1	Knipper *et al.* 2012
	Obermollern	5th-6th	27	8	Knipper *et al.* 2012
	Rathewitz	5th-6th	16	7	Knipper *et al.* 2012
Straubing					
	Straubing-Bajuwarenstrasse	5th-7th	94	-	Hakenbeck *et al.* 2010
Weingarten					
	Weingarten	6th-8th	37	2	Schutkowski *et al.* 1999
Greece					
Athens					
	Athens	13th - 15th	-	16	Garvie-Lok 2001
Corinth					
	Corinth	13th	-	5	Garvie-Lok 2001

Location	Site	Date	Human Samples	Faunal Samples	Study
	Nemea Early Christian	5th-6th	20	-	Garvie-Lok 2001
Crete					
	Eleutherna	6th-7th	5	2	Bourbou *et al.* 2011
Messene					
	Messene	6th-7th	21	-	Bourbou *et al.* 2011
Mitilini					
	Mitilini	14th-15th	-	6	Garvie-Lok 2001
Sourtara					
	Sourtara	6th-7th	27	-	Bourbou *et al.* 2011
Hungary					
Szolád					
	Szolád	6th	44	7	Alt et al. 2014
Italy					
Civitanova					
	Civitanova Marche	Roman	29	-	Nitsch 2012
Cosa					
	Cosa at Ansedonia	1st-12th	37	8	Scoranno *et al.* 2014
Friuli V.G.					
	Cividale Gallo	7th	7	4	Iacumin *et al.* 2014
	Cividale S. Stefano	6th-7th	11	-	Iacumin *et al.* 2014
	Invillino	6th-7th	2	5	Iacumin *et al.* 2014
	Mainizza	10th-11th	16	-	Iacumin *et al.* 2014
	Romans d'Isonzo	6th-7th	46	-	Iacumin *et al.* 2014
Pompei					
	Pompei	Roman	22	-	Nitsch 2012
Rome					
	ANAS	Roman	14	-	Prowse *et al.* 2004
	Casal Bertone Mausoleum	2nd - 3rd	12	-	Killgrove & Tykot 2013 and Killgrove 2010
	Casal Bertone Necropolis	2nd - 3rd	20	-	Killgrove & Tykot 2013 and Killgrove 2010
	Castellaccio Europarco	1st-2nd	8	-	Killgrove & Tykot 2013 and Killgrove 2010
	Isola Sacra	1st-3rd	189	9	Crowe *et al.* 2010 and Prowse *et al.* 2004
	Palestrina	Roman	9	-	Nitsch 2012
	St. Callixtus Catacombs	3rd-5th	21	-	Rutgers *et al.* 2009
Velia					
	Velia	1st-2nd	117	27	Craig *et al.* 2009

Location	Site	Date	Human Samples	Faunal Samples	Study
Portugal					
Bragança					
	Torre Velha-Castro de Avelãs	1st-13th	9	9	Umbelino *(personal correspondence)*
Spain					
Albarracín					
	Almacabra	10th-11th	31	8	Mundee 2010
	Castillo de Albarracín	10th-12th	-	39	Mundee 2010 and Alexander *et al.* 2015
Gandía					
	Alquería de Benipeixcar	15th-16th	20	23	Mundee 2010 and Alexander *et al.* 2015
	Colegiata de Santa María	13th-16th	24	-	Mundee 2010 and Alexander *et al.* 2015
Ibiza					
	Es Soto	10th-13th	21	54	Fuller *et al.* 2010
	S'Hort des Llimoners	4th-6th	64	13	Fuller *et al.* 2010 and Nehlich *et al.* 2012
Jaca					
	Hacienda. C/ Abellanas 1995	12th	-	3	Mundee 2010
	Joaquin Costa/ Pedro IV	12th	-	10	Mundee 2010
	Plaza Biscos	11th-15th	25	-	Mundee 2010
	San Jan Barbastro	11th	-	4	Mundee 2010
Mérida					
	Casa Herrera	8th-10th	-	2	current study
	Nova Romana	3rd-5th	2	-	current study
	Nova Romana III	3rd-10th	9	-	current study
	Nuevo Mérida	5th-8th	3	-	current study
	Velada	7th-8th	8	-	current study
	YAC	5th-8th	3	-	current study
Sanisera					
	Sanisera	5th-7th	33	23	current study
Valencia					
	Almonia	10th-16th	8	30	Mundee 2010
	Calle Alta 48-58	11th-13th	21	-	Mundee 2010
	Calle Pintor Sorolla	13th	3	-	Mundee 2010
	Calle Sagunto	11th-13th	6	-	Mundee 2010
	San Andres	14th-15th	4	-	Mundee 2010
	San Vicente 134	14th-15th	15	-	Mundee 2010

Location	Site	Date	Human Samples	Faunal Samples	Study
Zaragoza					
	Bab al-Qibla	10th-12th	23	-	Mundee 2010
	La Seo	12th	2	-	Mundee 2010
	Predicadores 26	9th-12th	13	-	Mundee 2010
	Roman Theatre	8th-16th	3	18	Mundee 2010
Tunisia					
Leptiminus					
	Leptiminus	2nd-6th	54	8	Keenleyside *et al.* 2009

The data originated from 11 different countries and, for simplicity, sites from the same city were grouped together yielding 34 locations. The majority of the individuals date from the 2nd - 13th centuries AD, while a small number of individuals, from Spain, dating from the 13th - 16th centuries AD were also included, as Spain was otherwise poorly represented. Finally, studies of Mediterranean fish with published $\delta^{13}C$ and $\delta^{15}N$ isotope values from both the Late Antique period and the modern era were included, so as to establish expected 'marine' values. The $\delta^{13}C$ values of modern fish were adjusted by +4‰ to compensate for the tissue fractionation between muscle and bone (DeNiro & Epstein 1978, Kennedy 1988 and Hare *et al.* 1991). An additional +1.5‰ was added to the $\delta^{13}C$ values of the modern samples to make them comparable to the archaeological samples to counteract the effect that fossil fuels have had on $\delta^{13}C$ values, better known as the Suess effect (Keeling 1979, Marino & McElroy 1991, Tieszen & Fagre 1992). All sites included in the Meta-analysis can be seen in Table 5.5.

The Meta-analysis data set contains variables describing both the individuals themselves, and their sites of origin. The individual variables examined include species, age at death (as defined by the publication and divided into categories of adult, juvenile and infant), sex (humans only), and date. The dates given in these studies were not consistent, so for ease of use, dates were divided into five general

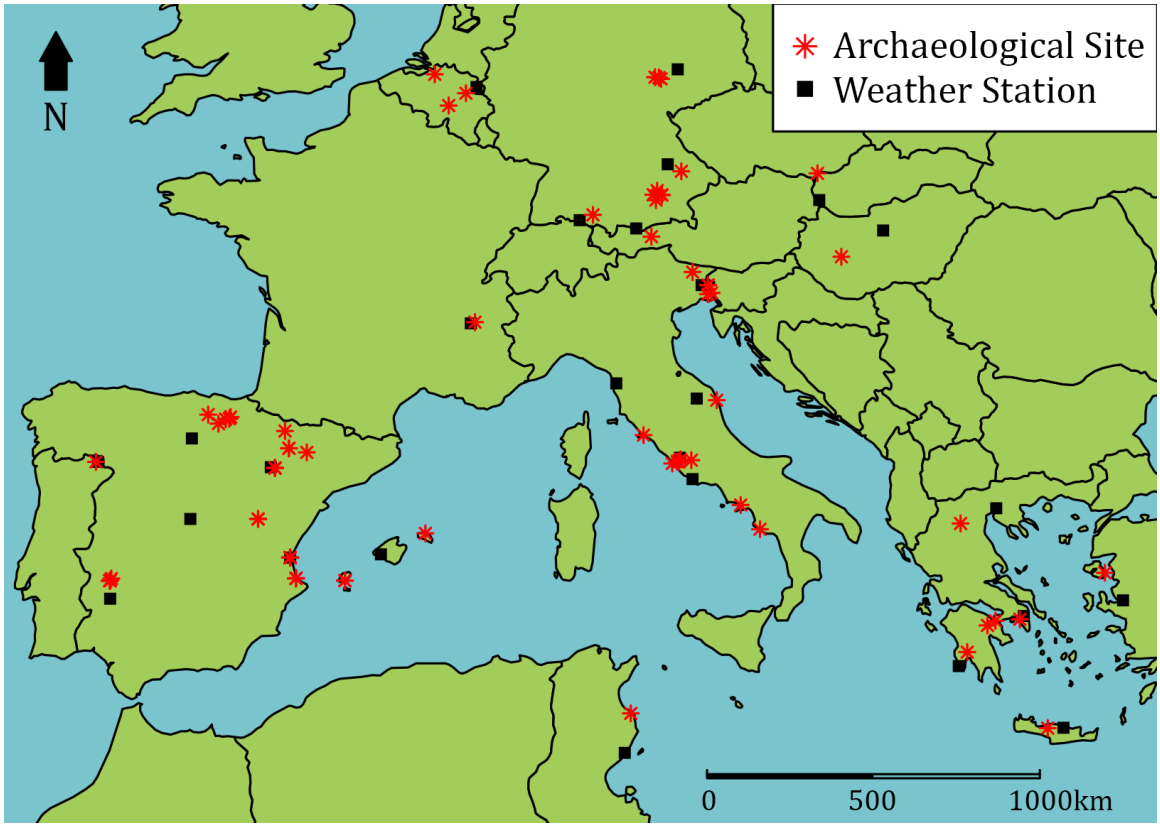


Figure 5.6: Map of the archaeological sites and the weather stations used in the Meta-analysis (map created by author using R).

categories and due to the fluid nature of time periods across the European continent, the categories were given very general names. The categories are as follows: AD 0-400 (Roman), AD 400-700 (Late Antique), AD 700-1200 (Early Medieval), AD 1200-1500, (Late Medieval) and Modern, which was only used for fish. Individuals dated between these time periods were defined by whichever time period most of their given date range fell into.

The location variables used in this analysis are country (as defined by modern political borders), latitude, longitude, whether a site was coastal or inland, and meters above sea level (MASL). Longitude and latitude were estimated using maps from site reports. Meters above sea level (MASL) was found using Google Maps by having the longitude and latitude (Google Maps 2017). Sites were defined as coastal or inland depending on their distance from the modern coastline; sites

Table 5.6: The weather stations where the climatic data for the Meta-Data set were sourced. Included is each station's World Meteorological Organization (WMO) code, the time period from when the data was sampled and the number of samples included.

Station	WMO Code	Time Period	Samples
Athens-Pendeli	1671601	2001-2014	157
Beek	638000	1981-1992	144
Bragança	857500	1988-1991	48
Bratislava	1181601	1988-1994	84
Budapest (Loerinc)	1284300	1977-1992	192
Burgos/Villa Fria	807500	2002-2003	15
Caceres Trujillo	826100	2000-2010	132
Feletto Umbreto	1604501	1985-1987	36
Fogliano	1626001	1998-2002	60
Garmisch-Partenkirchen	1096300	1978-2013	432
Grenoble	748601	1965-1970	72
Heraklion (Crete)	1675400	1960-1987	336
Izmir	1722000	2008-2013	72
Konstanz	1092900	1978-2013	432
Leipzig	1046900	1973-2005	396
Madrid-Retiro	822201	1970-2010	492
Methoni	1673400	1963-1971	108
Palma de Mallorca	830101	2000-2010	132
Pian Dell Elmo	1319401	2000-2002	36
Pisa (Central)	1615801	1992-2002	84
Regensburg	1077600	1978-2013	432
Rome-DST	1623501	1998-2003	72
Sfax	6075000	1992-2013	243
Thessaloniki	1662202	2000-2003	48
Valencia	824500	2000-2010	132
Zaragoza Aeropuerto	816001	2000-2010	132

within 10km of the coast were considered coastal and sites outside the 10km range were considered inland following the method used in Mays and Beaven 2012.

Two methods were used to establish climate for sites in this study. The first being climactic data obtained from 25 weather stations found on the International Atomic Energy Association's online database of the Global Network for Isotope

Precipitation (GNIP)[2] (Figure 5.6 and Table 5.6). Each station's data include mean and standard deviation for monthly temperature, mean and standard deviation of the annual temperature, the mean monthly precipitation and the mean total annual precipitation. To help identify seasonal variation the mean temperature and precipitation of each of the four seasons was calculated. Climactic data was assigned to each site based on which weather station was closest to the site.

The second means by which climate was assessed was by climate classification (or zone), as defined by the updated Köppen-Geiger climate classification (Kottek *et al.* 2006). The Köppen-Geiger Climate Classification assigns

Table 5.7: Description and defining criteria of Köppen-Geiger Climate Classifications that apply to this study. Taken from Peel *et al.* 2007 Table 1.

1st	2nd	3rd	Description	Criteria*
B			**Arid**	MAP < 10 x $P_{threshold}$
	S		- Steppe	MAP > 5 x $P_{threshold}$
		h	*- Hot*	MAT > 18
		k	*- Cold*	MAT < 18
C			**Temperate**	T_{hot} > 10 & 0 < T_{cold} < 18
	s		- Dry Summer	P_{sdry} < 40 & P_{sdry} < P_{wwet}/3
	f		- Without dry season	Not (Cs) or (Cw)
		a	*- Hot Summer*	T_{hot} > 22
		b	*- Warm Summer*	Not (a) & T_{mon10} < 4
D			**Cold**	T_{hot} > 10 & T_{cold} < 0
	f		- Without dry season	Not (Ds) or (Dw)
		c	*- Cold Summer*	Not (a, b, or d)

*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, T_{mon10} = number of months where the temperature is above 10, P_{sdry} = precipitation of the driest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{threshold}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{threshold}$ = 2 x MAT, if 70% of MAP occurs in summer then $P_{threshold}$ = 2 x MAT + 28, otherwise $P_{threshold}$ = 2 x MAT + 14).

[2] IAEA/WMO (2016). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://www.iaea.org/water

climate classifications based on vegetation, temperature and precipitation. It was first developed in 1900 by Wladimir Köppen, and has since been updated a number of times, most notably in 1954 and 1961 by Rudolf Geiger (Kottek *et al.* 2006). Current iterations of the world map use up-to-date data from weather stations to establish classifications as well as using models to extrapolate them up to 0.1º by 0.1º (Peel *et al.* 2007). The classification criteria used in this study are outlined in Table 5.7.

Based on the outlines in Table 5.7, each location was assigned to its appropriate climate zone. Figure 5.7 has each site mapped against the distribution of the Köppen-Geiger Climate Classification map of Europe, and the classification or zone, for each site, as well as further location data can be found in Table 5.8.

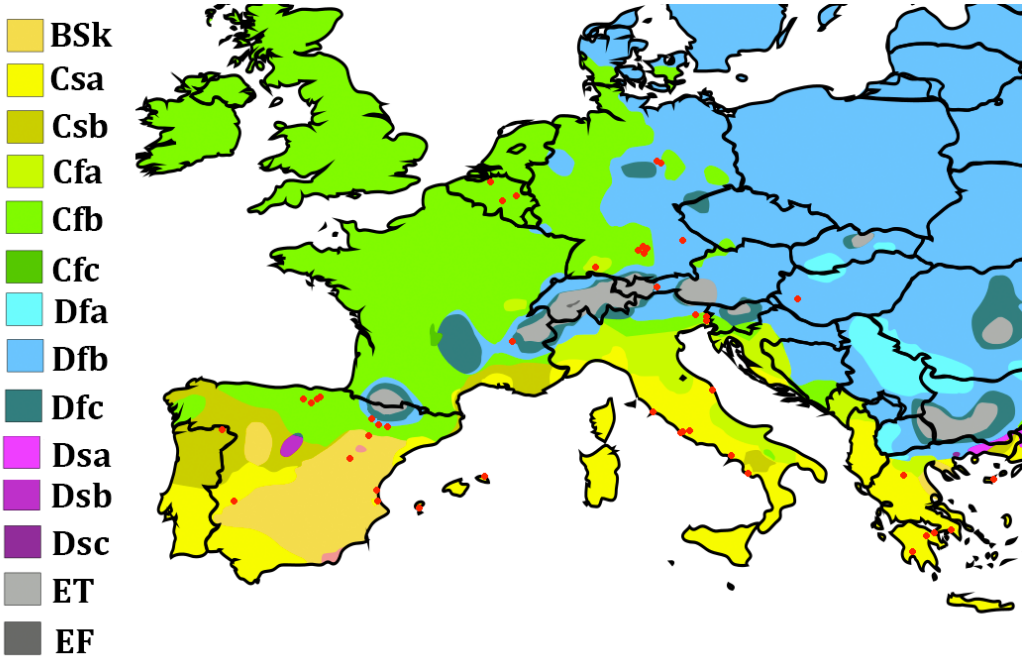


Figure 5.7: Map of the archaeological sites (in red) plotted on the Köppen-Geiger Climate Classification map of Europe (map taken from Peel *et al.* 2007 Figure 8, site of Leptiminus in North Africa excluded).

Table 5.8: Köppen-Geiger Climate Classifications for each site in the Meta-Data set.

Country	Location	Climate Classification
Austria	Volders	Dfc
Belgium	Antwerp	Cfb
	Namur	Cfb
	Tongeren	Cfb
Czech Republic	Mikulčice	Cfb
France	Grenoble	Cfb
Germany	Munich	Cfb
	Naumburg	Cfb
	Straubing	Cfb
	Weingarten	Cfb
Greece	Athens	Csa
	Corinth	Csa
	Crete	Csa
	Lesbos	Csa
	Messene	Csa
	Sourtara	Cfb
Hungary	Szolád	Cfb
Italy	Civitanova	Cfa
	Cosa	Csa
	Friuli V.G.	Cfb
	Pompei	Csa
	Rome	Csa
	Velia	Csa
Portugal	Bragança	Csb
Spain	Álava	Cfb
	Albarracín	Cfb
	Gandía	Csa
	Ibiza	Csa
	Jaca	Cfb
	Mérida	Csa
	Sanisera	Csa
	Valencia	Csa
	Zaragoza	BSk
Tunisia	Leptiminus	BSh

5.4.2 Meta-Analysis Statistical Methods

The Meta-Data set was analyzed using the statistical program R. A statistical program was needed over a general spreadsheet program due to the size of the data set. R was chosen over other statistical programs as it provided means for a wide variety of statistical and graphical analysis. R is also open-source and platform-independent, which offers reproducibility of the analysis[3].

The human data were analyzed first, followed by the faunal data, then the two were combined; to determine the difference between the human and faunal samples (for the three most common species, *Bos taurus, Sus domesticus*, and *Ovis/ Caprid*) at each location, for both carbon and nitrogen. The following section outlines the specific methods used in the statistical analysis. Each analysis was started by excluding outlying samples from the data set. Any samples from sites that did not have both human and faunal samples were excluded from the human-faunal analysis. Individuals identified as outliers were excluded by determining the $\delta^{13}C$ and $\delta^{15}N$ means and two standard deviations for each site and identifying and removing any individual that fell more than two standard deviations from their sites mean. The aim of excluding outliers was to insure that the statistical analyses faithfully represents the central tendency of each population. Even with the loss of the outlying faunal samples there was still a sufficient number of samples remaining to consider the baseline reasonably robust.

Categorical variables were analyzed first. These include, time period, sex, coastal vs. inland, location, and climate zone. The analysis of the categorical data was conducted using analysis of variance (ANOVA) tests in cases with more than two categories (time period, location and climate zone) and univariate linear regressions

[3] R can be downloaded at https://www.r-project.org/

for variables with only two categories (sex and coastal versus inland). This was done for both $\delta^{13}C$ and $\delta^{15}N$.

Analyses of the numerical variables were then conducted using univariate linear regressions relative to both $\delta^{13}C$ and $\delta^{15}N$ individually. Primary results are based on the individual significance (regression t-tests) of each variable analyzed separately. This means that both $\delta^{13}C$ and $\delta^{15}N$ were regressed against the latitude, longitude and altitude (meters above sea level) of the site as well as climatic variables from nearby weather stations. The climatic variables included 30 variables related to temperature and 18 variables related to precipitation. The temperature variables were the mean temperature (in degrees Celsius) for each month, the standard deviation from that mean for each month, the mean annual temperature, the standard deviation for the mean annual temperature, and the mean temperature for each of the four seasons (calculated from the monthly temperatures). While the precipitation variables included the mean monthly precipitation (in millimeters), the mean total annual precipitation, the standard deviation from the mean total annual precipitation, and the calculated total precipitation for each season.

The univariate analysis, however, does not account for joint effects and is likely to lead to biased result as each regression omits relevant variables (Sharma 1996). Therefore, univariate regressions were followed by multivariate linear regression analysis. Interactions between different variables were considered using direct interaction effects in the regression analyses. One issue that arises when analyzing such a large data set with so many regressions is the possibility of statistically significant results, which, nevertheless, accounts for only a small proportion of overall variance. For this reason, R^2 values are reported along with p-values, to clarify the relationship between two variables. R^2, as a measure of

goodness of fit, cannot be directly compared between univariate and multivariate regressions, since R^2 increases as the number of independent variables is increased. To avoid this, the adjusted-R^2 value, which is corrected for the number of variables included in the regression, was used for model comparisons (Sharma 1996).

5.5 Faunal Correction Model

The Faunal Correction Model is a new method to compare $\delta^{13}C$ and $\delta^{15}N$ results from different sites, which aims to minimize the effects of non-dietary variables associated with each location. This was done by comparing the differences between the human and faunal samples at each site. The model was constructed using only the 22 locations that had associated faunal data. As with the Meta-analysis, outliers, defined as those samples outside 1.5 times the Interquartile range of either $\delta^{13}C$ or $\delta^{15}N$, for each species, were excluded. This left a total of 1065 human samples and 281 faunal samples (84 cow, 76 pig, and 121 sheep/goat).

The simplest method of faunal comparison would be to subtract the faunal mean of a given isotope from the corresponding human mean. However, this loses the interpretive power of the standard isotopic scales, especially in terms of using $\delta^{13}C$ for making C_3 - C_4 comparisons. A better model is one expressed using the same scales as standard isotopic measurements. A second concern with this simple model is that it is easily subject to a bias created by the availability of different species of fauna, which may not accurately reflect a base-line on which dietary inferences can be made (Pearson & Grove 2013). A third problem is that by reducing all of the data to means, the identification and interpretation of outliers is lost.

Given these concerns and acknowledging that each site will have unique availability of faunal samples, the first step of a faunal correction was the

construction of a faunal standard, much as Van Klinken *et al.* (2002) used the arbitrary value of wood (Van Klinken *et al*. 2002). The faunal standards for the current data set ($\delta^{13}C_{Fs}$ and $\delta^{15}N_{Fs}$) were created in three steps. First, a **Species Mean** was calculated for each site. Second, a **Site Faunal Mean** for each site was calculated from the available Species Means. Finally, a **Faunal Standard** was calculated as the mean of all the Site Faunal Means currently under consideration. This was done in order to give all sites and all species equal weight in the Faunal Standard. While this is by no means the only manner to weight this calculation, it is the most straightforward in terms of theory and the data available. Other methods that could be explored in the future include: using wild species (to minimize the

Species Mean ($S\bar{x}$)

$$\delta^{13}C_{S\bar{x}} = \left[\frac{\sum \delta^{13}C_{species}}{n} \right] \qquad \delta^{15}N_{S\bar{x}} = \left[\frac{\sum \delta^{15}N_{species}}{n} \right]$$

- The sum of $\delta^{13}C$ or $\delta^{15}N$ of each species divided by the number of samples of each species

Site Faunal Mean ($SF\bar{x}$)

$$\delta^{13}C_{SF\bar{x}} = \left[\frac{\sum \delta^{13}C_{S\bar{x}}}{n} \right] \qquad \delta^{15}N_{SF\bar{x}} = \left[\frac{\sum \delta^{15}N_{S\bar{x}}}{n} \right]$$

- The sum of the $\delta^{13}C$ or $\delta^{15}N$ **Species Means ($S\bar{x}$)** divided by the number of species from a site

Faunal Standard (Fs)

$$\delta^{13}C_{Fs} = \left[\frac{\sum \delta^{13}C_{SF\bar{x}}}{n} \right] \qquad \delta^{15}N_{Fs} = \left[\frac{\sum \delta^{15}N_{SF\bar{x}}}{n} \right]$$

- The sum of the $\delta^{13}C$ or $\delta^{15}N$ **Site Faunal Means ($SF\bar{x}$)** divided by the number of sites

effects of variation in animal husbandry practices), biasing the data based on the amount of protein potentially available from each species, and, of course, the elimination of suspect data from a given species or sample based on the judgement of the investigator.

The last step in this Faunal Correction Model was to subtract the Site Faunal Mean ($\delta^{13}C_{Fauna}$ or $\delta^{15}N_{Fauna}$) from each individual human sample value ($\delta^{13}C_{Human}$ or $\delta^{15}N_{Human}$) for that site, and add the Faunal Standard ($\delta^{13}C_{Fs}$ or $\delta^{15}N_{Fs}$) established for the inter-site analysis (see formulas below). This effectively replaced each Site Faunal Mean with that of the Faunal Standard, normalizing the faunal contribution to human isotopic values of all sites contributing to the inter-site comparison.

$$\delta^{13}C_{Fc} = \left[\delta^{13}C_{Human} - \delta^{13}C_{Fauna} \right] + \delta^{13}C_{Fs}$$

$$\delta^{15}N_{Fc} = \left[\delta^{15}N_{Human} - \delta^{15}N_{Fauna} \right] + \delta^{15}N_{Fs}$$

The Faunal Correction Model adjusts the isotope values for the human samples at each site based the differences between the faunal data from that site and the mean faunal values for all the sites currently under consideration, the Faunal Standard. This correction was accomplished using only isotopic data, limiting sources of error to those which characterize all such isotopic data. This also means that in use, no additional technique or medium beyond that of isotopic analysis was required.

Chapter 6: Osteological and Isotopic Results

In this chapter, the osteological results for Sanisera and Mérida are presented for human and faunal samples, followed by the results of radiocarbon dating and finally the carbon and nitrogen isotopic findings of the faunal and human samples from both Sanisera and Mérida.

6.1 Osteological Results

6.1.1 Sanisera

6.1.1.1 Faunal Age at Death

Age at death for the 24 faunal samples was estimated using the methodology outlined in Grant 1982. The age categories were Juvenile, Older Juvenile and Adult (more on how these categories were defined can be found in Chapter 5). The results of the wear assessment for each individual tooth can be seen in Appendix 2 and the summary of these results are shown in Table 6.1. Two-thirds of the fauna sampled were adults, suggesting that they were being kept for their secondary by products as well as being used for meat.

Table 6.1: Number of analyzed faunal samples per age group by species.

Species	Common Name	Age Group	n	Percent of species
Bos Taurus	Cattle	Adult	4	100%
Canis Canis	Dog	Adult	1	100%
Sus domesticus	Pig	Juvenile	3	30%
		Older Juvenile	2	20%
		Adult	5	50%
Ovicaprid	Sheep/Goat	Juvenile	1	11%
		Older Juvenile	2	22%
		Adult	6	67%

6.1.1.2 Human Age at Death

The age at death of 76 individuals from Sanisera Necropolis 6 was determined using dental attrition, as outlined in Brothwell 1989 and in Chapter 5. The assessment of wear stage for each of the 117 teeth collected from the 76 individuals can be seen in Appendix 2. The summary of the results is shown in Table 6.2 and Figure 6.1.

Table 6.2: Number of analyzed individuals, from Sanisera, per age at death category (as defined by the methods outlined in Brothwell 1989).

Age at Death Category	n	Percent of Analyzed Population
<17	17	22.4%
17-25	34	44.7%
25-35	11	14.5%
33-45	11	14.5%
45+	3	3.9%

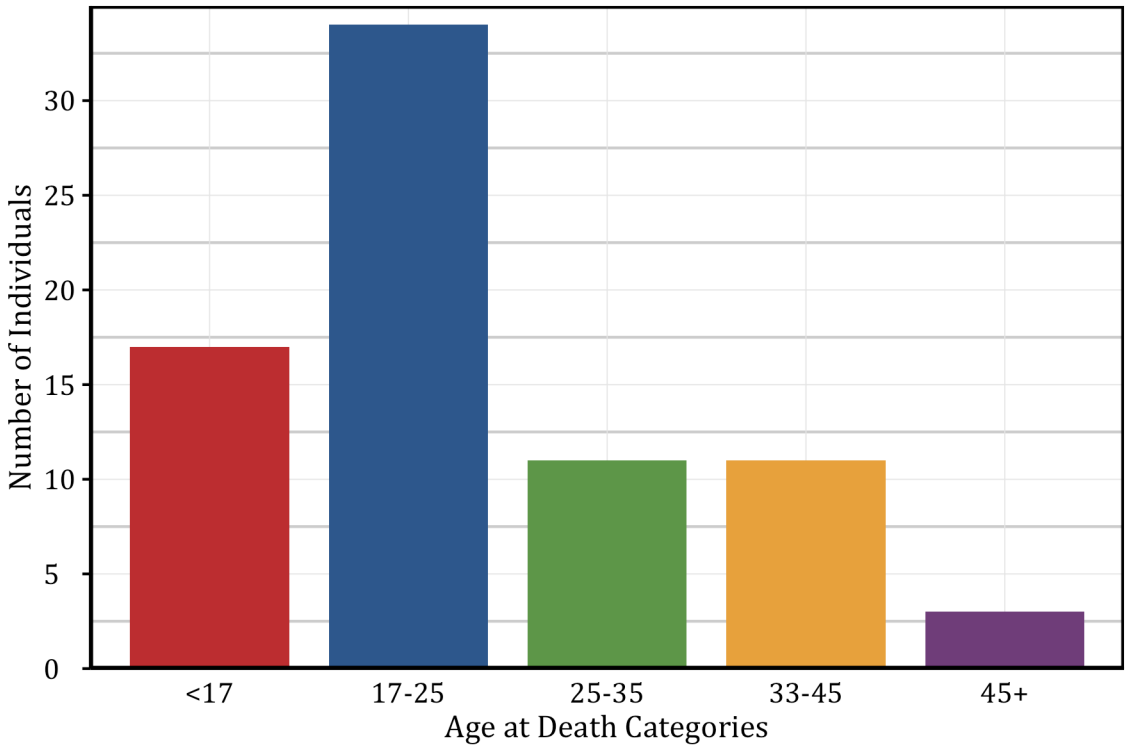


Figure 6.1: The number of individuals, from Sanisera, in each age at death category as defined by the methods outlined in Brothwell 1989.

Determination of age at death based solely on dental attrition will likely differ from age at death assessments based on the full skeleton (which would include a review of cranial sutures, pubic symphyses, auricular surface and dental wear[1]). This variation can be attributed to dietary differences between the population used to establish Brothwell's standard, and the Sanisera samples. Specifically, differences in the physical consistency of the diets of the two populations might produce variations in the wear of the teeth. The British Neolithic to Medieval populations used to establish the standard (Brothwell 1989; 72) most likely consumed a diet that lead to more extreme wear patterns, due to the coarser nature of their diet. Despite the discrepancy between these two age at death assessments, the distribution of the age at death estimates done with Brothwell's method match the overall distribution curve of the adult population assessed using a wider range of methods (Hurst *et al.* 2011). Regardless of the true age of these individuals, the relative aging provided by dental wear should be consistent within the population, and serves as a framework for interpreting the stable isotope results.

6.1.2 Mérida

6.1.2.1 Faunal Age at Death

The cattle from the nearby site of Casa Herrera were determined to be adults using the methods outlined in Grant 1982. Since these were the only faunal samples collected from Mérida, they were compared to contemporary sites to provide an isotopic baseline against which to compare the human data.

[1] These elements were not used in this study since they were not present for all individuals.

6.1.2.2 Human Age at Death

The results of age at death for the humans, as assessed by dental attrition, can be seen in Table 6.3 and Figure 6.2.

Table 6.3: The number of individuals and the percent of the analyzed populations, from each Mérida site, in each age at death category (as defined by the methods outlined in Brothwell 1989).

Site (no.)	Age at Death Category	n	Percent of Analyzed Population
Nova Romana (1021)	17-25	2	67%
	25-35	1	33%
Nova Romana III (7017)	17-25	10	77%
	25-35	3	23%
Nuevo Mérida (7034)	17-25	3	80%
	25-35	1	20%
Velada (8060)	17-25	6	50%
	25-35	4	33%
	35-45	2	17%
YAC (83925)	17-25	1	33%
	25-35	1	33%
	33-45	1	33%

Of the 35 individuals included in this study, 22 have the dental wear of individuals between the ages of 17 and 25, ten were estimated between the ages of 25 and 35, and three were estimated to be aged between 33 and 45. While individuals in the study were preselected to be adults, the majority of individuals have dental wear indicating a relatively young age. With this population being spread across five different necropoles and multiple time periods, the lack of dental wear suggested that the diet of individuals from Mérida was particularly soft and that age at death based on dental attrition may underestimate the true age at death. Supporting this hypothesis was the age at death assessment done for the individuals from Nova Romana III, using other osteological indicators, in which over two-thirds of the individuals (9 of 13) fall between the age of 40 and 60. Again, what is

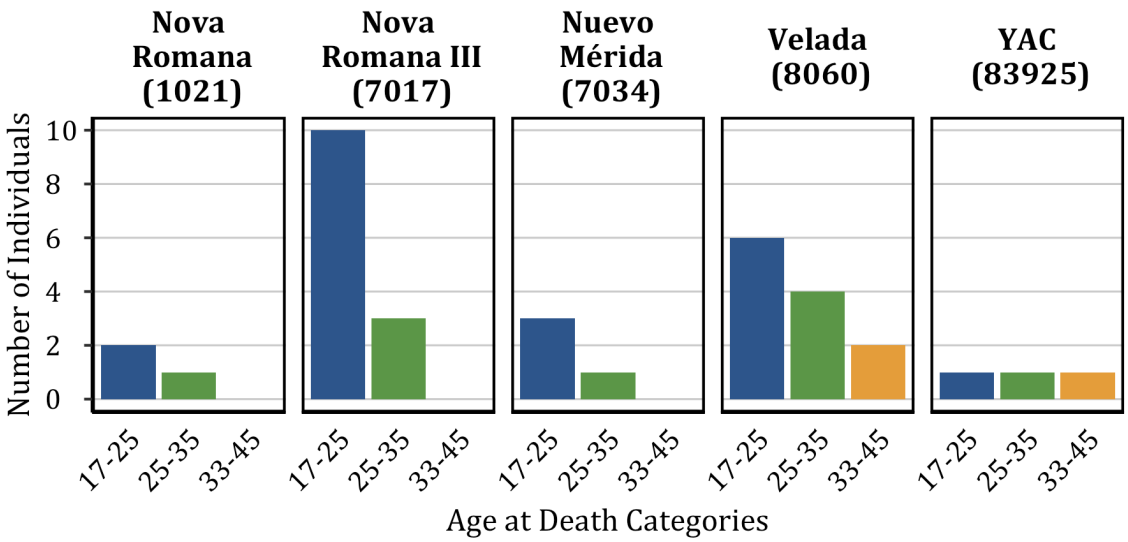


Figure 6.2: The number of individuals, from each Mérida site, in each age at death category as defined by the methods outlined in Brothwell 1989.

important to keep in mind is that these age estimates were aimed to provide a relative age at death, rather than an absolute age at death.

6.2 Radiocarbon Dating Results

Five samples were chosen for exploratory radiocarbon testing at the Oxford Radiocarbon Laboratory. This was done to confirm the dates of the samples used in this study. The paucity of artifacts from Necropolis 6 and the enriched $\delta^{13}C$ values of some of the Mérida samples made for uncertain dates. With this in mind, the samples were submitted for radiocarbon dating to confirm the original dates.

Four of the five samples submitted were preserved well enough to test. The fifth sample, F2, was not acceptable by laboratory standards. The results of the radiocarbon dating results for each of the four samples can be seen in Table 6.4 and Figures 6.3 though 6.6. The dates were calibrated using Oxcal version 4.2.3 (Ramsey 2013), and the IntCal 13 atmospheric curve (Reimer *et al*. 2013).

Table 6.4: The calibrated and uncalibrated radiocarbon dates of samples from Mérida and Sanisera. The calibrated dates were calibrated using Oxcal version 4.2.3 (Ramsey 2013), and the IntCal 13 atmospheric curve (Reimer *et al.* 2013).

Site	Sample	OxA	$\delta^{13}C$	Date BP	Date cal AD
Sanisera	S-86	OxA-V-2553-9	-18.5	1549 ± 27	425-570 cal AD(95.4%)
	S-106	OxA-V-2553-10	-18.5	1572 ±27	418-548 cal AD (95.4%)
	S-F2	P-35328	NA	NA	NA
Mérida	NR3-25	OxA-V-2552-54	-19.0	1272 ±27	665 - 775 cal AD (95.4%)
	V-nn	OxA-V-2551-37	-14.1	1352 ±23	641-690 cal AD (94.1%) / 752-760 cal AD (1.3%)

The samples from Sanisera date to the 5th and 6th centuries AD, which concurs with dates for Necropolis 6 established using archaeological material (Hurst *et al.* 2011). Sample 25 from Nova Romana III was from Tomb A6, which was classified as one of the 39 burials of the Islamic Period (see Chapter 4), and dated to between the 8th and 10th centuries AD. The radiocarbon dates fall within the earlier

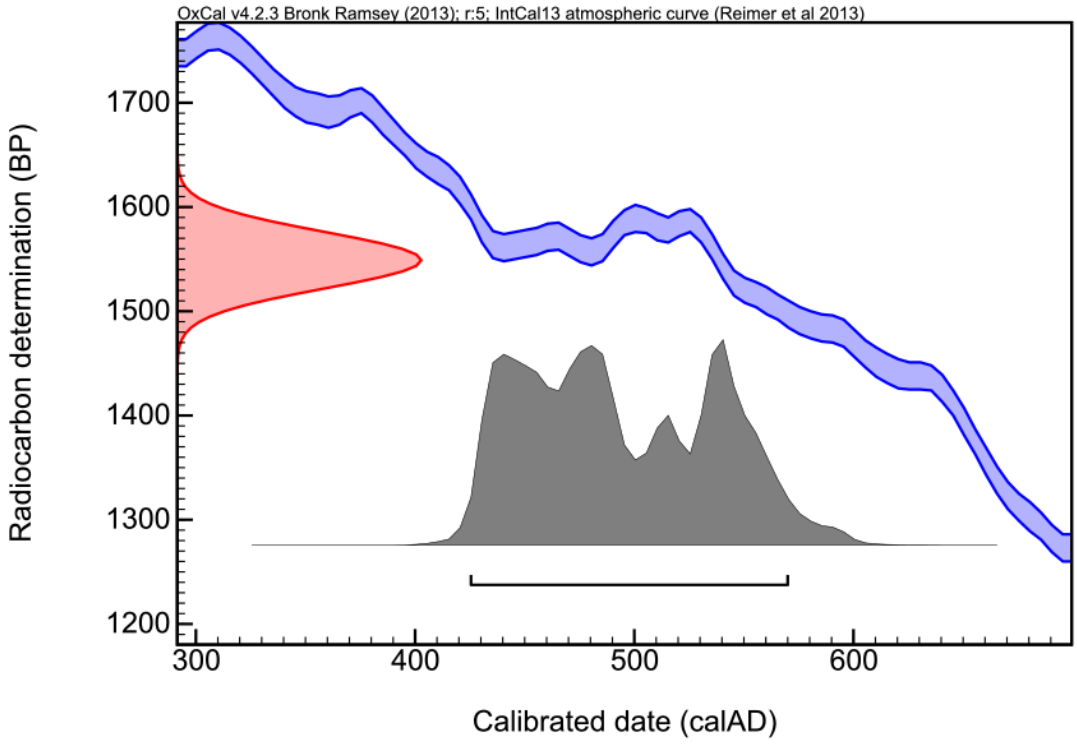


Figure 6.3: The radiocarbon determination in years BP and the calibrated date for Sample 86 from Sanisera, Necropolis 6.

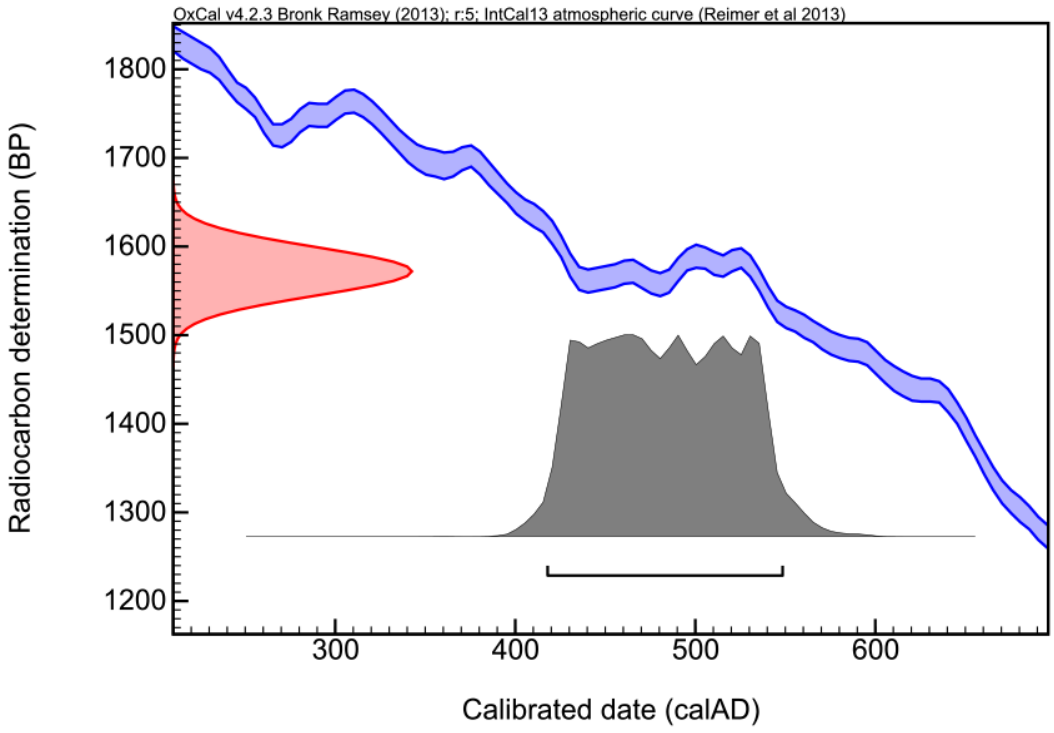


Figure 6.4: The radiocarbon determination in years BP and the calibrated date for Sample 106 from Sanisera, Necropolis 6.

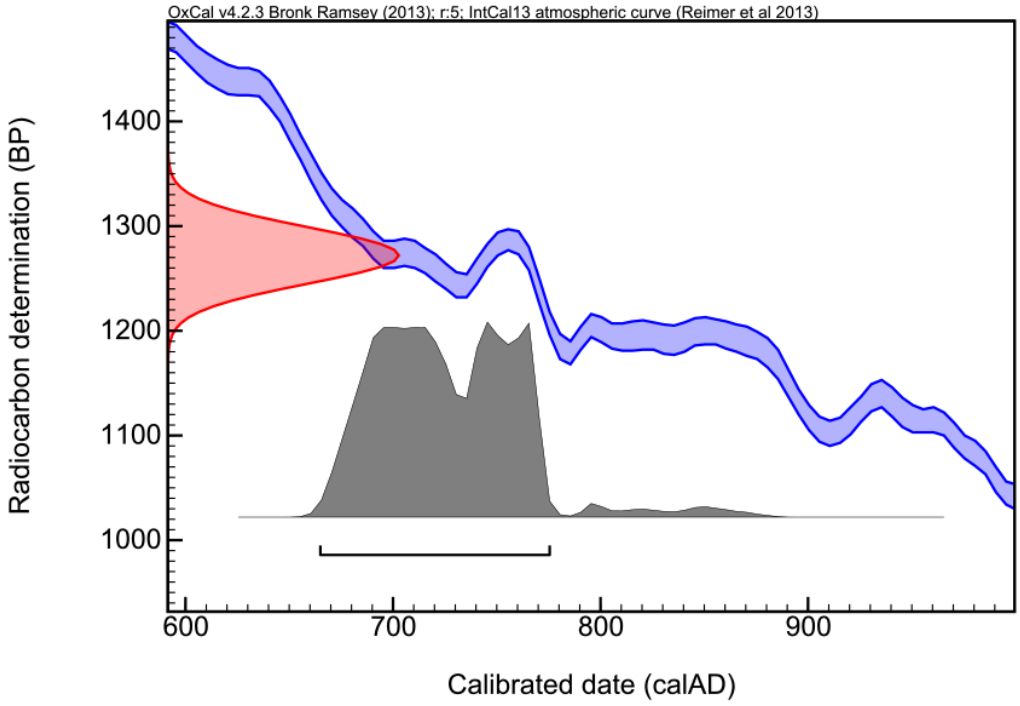


Figure 6.5: The radiocarbon determination in years BP and the Calibrated date for Sample NR3-25 from Mérida.

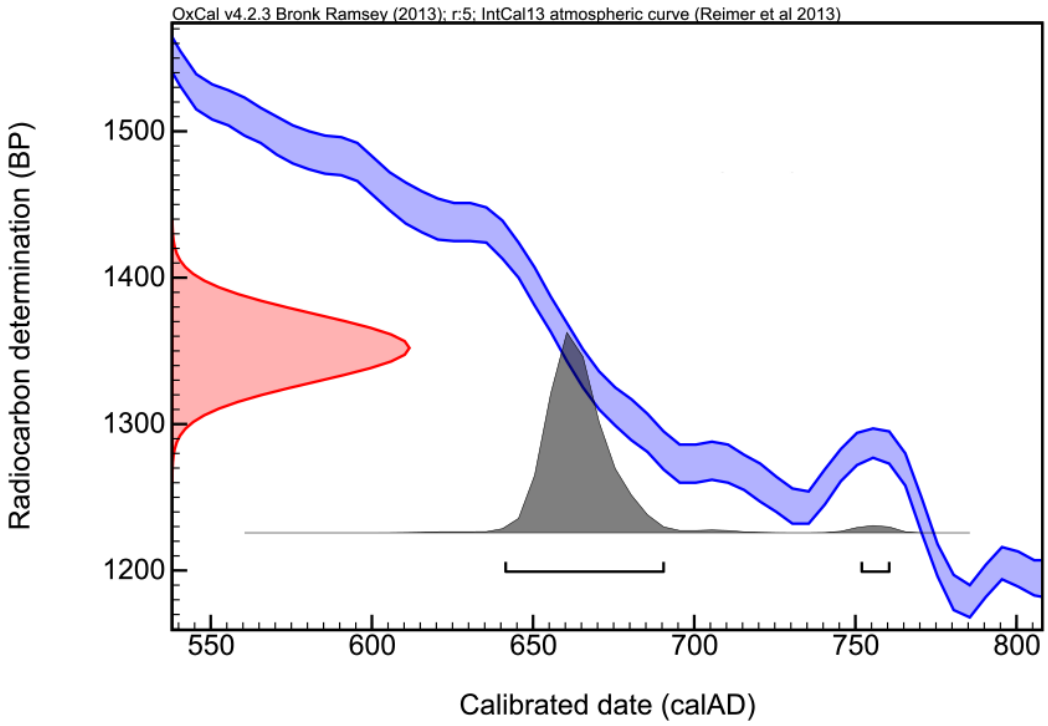


Figure 6.6: The radiocarbon determination in years BP and the Calibrated date for Sample V-nn from Mérida.

range of this period. The site report (Alba Calzado 2005) notes that a quarter of the Islamic remains had their faces oriented to the south, and suggests that this could be an indication of earlier chronology, because in the early days of Islam in al-Andulus the Qibla, or direction of Ka'abba in Mecca, was not as firmly established. The report also references that the mosque of the Alcazaba in Mérida was constructed in AD 835 and was oriented correctly (Alba Calzado 2005; 339). The radiocarbon date of Sample 25 (cal AD 665-775) fits with this assessment.

Sample V-nn from Velda was so named because, while identified as from the site of Velada, it was not labeled as being associated with any one context. This, coupled with the individual's unusually high $\delta^{13}C$ value from second molar dentine (-13.38‰) put inclusion in this study in jeopardy. However, its radiocarbon date suggests it was from the Late Antique Period which coincides with the dating of the other samples from Velada, and carbon and nitrogen isotope values from other samples originating from this individual fell within the normal distribution of the sample population.

6.3 Isotopic Results

6.3.1 Sanisera

6.3.1.1 Faunal

Isotope analysis of contemporary faunal remains is commonly used to determine the local isotope baseline and, thus, to better understand the human diets. The results of the carbon and nitrogen isotope analysis of the faunal samples from the site of Sanisera can be seen in Table 6.5 and Figure 6.7.

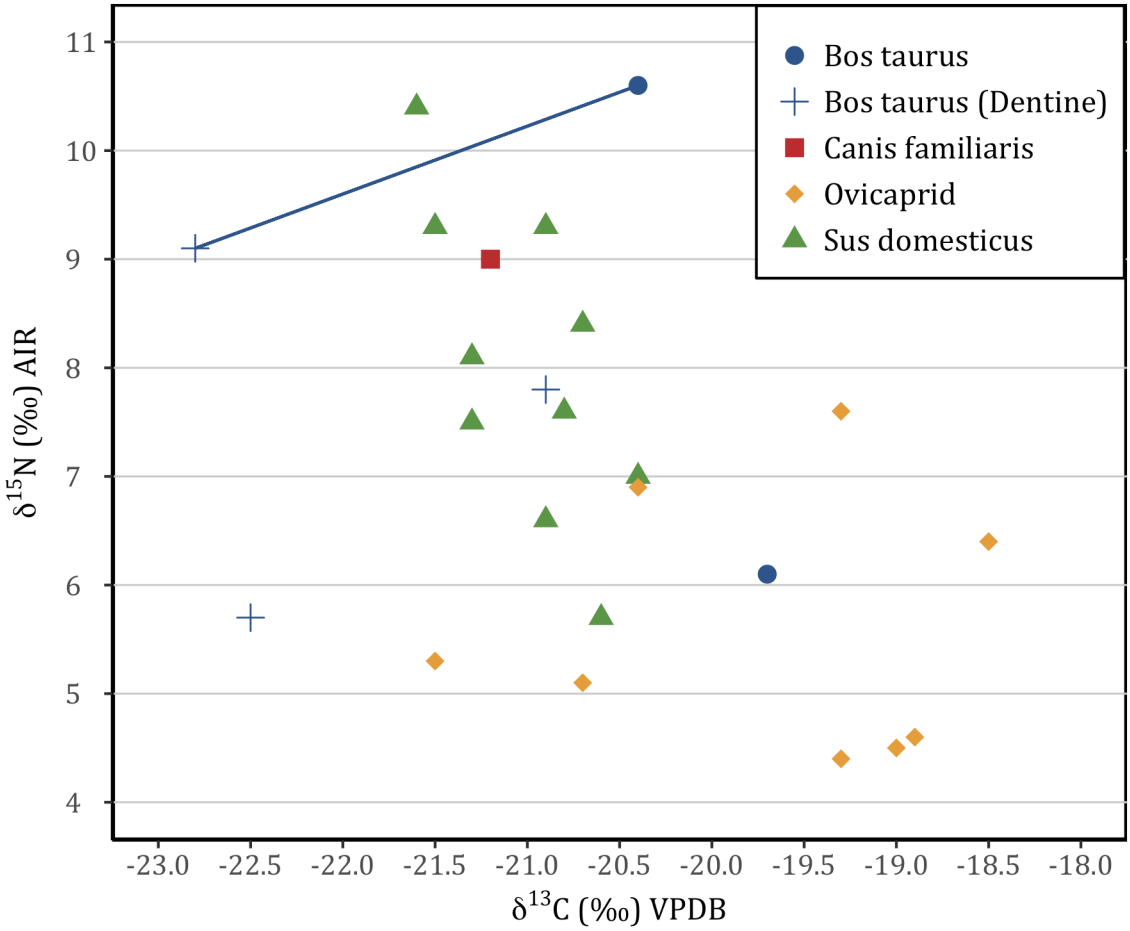


Figure 6.7: The $\delta^{13}C$ and $\delta^{15}N$ results on the faunal bone samples and the cow dentine samples from Sanisera. The connected samples were from the same cow.

Table 6.5: Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of bone and dentine collagen taken from the fauna found at the city site of Sanisera. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), are italicized.

Sample	Species	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
F 1	*Bos taurus*	Maxilla	3.8	41.0	14.7	3.3	-19.7	6.1
F 2	*Bos taurus*	Maxilla	2.2	31.3	10.5	3.5	-20.4	10.6
	Bos taurus	M2	9.6	21.1	7.5	3.3	-22.8	9.1
F 4	*Bos taurus*	M3	12.2	34.3	12.2	3.3	-22.5	5.7
F 5	*Bos taurus*	M2	11.5	36.9	13.4	3.2	-20.9	7.8
F 8	*Canis canis*	Mandible	2.0	16.7	5.8	3.4	-21.2	9.0
F 9	*Sus domesticus*	Mandible	7.8	44.8	16.0	3.3	-21.3	7.5
F 10	*Sus domesticus*	Mandible	5.8	42.5	35.3	3.3	-20.8	7.6
F 11	*Sus domesticus*	Mandible	6.8	40.4	35.3	3.3	-21.3	8.1
F 12	*Sus domesticus*	Mandible	4.6	30.9	35.9	3.3	-20.9	9.3
F 13	*Sus domesticus*	Mandible	9.8	37.5	13.4	3.3	-21.5	9.3
F 14	*Sus domesticus*	Maxilla	7.8	33.5	12.1	3.3	-20.4	7.0
F 15	*Sus domesticus*	Mandible	3.0	40.8	13.9	3.4	-20.9	6.6
F 16	*Sus domesticus*	Maxilla	7.7	30.1	10.7	3.3	-21.6	10.4
F 17	*Sus domesticus*	Mandible	12.2	42.0	35.9	3.3	-20.7	8.4
F 18	*Sus domesticus*	Maxilla	4.2	37.6	35.5	3.3	-20.6	5.7
F 19	Ovicaprid	Mandible	4.6	26.8	9.4	3.3	-20.7	5.1
F 20	Ovicaprid	Mandible	5.8	40.5	35.4	3.3	-18.9	4.6
F 21	Ovicaprid	Mandible	4.7	35.8	35.6	3.3	-20.4	6.9
F 22	Ovicaprid	*Mandible*	*0.7*	-	-	-	-	-
F 23	Ovicaprid	Maxilla	5.4	36.6	13.1	3.3	-21.5	5.3
F 25	Ovicaprid	Mandible	4.8	40.8	35.1	3.3	-19.3	7.6
F 26	Ovicaprid	Mandible	7.0	42.0	35.9	3.3	-18.5	6.4
F 27	Ovicaprid	Mandible	9.1	44.2	35.3	3.3	-19.3	4.4
F 28	Ovicaprid	Mandible	4.9	43.2	15.4	3.3	-19.0	4.5

Of the 25 faunal samples only one (F22) failed to produce enough collagen to test due to poor preservation of the sample. The remaining samples tested all had adequate preservation; defined as >1% collagen (Dobberstein *et al.* 2009) and a C:N ratio between 2.9 to 3.6 (DeNiro 1985). As previously stated the analytical error for the carbon and nitrogen isotope analysis run in this thesis is ±0.2‰ for $\delta^{13}C$ and

±0.1‰ $\delta^{15}N$. It is also important to specify that the dispersion in the following analyses is given as ±1 standard deviation from the mean.

Table 6.6: The means of $\delta^{13}C$ and $\delta^{15}N$ (± σ) of each species from the fauna sampled from Sanisera. The means consist of bone collagen, except for the *Bos taurus* mean, which is derived from one bone sample and three dentine samples.

Species	Common name	n	$\delta^{13}C$ ± σ (‰)	$\delta^{15}N$ ± σ (‰)
Bos taurus	Cow	4	-21.5 ± 1.4	7.2 ± 1.6
Canis canis	Dog	1	-21.2	9.0
Sus domesticus	Pig	10	-21.0 ± 0.4	8.0 ± 1.4
Ovicaprid	Sheep/Goat	8	-19.7 ± 1.0	5.6 ± 1.2

From these results, it can be seen that, as would be expected, the fauna from Sanisera had a plant-based terrestrial C_3 diet. While inter-species variation suggested differences in animal husbandry practices between each species (For faunal means see Table 6.6).

The bovine sample with a $\delta^{15}N$ value above 10.5‰ was unusual, as such high values were more in keeping with a human population. However, animals were commonly kept in stalls during this time period (White 1970; 126) and increased $\delta^{15}N$ could indicate an animal being fed crops fertilized with manure (Bogaard *et al.* 2007). The values for the dentine of that same cow were lower in $\delta^{15}N$ as well as $\delta^{13}C$, which could suggest that its diet differed over the course of its life. Despite the difference in this one pairing, there was no significant difference between the mean values of the bovine bone and dentine samples overall (Mann-Whitney Test, $\delta^{13}C$ p=0.248 and $\delta^{15}N$ p=0.564). With this in mind, the bone and dentine samples were considered together, with the dentine sample from F2 being excluded to avoid redundancy[2].

[2] The dentine sample was chosen over the bone sample, due to the F2 bone sample having such an unusually high $\delta^{15}N$ value as compared to the other 3 bovine samples.

The range of isotope values in the sheep/goats (*Ovis/Caprid)* and the pigs (*Sus domesticus)* suggested a variety of dietary regimes. One explanation is local variation in animal husbandry practices, with different families feeding their animals differently, or at least confining them to pastures having different plant species. Leaving animals, particularly sheep, to roam is congruent with modern animal husbandry practices on the island. The range of $\delta^{15}N$ values in the pigs suggests an omnivorous diet, were it not for the high bovine values. With that in mind, all the $\delta^{15}N$ values indicate is that the pigs sampled consumed different plants than the sheep/goats. The lower $\delta^{13}C$ values for the pigs as compared to the sheep/goats, also support this hypothesis. One possibility is that the pigs preferred to consume plants that grew under the shade of a tree or bush, which, due to canopy effect (discussed previously in Chapter 2), would mean that they were consuming plants with lower $\delta^{13}C$ values. The wider range of $\delta^{15}N$ values might also be due to pigs having a closer association with humans, and consuming human refuse (Hamilton *et al.* 2009; 1000). The $\delta^{13}C$ and $\delta^{15}N$ results for the dog (*Canis canis*) indicate a terrestrial C_3-based diet including small amounts of animal protein. Dogs generally consume a diet similar to the humans they live with/near, on average not varying more than 2-3‰ in both $\delta^{13}C$ and $\delta^{15}N$ across various temporal and cultural contexts (Guiry 2011; 4). The similar isotope values of the dog to some of the pigs tested when compared to the sheep/goats, furthers the hypothesis that the pigs were kept closer to the human settlements and possibly consuming human refuse, while the sheep/goats were left to roam.

6.3.1.2 Human

The 57 human samples (21 bone and 36 dentine) were taken from 36 individuals from Sanisera Necropolis 6 and analyzed using the methods described in Chapter 5. The results of the stable carbon and nitrogen isotope analysis can be seen in Table 6.7 and Figure 6.8.

Table 6.7: Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of the human bone and dentine collagen from Necropolis 6 at Sanisera. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), and a C:N ratio outside the standard 2.9-3.6 (DeNiro 1985), are italicized.

Sample	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPVD	$\delta^{15}N$ (‰) AIR
7	*Mandible*	*0.5*	*41.3*	*13.2*	*3.7*	*-19.3*	*11.7*
	LRM2	12.1	35.7	12.6	3.3	-18.5	12.3
9	Mandible	10.7	39.8	14.4	3.2	-17.7	12.2
	LRM2	17.2	39.2	13.9	3.3	-18.6	13.1
10	LRM2	11.9	39.3	14.3	3.2	-18.9	12.1
11	LRM2	6.7	37.3	13.5	3.2	-19.5	11.7
15	LLM2	10.5	39.1	14.0	3.3	-19.2	12.6
16	LLM2	11.0	40.7	14.4	3.3	-18.6	12.4
18	Mandible	5.7	41.7	15.0	3.2	-18.6	10.5
	LLM2	16.8	34.6	12.4	3.3	-19.1	11.1
21B	LLM2	4.5	32.4	11.6	3.3	-19.9	11.3
26	LLM2	*0.0*	-	-	-	-	-
29	Mandible	7.8	45.6	16.1	3.3	-17.9	12.1
	LLM2	12.3	37.2	12.2	3.6	-19.4	12.7
31	URM2	6.6	39.7	14.3	3.3	-19.4	12.0
32	Mandible	8.1	41.4	14.8	3.3	-18.5	10.3
	LLM2	14.3	51.6	19.1	3.2	-18.8	11.7
35	LLM2	10.0	40.3	14.4	3.3	-18.9	12.2
38	Mandible	3.4	41.1	34.7	3.4	-18.2	12.0
	LLM2	8.2	38.4	13.5	3.3	-18.7	12.2
40	Maxilla	7.8	44.1	35.2	3.3	-18.6	9.2
	URM2	16.3	39.7	14.4	3.2	-18.9	9.1
43	Maxilla	3.3	40.5	34.8	3.4	-18.2	12.5
	URM2	11.0	42.3	15.5	3.2	-18.4	13.1

Sample	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPVD	$\delta^{15}N$ (‰) AIR
52	LLM2	6.3	32.8	11.7	3.3	-20.0	11.0
58	LRM2	10.0	39.7	14.3	3.2	-18.9	12.0
60	*Mandible*	*0.2*	*39.8*	*13.0*	*3.6*	*-20.0*	*12.4*
	LRM2	7.0	43.0	15.4	3.3	-19.4	10.7
61	Mandible	1.8	37.0	12.8	3.4	-17.9	10.9
	LRM2	13.4	34.3	12.2	3.3	-18.4	11.4
62	*Mandible*	*0.0*	-	-	-	-	-
	LRM2	5.0	27.5	9.5	3.4	-18.6	10.2
63	Mandible	5.4	41.3	14.7	3.3	-17.9	11.1
	LRM2	13.0	40.9	14.6	3.3	-18.7	12.6
64	Mandible	3.7	32.5	11.3	3.4	-19.6	11.5
	LRM2	9.9	39.3	14.2	3.2	-18.3	11.6
70	*Mandible*	*0.0*	-	-	-	-	-
	LRM2	*0.0*	-	-	-	-	-
71	*Mandible*	*0.6*	*12.3*	*3.7*	*3.9*	*-20.4*	*10.0*
	LRM2	*0.0*	-	-	-	-	-
80	Maxilla	5.0	43.3	34.5	3.4	-17.9	11.8
	ULM3	12.0	42.5	15.5	3.2	-18.1	11.8
81	Mandible	5.0	43.0	35.4	3.3	-17.2	12.4
	LRM2	18.0	40.0	14.3	3.3	-18.3	11.4
86	Mandible	9.0	44.1	15.7	3.3	-18.1	12.5
	LRM2	11.4	39.2	13.9	3.3	-18.8	13.5
98	LRM2	7.8	41.9	14.7	3.3	-19.3	12.0
103	LRM3	8.1	43.0	15.4	3.3	-18.7	12.1
106	Maxilla	7.9	43.6	35.2	3.3	-18.0	9.2
	URM2	13.1	40.0	14.4	3.3	-18.2	9.9
107	Maxilla	2.9	17.8	6.2	3.4	-19.9	9.0
	URM2	10.7	35.6	12.6	3.3	-17.8	10.5
114 A	LLM2	8.1	38.0	13.6	3.3	-18.6	11.9
114 B	LLM2	8.2	41.7	14.9	3.3	-19.0	12.1
115	LLM2	10.0	41.6	14.9	3.3	-19.1	12.2
119	Mandible	1.9	40.1	13.8	3.4	-18.1	10.9
	LRM2	11.4	30.7	10.8	3.3	-18.6	10.6

Five samples did not produce enough collagen to be tested (the bone from S-26, S-62 and S-70 and the dentine from S-70 and S-71). The samples taken from the mandibles of S-7, S-60, and S-71 had less than 1% collagen, which is an indicator of poor collagen preservation (Dobberstein *et al.* 2009) and were therefore excluded from further analysis. This means that 91% (52 of 57) of the Sanisera samples produced sufficiently well-preserved collagen for analysis. The low collagen yield in the excluded samples was most likely due to greater exposure to the Menorcan

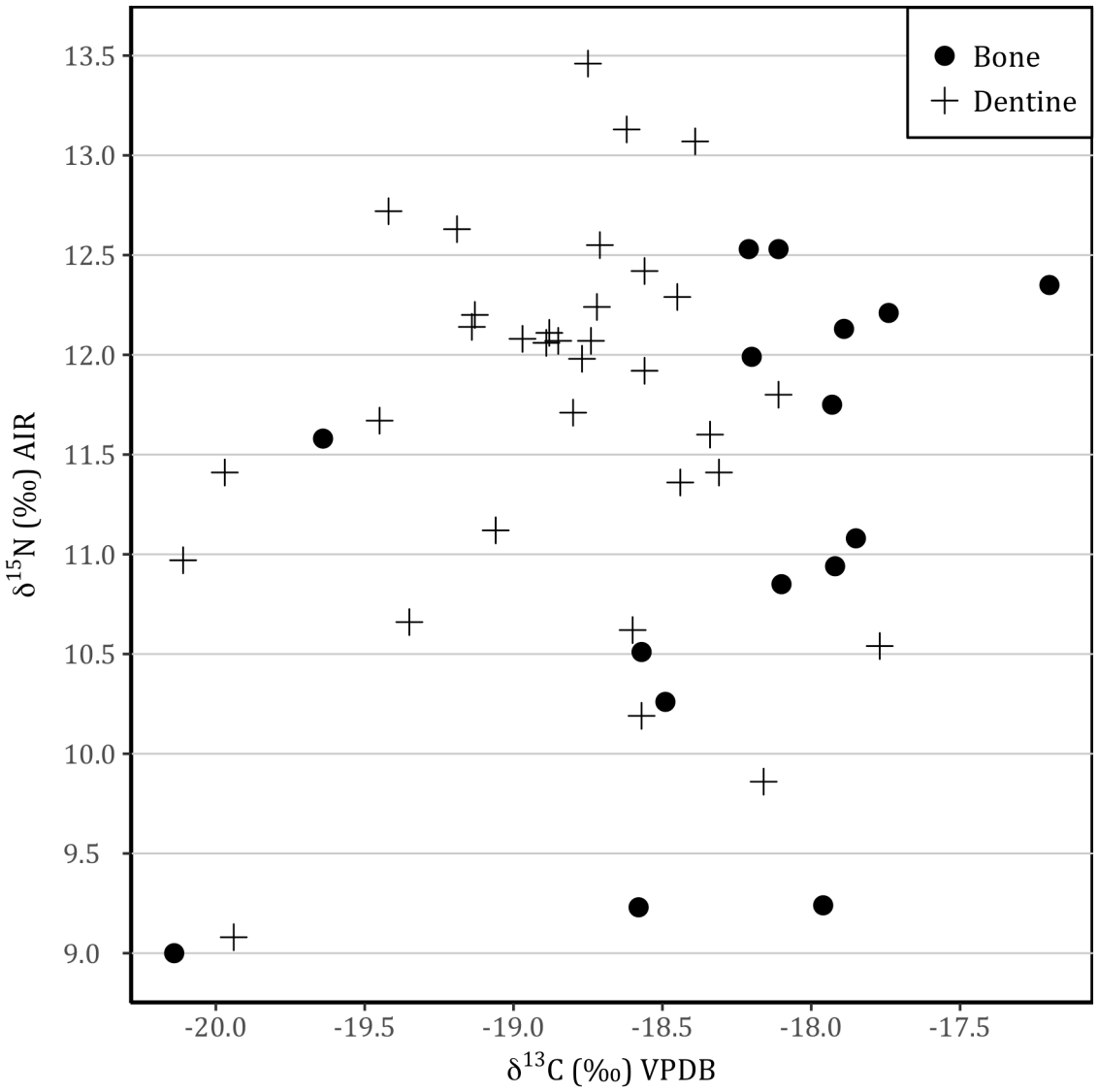


Figure 6.8: The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Sanisera's Necropolis 6.

climate, with its relatively high temperatures, which degrades collagen more rapidly (Collins *et al.* 2002; 385). It is important to note that the $\delta^{13}C$ and the $\delta^{15}N$ values for the accepted samples are not normally distributed, based on the Shaprio-Wilk test. Consequently, Mann-Whitney U tests were used in the statistical analysis.

While both bone and dentine samples were taken for this study, it is important to treat them separately, before discussing them together. Collagen extracted from bone and dentine represent different periods of life during which these tissues were formed. The data from bone collagen, which reflects diet in the last decade or more of life (Hedges *et al.* 2007), were considered first and then the data from the dentine collagen, which relates to early life (Ubelaker 1979, Hillson 2002 & 2005), were reviewed. Finally, the two materials were considered together to gain an understanding of the variation between childhood and adulthood.

6.3.1.2.1 Bone

The sixteen acceptable bone samples (seen in Figure 6.9) had a mean $\delta^{13}C$ of -18.3 ± 0.7‰ and a mean $\delta^{15}N$ of 11.1 ± 1.2‰. In terms of palaeodietary analysis, these results indicate that the diet of those tested consisted mainly of C_3 terrestrial plants and animals, occasionally supplemented with marine resources, although the lack of a relationship between the two isotopes (R^2=0.245) suggests that consumption of marine and animal resources was minimal (Richards and Hedges 1999). This coincides with literary sources and contemporary isotopic studies, the extent to which they do, and what can be concluded visa-via protein scrambling when these results are compared to the faunal results will be discussed in Chapter 7.

Three individuals were identified as outliers to the sample mean (S-40, S-106 and S-107) based on their $\delta^{15}N$ values being more than 1.5 standard deviations from the mean. Individual S-107 was also over two standard deviations from the $\delta^{13}C$

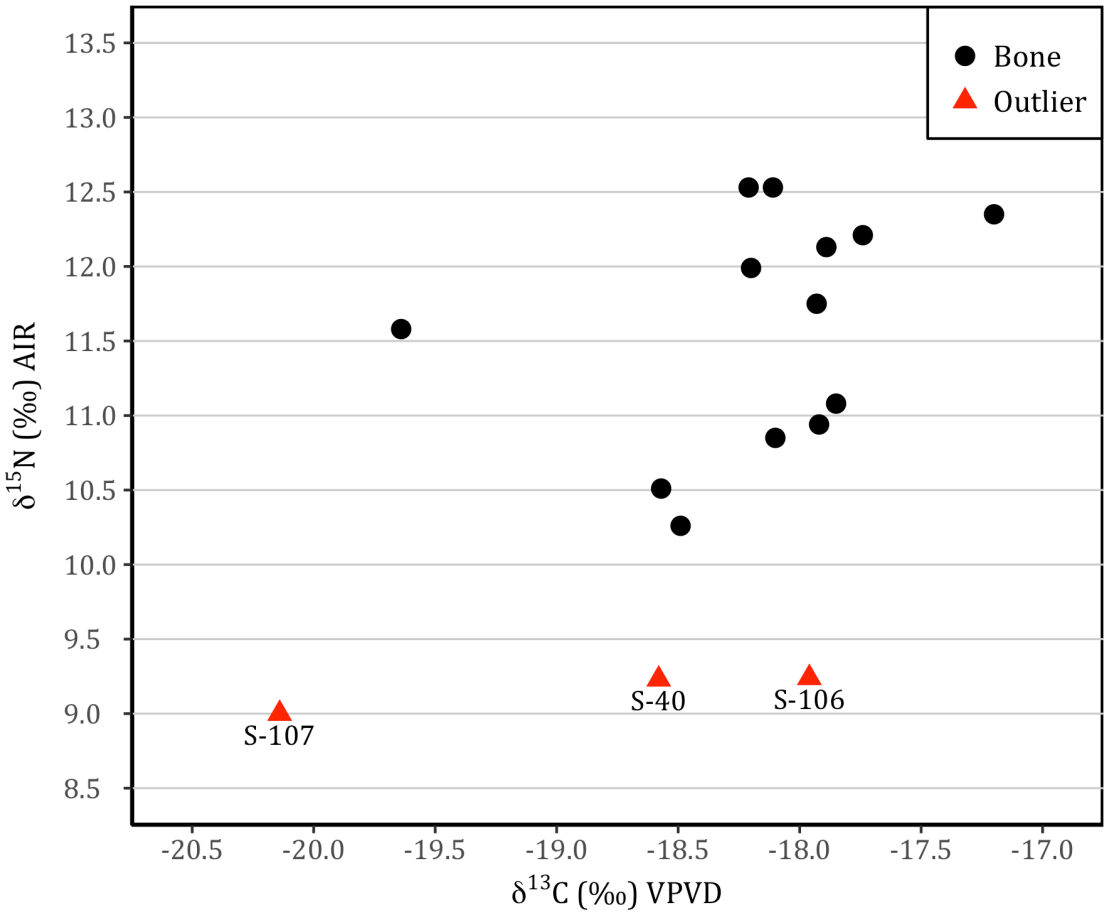


Figure 6.9: The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Sanisera's Necropolis 6 with the outliers (defined as values >2σ from the population mean) identified with red triangles.

mean. The outliers were in no other way distinct from the rest of the sample, they were not from a unique zone, nor were they from unique tombs. There were no artifacts associated with any of the Sanisera individuals, nor were there any bioanthropological differences, such as indications of disease, stress markers or trauma, observed in the bone from which the samples were extracted. The fact that these individuals are isotopically distinct is of interest as it could be indicative of a variety of social factors (i.e. social status, occupations, different origins, etc.) that are not apparent in the archaeological record of this site. This is further explored in Chapter 7. While the outliers are graphed with the rest of the population in Figure 6.9, they were excluded from the statistical analysis. This means that the site mean,

as determined by the remaining thirteen individuals, is -18.1 ± 0.6‰ for $\delta^{13}C$ and 11.6 ± 0.8‰ for $\delta^{15}N$.

The samples in this study originated from thirteen distinct tombs. As stated in Chapter 4, the remains were found within stone-lined tombs with multiple, commingled inhumations (including, in the case of Tomb 13, as many as sixteen individuals). One explanation for multiple inhumations is that these were family tombs. If so, it might be expected that the isotope values for individuals within each tomb would be more similar than isotope values between tombs, given that families would generally share the same socio-economic status and eating habits. However, this was not the case. This may be due to the large number of tombs where only one individual was sampled (10 of 13). However, the variability between the individuals

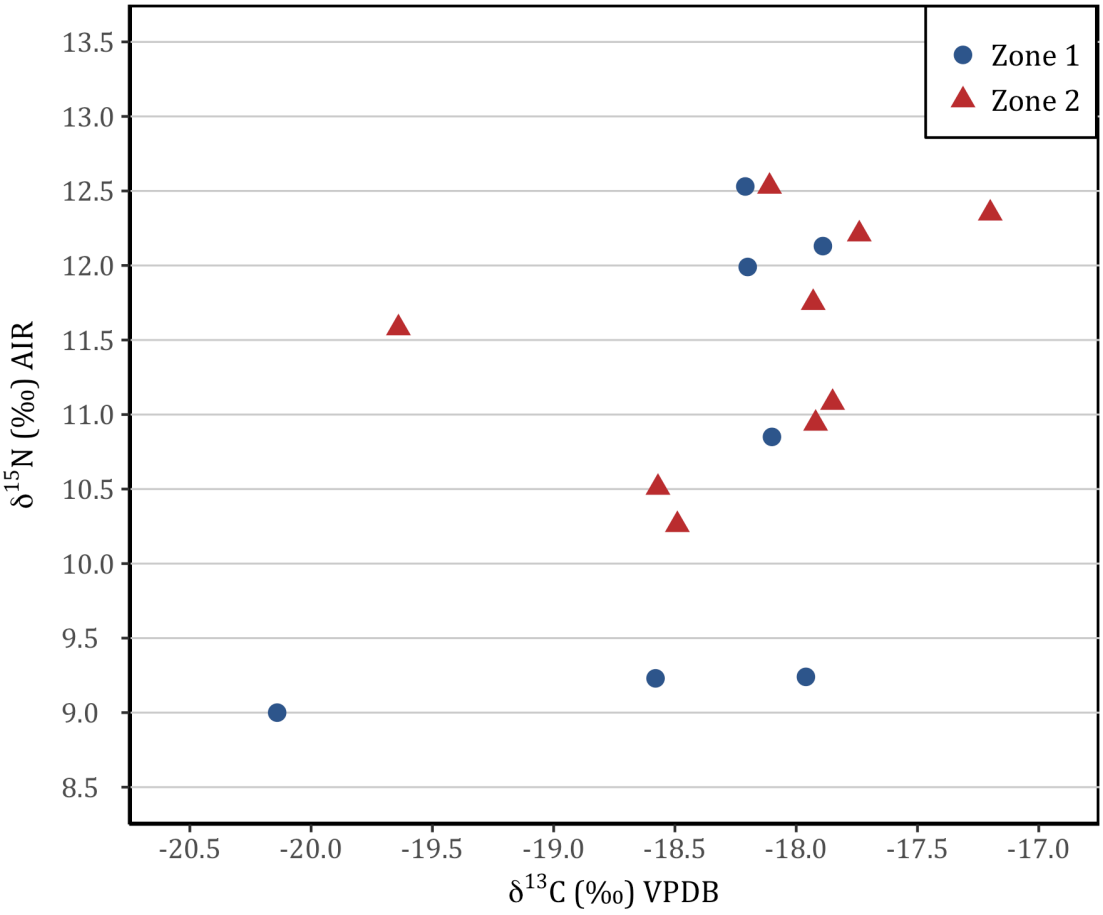


Figure 6.10: The $\delta^{13}C$ and $\delta^{15}N$ results of the human bone samples from Sanisera's Necropolis 6 plotted by Zone.

of similar tombs was considerable, suggesting that there was no correlation between which tomb an individual was buried in and their isotope values.

As noted in Chapter 5, Necropolis 6 of Sanisera was divided into three zones based on geographical location (Hurst *et al.* 2011). For the present study, samples were obtained from two of the three zones (Zones 1 and 2) (see Figure 6.10). There were not enough samples in Zone 1 without the three outlying individuals to make any definitive statistical conclusions, though graphically they do appear to be similar to the individuals from Zone 2.

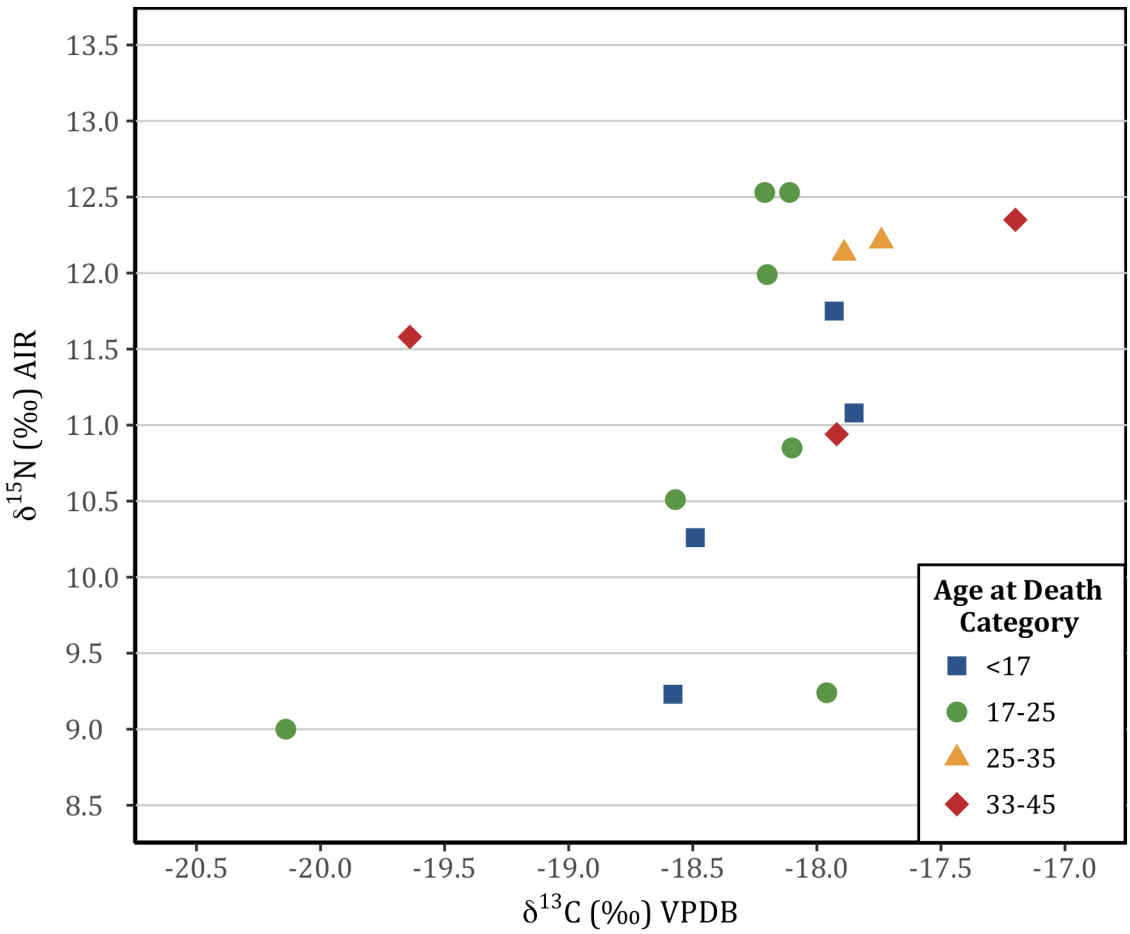


Figure 6.11: The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Sanisera's Necropolis 6, plotted by age at death category, as determined by dental attrition (Brothwell 1989).

The only variable that could be determined osteologically was age at death. As can be seen in Figure 6.11, there was no consistent trend based on age at time of death. The two individuals in the 25-35 age range have the smallest variation of any age group, but due to the small sample size it is impossible for any solid inferences to be made, or statistical testing to be relevant. While it would be interesting to explore the relation between sex and diet, this would require samples where sex can be reliably determined, which, as stated in Chapter 5, was not possible for the samples included in this study, given their poor preservation and incomplete state.

6.3.1.2.2 Dentine

Thirty-three of the thirty-five samples produced collagen deemed acceptable to be included in the analysis. Overall, the dentine was better preserved than the bone; this is not surprising due to the more robust nature of dentine, as well as the protection provided by being encased in mandibular or maxillary bone (Schulting *et al.* 2012). The results of the isotope analysis of the dentine samples can be seen in Table 6.8 (in the next section) and Figure 6.12.

The mean $\delta^{13}C$ of the dentine samples was -18.8 ± 0.5‰, while the mean $\delta^{15}N$ was 11.8 ± 1.0‰. In terms of palaeodietary reconstruction for the Mediterranean region, these isotope values represent a C_3 terrestrial-based diet. Only minor consumption of marine resources was likely given the absence of any positive correlation between the isotopes (see Figure 6.12). There was no variation in isotope values based on tomb or zone (Mann-Whitney U for Zone 1 vs Zone 2 $p=0.873$ for $\delta^{13}C$ and $p=0.624$ for $\delta^{15}N$).

With isotope values of dentine being determined during the development of the tooth, to truly test the effect that age has on isotope values, the age at which each tooth was formed was considered. Only second and third molars were sampled from

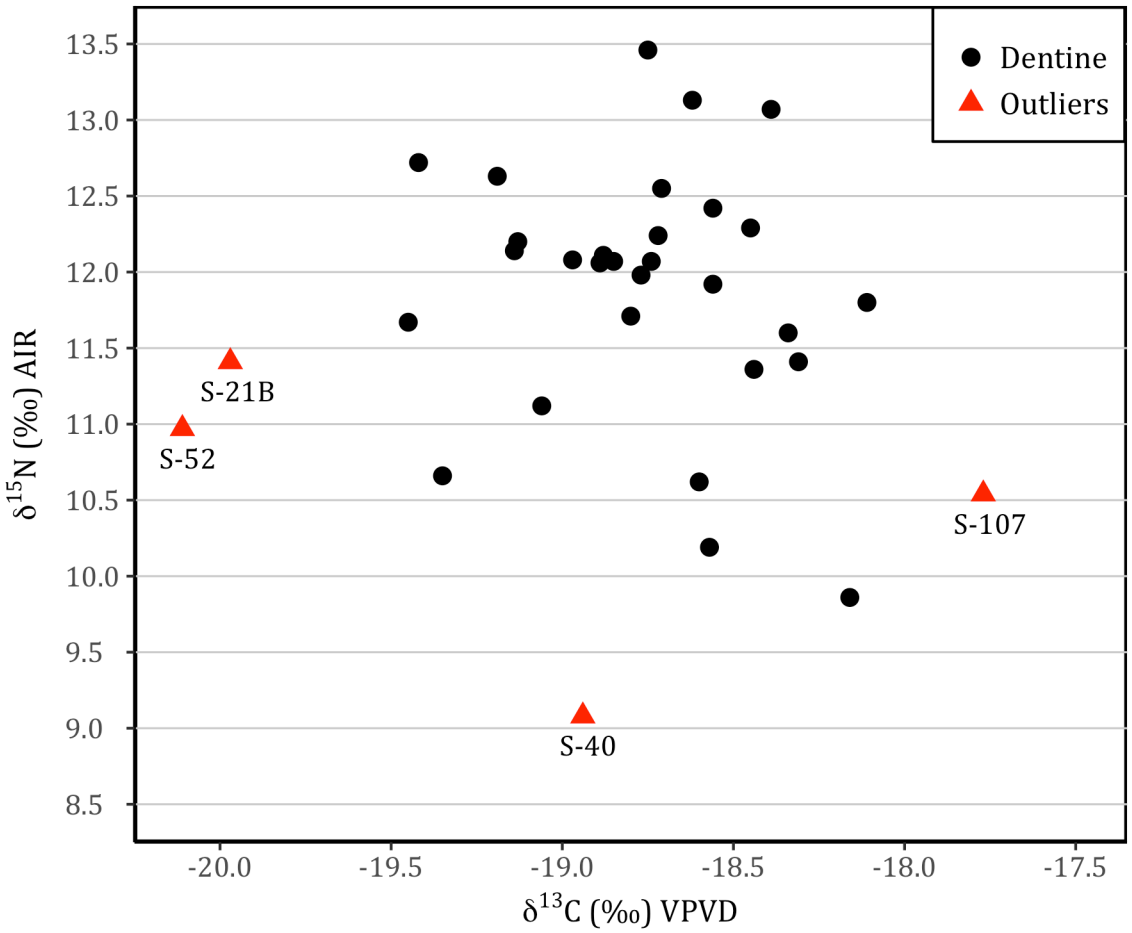


Figure 6.12: The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Sanisera's Necropolis 6 with the outliers (defined as values >2σ from the population mean) identified with red triangles.

the Sanisera population to avoid interference by any weaning signal that might be present in the first molar. As described in Chapter 5, dentine samples were taken from 2-3mm distal from the crown to the root tip. The roots of second molars are formed between ages of 8 and 15, while the roots of third molars are formed between the ages of 13 and 21 (Moorrees *et al.* 1963, Ubelaker 1979). While there are a few years of overlap, the second molar is more representative of late childhood/early adolescence, and the third molar is more representative of late adolescence/early adulthood. Only two samples were taken from third molars, too few for any statistical tests to be meaningful; however, the two samples were both within two standard deviations of the population mean. This suggests that

variations between individuals was likely based on factors uncorrelated with any age-based dietary difference during the period represented.

By comparing age at death to isotope values in dentine, it was possible to look for correlations between diet during adolescence (the isotope values) and longevity. These data address the hypothesis that individuals with low-quality diets do not live as long as individuals with high-quality diets (Sandberg *et al.* 2014). In this instance, low-quality diets were interpreted as being less enriched in ^{15}N and ^{13}C (this is further explained in Chapter 7). The results of this comparison can be seen in Figure 6.13. In terms of the individuals from Sanisera Necropolis 6, there was no difference in age at death correlated with dentine isotope values. Alternately,

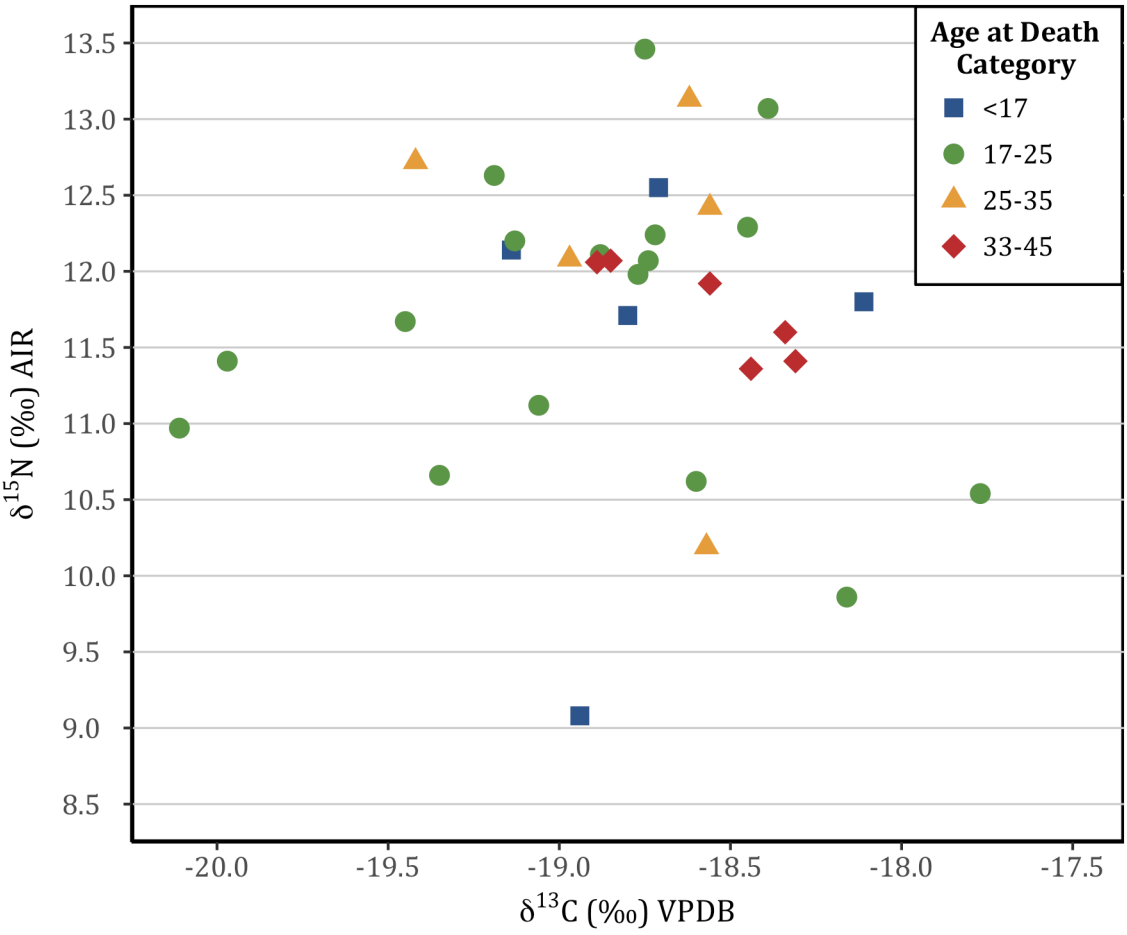


Figure 6.13: The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Sanisera's Necropolis 6, plotted by age at death as determined by dental attrition (Brothwell 1989).

there simply might not be enough intra-population variability for this hypothesis to be adequately tested, or the effect may only happen at the dietary extremes, which were not represented here.

6.3.1.2.3 Dentine/Bone Comparison

To gain a better understanding of the variation in isotope values that accompany age-related changes in diet, it is important to compare bone and dentine results. One of the most noted cases of this is the considerable variation in $\delta^{15}N$ isotope values that occurs during nursing and subsequent weaning (Schurr 1998, Sandberg *et al.* 2014). However, the samples from Sanisera were specifically chosen to be second and third molars, to exclude the effects of the weaning process. The results for both the bone and dentine samples can be seen in Table 6.8 and in Figure 6.14.

Table 6.8: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the bone and dentine samples from Necropolis 6 at Sanisera, excluding outliers.

Material	n	$\delta^{13}C$ ± σ (‰)	$\delta^{15}N$ ± σ (‰)
Bone	13	-18.1 ± 0.6	11.6 ± 0.8
Dentine	29	-18.8 ± 0.4	11.9 ± 0.8

On average, the dentine samples do not differ significantly from the bone samples in terms of $\delta^{15}N$ (Mann-Whitney U Test p=0.342), but $\delta^{13}C$ values were slightly, but significantly lower in dentine than in bone (Mann-Whitney U Test p=0.000). Variations in the diets of juveniles and adults in the literature suggest that juveniles consumed less meat than their adult counterparts (Bradley 1998, Garnsey 1999). Isotopically, this would most likely present as lower $\delta^{13}C$ and $\delta^{15}N$ values in dentine formed during childhood, as compared to bone, which is constantly turning over throughout life (Schwartz 1995).

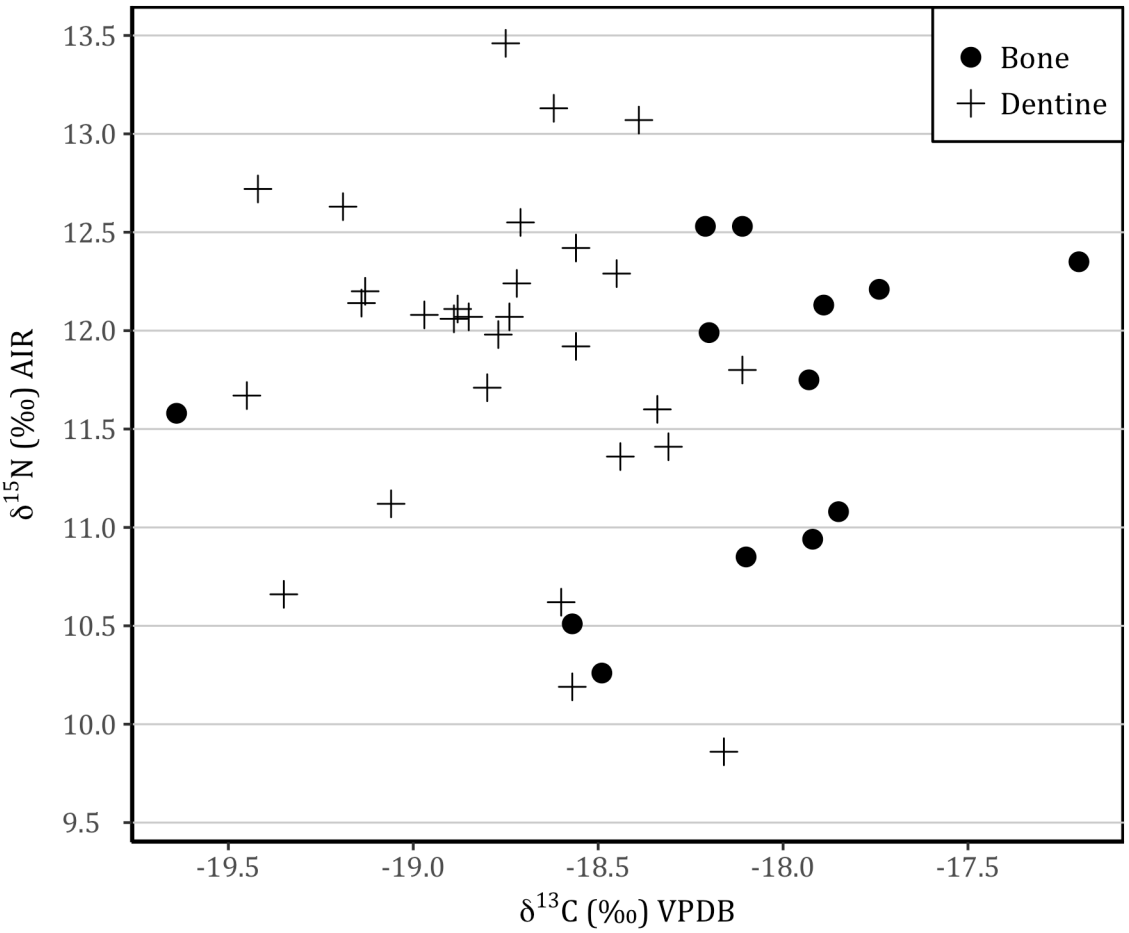


Figure 6.14: The $\delta^{13}C$ and $\delta^{5}N$ isotopic values of both bone and dentine from Necropolis 6 at Sanisera (excluding outliers).

The present data only show minor evidence of an age-related change in diet with the dentine mean having a lower $\delta^{13}C$ value but a higher $\delta^{15}N$ value. While the difference between the two materials was statistically significant in terms of their carbon isotope values, the mean isotope values varied by less than 1‰ (0.7‰ for $\delta^{13}C$ and 0.3‰ for $\delta^{15}N$). This suggests that any age-related dietary variation was minimal. The manner in which the difference in specific dentine-bone isotope values presents itself in individuals is discussed further in Chapter 7.

6.3.2 Mérida

6.3.2.1 Human/Faunal Results

Due to the nature of the sample collection from Mérida, it was possible to collect isotopic data from only three faunal specimens (see Chapter 5 for details). These were all cattle (*Bos taurus*) from the nearby site of Casa Herrera. A great variety of faunal samples would justify increased confidence that the sample values were representative of local isotope values. Unfortunately, the bovine samples were the best available at the time, though they admittedly form only a provisional faunal baseline. In Chapter 7, these results were used in congress with contemporary faunal samples from Spain to provide a better faunal baseline than these samples taken alone.

The results of the isotope analysis of the human and faunal remains from Mérida can be seen in Table 6.9 and Figure 6.15. Of the 35 human individuals sampled only ten (of 25) bone samples and 42 (of 67) dentine samples produced enough collagen (>1%) with an acceptable C:N ratio (2.9-3.6) (DeNiro 1985). This was likely due to the acidic condition of the soil in Mérida.

Table 6.9: Results of $\delta^{13}C$ and $\delta^{15}N$ isotopic analysis of the human and faunal bone and dentine collagen from Mérida, grouped by site. Samples excluded from further analysis due to poor preservation, less than 1% collagen (Dobberstein *et al.* 2009), and a C:N ratio outside the standard 2.9-3.6 (DeNiro 1985), are italicized. The samples indicated by * only had one acceptable run and should be regarded with caution.

Sample	Species	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
Casa Herrera (8265)								
A	*Bos taurus*	Mandible	5.4	24.5	8.1	3.5	-18.5	8.7
		M2	10.4	36.1	12.8	3.3	-15.3	8.7
B	*Bos taurus*	*Mandible*	*0.5*	*8.2*	*1.4*	*7.2*	*-16.8*	*7.8*
		M2	1.0	32.8	11.2	3.4	-19.7	8.9
Nova Romana (1021)								
140	Human	Mandible	1.3	31.4	11.3	3.3	-18.7	8.8
		M1	*1.1*	*5.6*	*1.4*	*4.8*	*-21.3*	*8.2*
		M2	3.3	31.1	11.0	3.3	-18.8	11.2
		M3	4.1	35.2	12.4	3.3	-19.2	9.0
141	Human	Maxilla	1.9	18.4	6.3	3.4	-18.9	10.2
		M2 Cervical	3.6	34.0	12.1	3.3	-19.0	11.1
		M2 Apical	3.6	29.2	10.4	3.3	-19.1	12.0
149	Human	*Mandible*	*2.1*	*3.5*	*1.1*	*3.9*	*-20.6*	*8.9*
		M1	*0.6*	*5.1*	*0.2*	*30.9*	*-4.8*	*-0.1*
		M2	*0.5*	*2.2*	*0.1*	*18.8*	*-27.3*	*-6.4*
Nova Romana III (7017)								
16	Human	*M3 Cervical*	*2.1*	*7.7*	*1.0*	*8.7*	*-7.8*	*10.2*
		M3 Apical	1.7	22.7	8.0	3.3	-18.9	11.7
25	Human	Mandible	5.2	39.6	13.8	3.4	-18.1	11.9
		M2	7.1	34.3	12.0	3.3	-18.9	8.3
69	Human	*M2*	*1.7*	*5.8*	*0.8*	*8.5*	*-7.5*	*7.4*
84	Human	Mandible	2.7	25.7	10.9	3.4	-19.8	11.9
		M3	*0.0*	-	-	-	-	-
96	Human	*M2*	*2.6*	*6.3*	*1.3*	*5.6*	*-23.1*	*8.6*

Sample	Species	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
103	Human	M2 Cervical	2.4	31.3	11.1	3.3	-18.5	10.3
		M2 Apical	1.8	29.9	10.3	3.4	-18.4	10.6
107	Human	*M2 Cervical*	*0.8*	*7.2*	*0.8*	*10.0*	*-12.0*	*8.6*
		M2 Apical	*4.0*	*3.0*	*0.6*	*5.6*	*-22.6*	*6.1*
140	Human	M3 Cervical	5.4	31.3	11.2	3.3	-14.0	9.2
		M3 Apical	*3.2*	*2.9*	*0.5*	*6.4*	*-23.4*	*4.6*
144	Human	M2 Cervical	5.7	33.3	12.1	3.2	-14.2	9.9
		M2 Apical	*5.0*	*3.3*	*0.2*	*16.9*	*-5.2*	*5.0*
150	Human	*M2 Cervical*	*0.5*	*4.6*	*1.2*	*4.5*	*-20.9*	*8.1*
		M2 Apical	3.2	60.5	22.1	3.2	-18.9	11.2
153	Human	*Mandible*	*0.1*	*2.3*	*0.3*	*9.3*	*-23.3*	*4.2*
		M2	1.9	22.9	7.9	3.4	-18.3	8.2
162	Human	*M3 Cervical*	*0.4*	-	-	-	-	-
		M3 Apical	*1.5*	*8.4*	*2.5*	*4.0*	*-20.3*	*9.3*
174	Human	M2 Cervical	2.8	36.7	13.1	3.3	-18.9	10.9
		M2 Apical	6.9	33.9	12.0	3.3	-18.7	10.8
Nuevo Mérida (7034)								
17	Human	*Mandible*	*1.3*	*7.7*	*2.7*	*3.7*	*-22.4*	*6.5*
		M1 Cervical	5.9	34.5	12.3	3.3	-18.8	11.3
		M1 Apical	2.6	30.5	10.7	3.3	-18.9	11.6
		M2 Cervical	1.9	30.2	10.7	3.3	-19.3	11.4
		M2 Apical	3.7	27.0	9.4	3.4	-19.5	10.9
		M3	24.8	23.1	8.0	3.4	-19.2	9.8
23	Human	Mandible	1.3	2.5	0.4	8.9	-23.8	4.0
		M1	*2.1*	*2.6*	*0.2*	*22.8*	*-27.4*	*-3.4*
		M2	*0.0*	-	-	-	-	-
26	Human	Mandible	4.9	25.4	8.6	3.4	-18.9	10.5
		M2	10.0	43.4	15.7	3.2	-18.3	11.6

Sample	Species	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
67	Human	*Maxilla*	*1.6*	*2.5*	*0.3*	*9.0*	*-23.2*	*6.2*
		M1	1.9	21.1	7.2	3.4	-19.0	10.5
		M2	8.6	44.4	16.1	3.2	-18.5	9.8
Velada (8060)								
73	Human	*Mandible*	*1.9*	*2.7*	*0.4*	*8.5*	*-22.2*	*9.3*
		M2	*0.9*	*7.9*	*2.2*	*4.2*	*-20.8*	*9.4*
96	Human	*Mandible*	*0.4*	*1.7*	*0.2*	*10.7*	*-23.8*	*8.0*
		M1 Cervical	3.1	35.0.3	12.6	3.3	-19.0	9.8
		M1 Apical	2.6	30.7	10.8	3.3	-19.3	10.4
		M2	13.1	41.6	15.0	3.2	-18.2	11.4
		M3 Cervical	3.1	32.7	11.8	3.2	-19.0	11.4
		M3 Apical	5.0	33.4	12.0	3.3	-19.2	11.8
99	Human	*Mandible*	*2.6*	*1.5*	*0.1*	*15.7*	*-23.7*	*7.8*
		M3	1.5	17.3	5.8	3.5	-19.3	8.5
115	Human	*Mandible*	*0.4*	*3.9*	*0.9*	*5.2*	*-19.6*	*6.5*
		M2	*1.2*	*2.7*	*0.4*	*8.6*	*-24.7*	*4.4*
162	Human	*Mandible*	*3.1*	*6.3*	*1.6*	*4.6*	*-19.5*	*8.2*
		M3	6.3	25.5	8.9	3.4	-18.3	9.9
207	Human	*Mandible*	*0.5*	*5.0*	*0.5*	*11.5*	*-10.6*	*7.2*
		M2	*4.1*	*1.6*	*0.3*	*7.1*	*-20.7*	*10.0*
208	Human	*Mandible*	*0.5*	*8.9*	*2.0*	*5.3*	*-23.2*	*10.1*
		M2	13.3	29.1	10.3	3.3	-18.0	10.9
216	Human	*Mandible*	*0.7*	*7.5*	*5.8*	*1.5*	*-20.1*	*11.3*
		M1 Cervical	2.6	30.4	11.0	3.2	-19.4	10.1
		M1 Apical	*1.1*	*1.6*	*0.1*	*15.7*	*-26.7*	*-3.8*
		M2 Cervical	*1.1*	*3.2*	*0.4*	*11.6*	*-20.2*	*4.6*
		M2 Apical	*0.0*	-	-	-	-	-
		M3	2.2	28.4	10.0	3.3	-18.9	9.5

Sample	Species	Material	% Col.	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
232	Human	*Mandible*	*0.7*	*2.1*	*0.5*	*8.6*	*-25.3*	*1.7*
		M1	*2.1*	*3.6*	*0.2*	*27.1*	*-28.8*	*-0.2*
		M2	*3.2*	*1.9*	*0.3*	*8.1*	*-21.5*	*4.4*
248	Human	Mandible	2.5	12.4	4.2	3.4	-19.9	10.6
		M1 Cervical	2.1	24.4	8.3	3.5	-19.5	9.3
		M1 Apical	2.2	23.1	7.9	3.4	-19.9	9.7
		M2	*1.6*	*9.4*	*2.8*	*4.0*	*-20.7*	*8.8*
nn	Human	*Mandible*	*0.5*	*2.0*	*0.2*	*10.6*	*-21.7*	*8.7*
		M2	10.6	31.8	11.3	3.3	-13.4	9.1
		M3 Cervical	2.8	35.9	12.9	3.2	-18.6	11.4
		M3 Apical	2.6	33.4	11.7	3.3	-19.4	10.6
Tomb 17	Human	Mandible*	0.9	28.3	9.8	3.4	-19.5	11.0
		M2	3.5	29.9	10.4	3.4	-18.6	9.3
		M3	2.2	24.1	8.4	3.4	-19.4	9.3
YAC (83925)								
16	Human	Mandible*	2.8	18.1	6.0	3.5	-18.6	9.2
		M2	12.4	35.0	12.6	3.2	-16.4	9.3
27	Human	Mandible	1.5	38.9	14.2	3.2	-18.9	11.6
		M3	7.5	27.7	9.9	3.4	-18.3	9.8
31	Human	Mandible	3.6	24.3	8.5	3.4	-18.7	11.5
		M3	1.2	29.5	10.4	3.4	-18.2	11.9

6.3.2.2 Human/Faunal Comparison

Bovine sample A (Bov-A) from Casa Herrera (grey symbols) is of particular interest due to the difference in its $\delta^{13}C$ values between its bone and dentine indicating it consumed C_4 plants early in life, but C_3 plants later on. Such a drastic shift is highly unusual as the root of a second mandibular molar is formed roughly

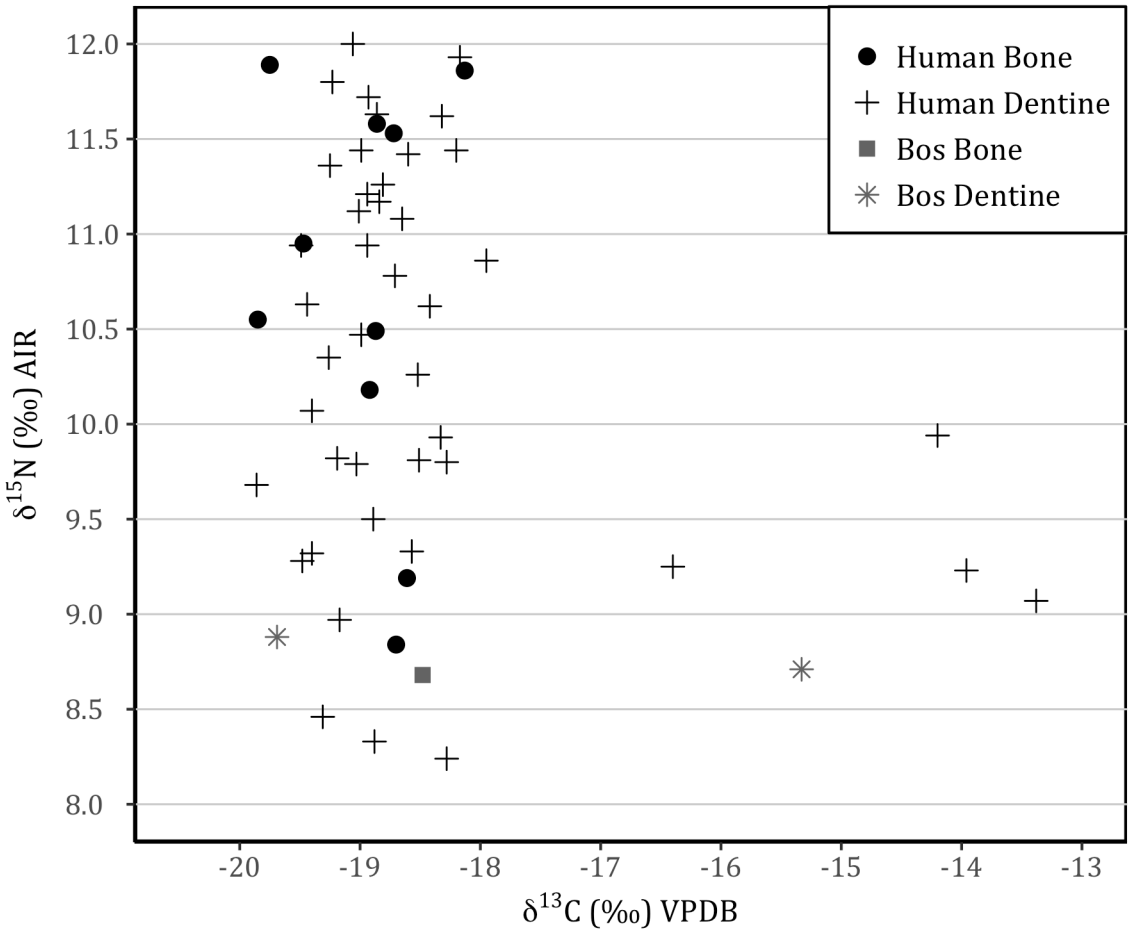


Figure 6.15: The $\delta^{13}C$ and $\delta^{15}N$ of human and faunal bone and dentine samples from Mérida.

between 12-24 months in cattle (Brown *et al.* 1960), and even though the cow in question was determined to be an adult, there still would not have been a very long period of time between the development of the second mandibular root and the cow's death. When compared to the humans, the cow $\delta^{15}N$ values were amongst the lower values of the human dentine samples, but were low enough in terms of the human bone values that it could be assumed that cattle could be a dietary component for some of the population of Mérida. For individuals with lower $\delta^{15}N$ values than the cows, this could be an indication that these individuals were immigrants or that they had a diet which included more legumes (DeNiro and Epstein 1981).

The $\delta^{13}C$ values of the bone sample from Bov-A and the dentine from bovine sample B (Bov-B) are very similar to the human mean. A population that consumed animal protein from sources similar to Bov-A, would have an expected increase of $\delta^{13}C$ between 0-2‰ greater than the cattle's value (Bocherens and Drucker 2003). This increase might not be observed if the cattle's diet included C_4 plants. The diet of other fauna that were more frequently consumed by the human population did not include C_4 plants. The dentine from Bov-A, certainly helps to reinforce this theory, with its unusually elevated $\delta^{13}C$ values. The most common C_4 plants in this region, at that time, were millet and sorghum. They were most commonly only consumed by humans during times of famine to take the place of wheat and barely (Spurr 1983, Rowley-Conwy *et al.* 1999, Mundee 2010), so it would follow that it was used as animal fodder during times of prosperity.

6.3.2.3 Analysis of Human Samples

As can be seen in Figure 6.16, there were four dentine samples with substantially different $\delta^{13}C$ values than the rest of the population (NR3-140, NR3-144, V-nn, and Yac-16). These values were more than two standard deviations from the $\delta^{13}C$ mean and were outliers from the general population, at least as represented by the sample. These samples were removed from the following analysis, but they are explored further in Chapter 7.

The remaining 48 human samples consist of ten bone and 38 dentine samples from a total of 23 individuals. Again, Mann-Whitney U tests were used in all cases to assess the statistical significance of any differences among groups. The $\delta^{13}C$ and $\delta^{15}N$ means of each material can be seen in Table 6.10. Due to the variety of material that was sampled (from bone to cervical M1), the sectioned samples of

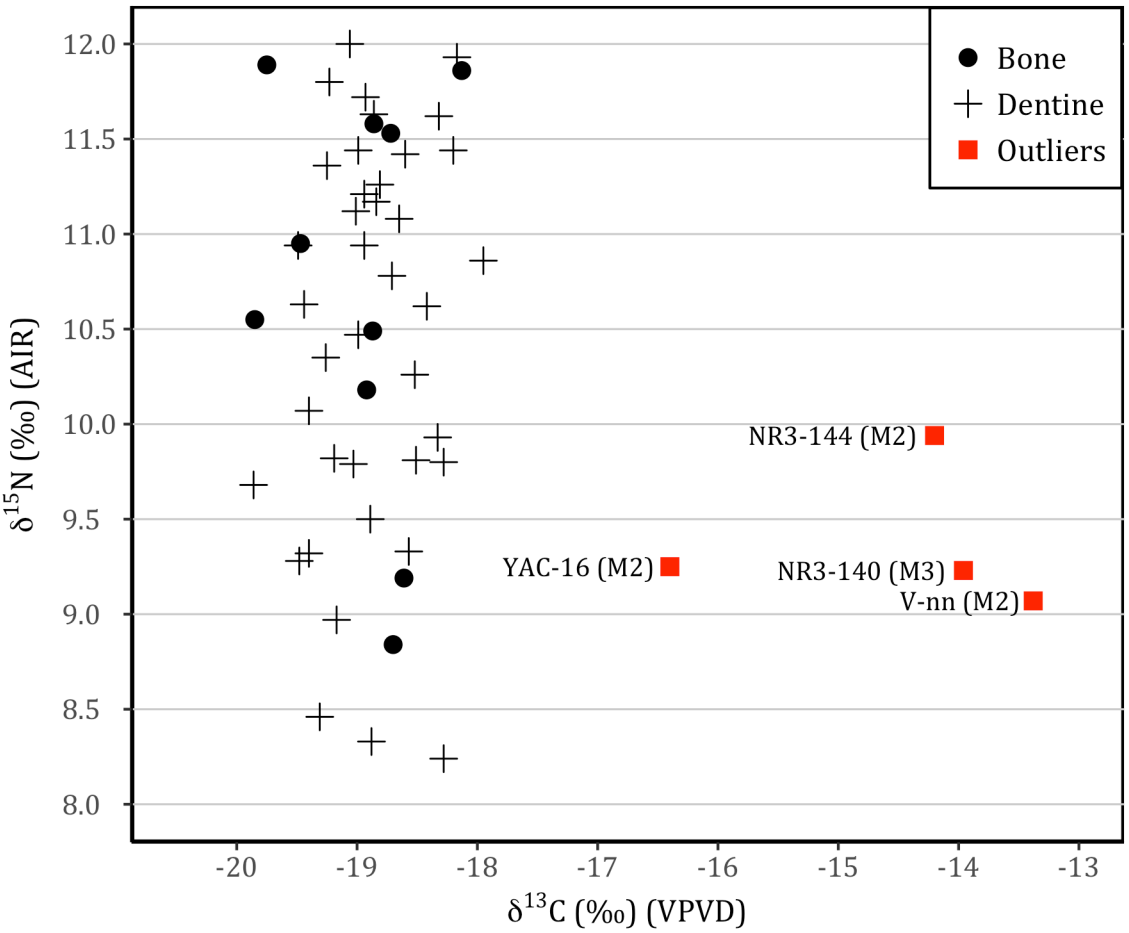


Figure 6.16: The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Mérida with the outliers (defined as values >2σ from the population mean) identified with red squares. All outliers are dentine.

Table 6.10: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the human bone and dentine samples from Mérida (excluding outliers).

Material	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
Bone	10	-19.0 ± 0.5	10.7 ± 1.1
1st Molar (M1)	5	-19.2 ± 0.3	10.3 ± 0.7
2nd Molar (M2)	13	-18.6 ± 0.4	10.5 ± 1.2
3rd Molar (M3)	11	-18.9 ± 0.4	10.2 ± 1.2

molars were averaged together by molar, to avoid over-representation of any one individual.

In general, these results indicated a terrestrial C_3 grain-based diet supplemented with animal protein. This diet is in agreement with other similar

results for the period (Fuller *et al.* 2010, Garcia *et al.* 2004) and the population from Sanisera in the current study.

Statistically, there was no difference between any of the materials for either carbon or nitrogen isotope values. The only exception was that there was a difference between the first and second molars based on their $\delta^{13}C$ values (Mann-Whitney U test p=0.016). With this in mind, first molars were included in the following analysis only when there was no other sample available to represent an individual.

6.3.2.3.1 By Sex

In many cultures, the sex of an individual influences their diet. In Late Antiquity, sexual differentiation in diet is hinted at in the literature, but it is typically absent in isotope studies (Craig *et al.* 2009, Alexander *et al.* 2015). Another possible explanation for a difference in isotope values between the sexes, is a difference in mobility. For example, if women were more likely to relocate after marriage, or if men were more likely to relocate to a new area after military service or following travel to engage in trade.

The sex of fourteen individuals (with acceptable isotope results) in this study was determined (see Chapter 5 for methods), ten males and four females. The results of this analysis can be seen in Table 6.11 and Figure 6.17.

On average, males had higher $\delta^{15}N$ values; however, this was due to one individual lowering the overall female mean. Unfortunately, due to the small sample size, statistical tests might yield significant results but the high variability makes any conclusions reached suspect. The similar means of the sexes, and the presence of both sexes in the outlier group, suggests a lack of dietary variation based on sex.

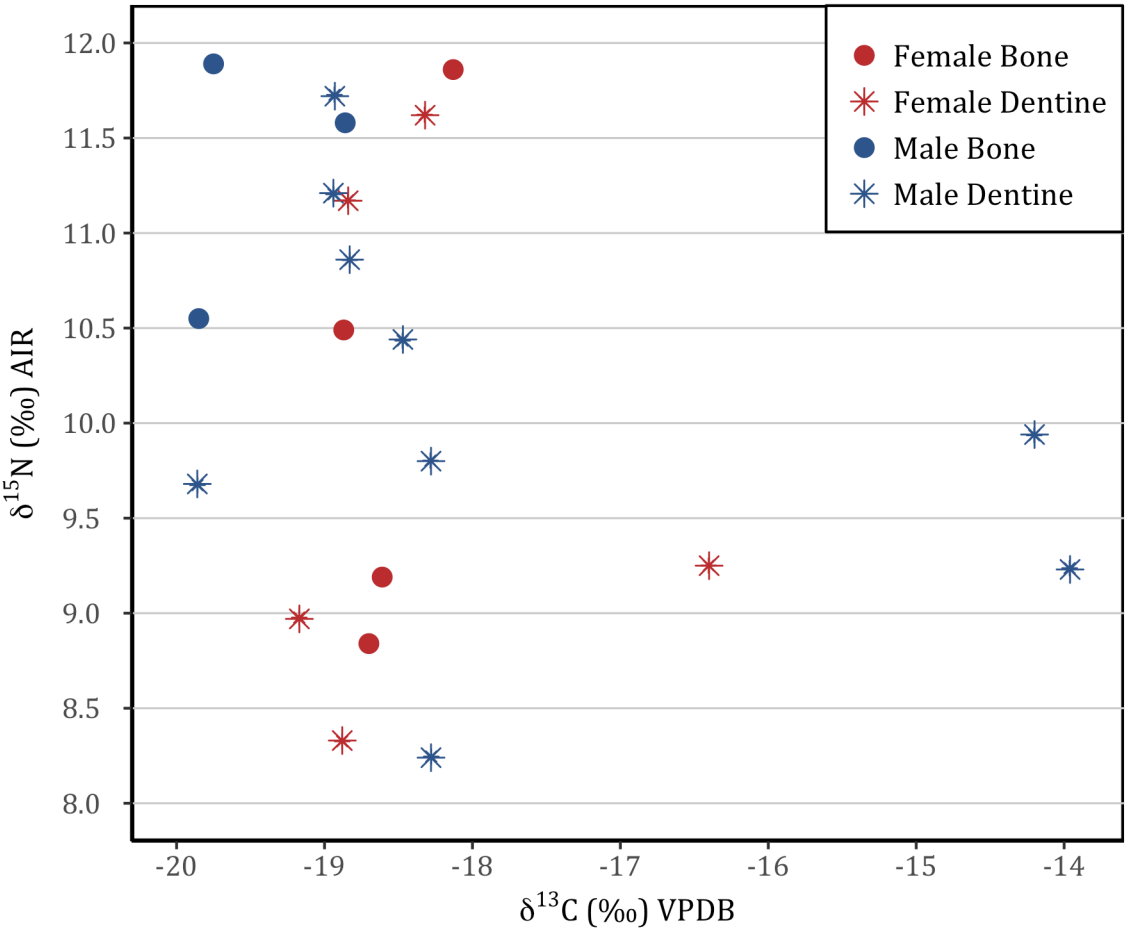


Figure 6.17: The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples of individuals with known sex, from Mérida, plotted by sex.

6.3.2.3.2 By Age at Death

One of the major variables to consider when dealing with past populations is age at the time of death. With the small number and variable quality of samples, the variable of age needs to be treated cautiously in regard to the Mérida population.

Table 6.12: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the bone samples from Mérida based on their age at death category (as defined by the methods outlined in Brothwell 1989).

Age at Death Category	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
17-25	3	-18.6 ± 0.4	11.2 ± 0.9
25-35	6	-19.2 ± 0.6	10.3 ± 1.1
33-45	1	-18.7	11.5

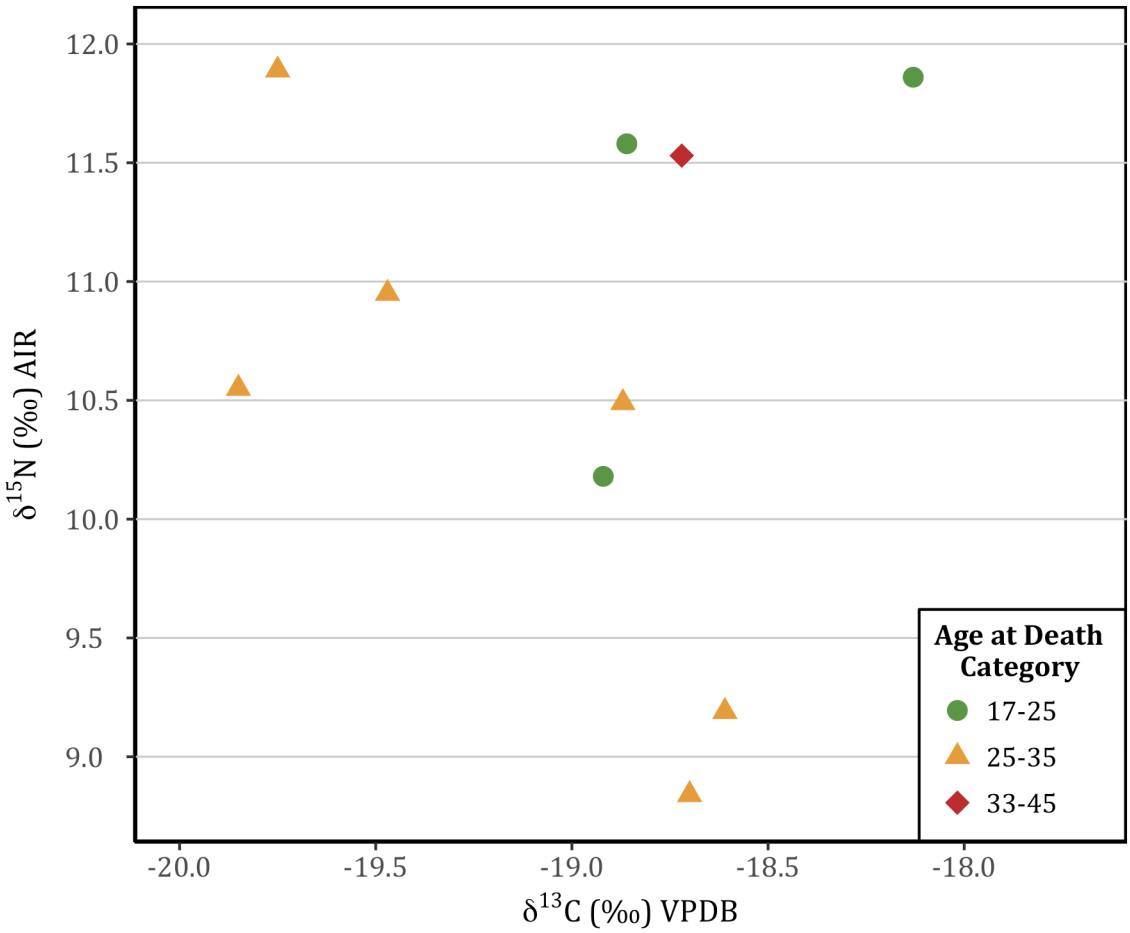


Figure 6.18: The $\delta^{13}C$ and $\delta^{15}N$ of human bone samples from Mérida, plotted by age at death as determined by dental attrition (Brothwell 1989).

With this in mind, the samples are discussed separately by material, then combined to help create a more complete picture.

The turnover of bone collagen throughout adult life (Hedges *et al.* 2007) means that, for adults, it is representative of anywhere from 10 to 20 years preceding death. As can be seen in Table 6.12 and Figure 6.18, the three individuals in the 17-25 years old and the 33-45 years old age categories, on average, have higher $\delta^{13}C$ and $\delta^{15}N$ values, than the individuals aged 25-35. Unfortunately, the number of samples was insufficient to support any further analysis. Fortunately, there were more dentine samples to help further this analysis.

When using dentine to explore the effect of age on diet, it is important to note which tooth was the source of the collagen. As outlined in Chapter 5, samples were taken only from molars, and only dentine beyond the cemento-enamel junction was sampled. The mean age of formation of the sampled dentine from the first molar is between the ages of 3 and 9, between the ages of 7 and 15 for the second molar, and between the ages of 13 and 20 for third molars (Moorrees *et al.* 1963, Ubelaker 1979). The first step in analyzing the relationship between age and dentine isotope values is to determine if there is any variation among the different types of teeth being studied. These data are shown in Table 6.13 and Figure 6.19.

Table 6.13: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the individuals from Mérida based on tooth tested. The age at which the dentine sampled was developed for each tooth is based on Moorrees *et al* 1963 and Ubelaker 1979.

Tooth	Average age of development	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
1st Molar	3-9 years	5	-19.2 ± 0.3	10.3 ± 0.7
2nd Molar	7-15 years	13	-18.6 ± 0.4	10.5 ± 1.2
3rd Molar	13-20 years	11	-18.9 ± 0.4	10.2 ± 1.2

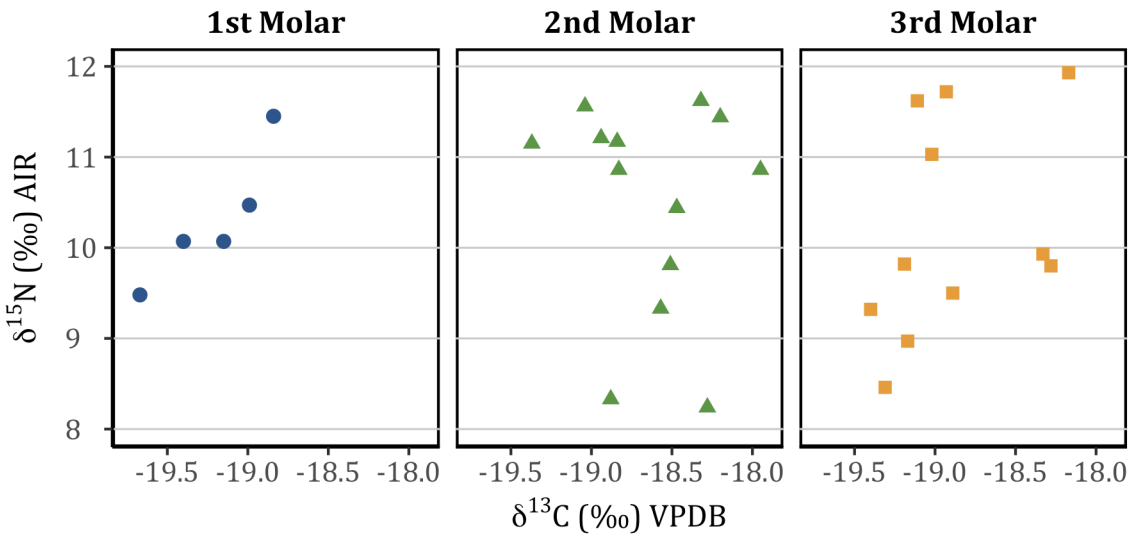


Figure 6.19: The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by tooth.

When the individuals in this study were grouped according to which tooth was used in the analysis (and subsequently the age at which the dentine was formed), it can be seen that there was no statistical difference between the groups in either carbon or nitrogen isotope values, except for the difference between the $\delta^{13}C$ values of the first and second molars (Mann-Whitney U p=0.016). This indicates no difference in nitrogen values by age and only a slight difference in carbon between children and adolescents for these individuals.

Another age-related variable associated with these dentine samples was age at death, as determined by the wear on the occlusal surfaces of the teeth (Brothwell 1989). By comparing the isotope values in dentine (formed during childhood), to the relative age at which an individual died, it was possible to see if childhood diet play a role in individual longevity. This is explored in Chapter 7.

6.3.2.3.3 By Necropolis

The manner and location in which an individual was interred was very important during Late Antiquity, as discussed in Chapter 2. While the exact reasoning behind why an individual was buried in one of these necropoles over another is unknown, it is fair to assume that this choice was not arbitrary. The necopoles in this study were all very similar to each other archaeologically; they were all multiphase, located outside the city walls, and have tombs with grave goods that correspond to the Late Antique time period. All individuals presented with similar burial methods (pit burials with variations based on time period), and most had relatively similar grave goods (variation attributed to time period). The results of grouping the individuals by necropolis can be see in Figure 6.20. and Table 6.14

Overall, carbon and nitrogen isotope results do not vary based on burial location. The bone sample from Nova Romana (NR-140) does have a noticeably

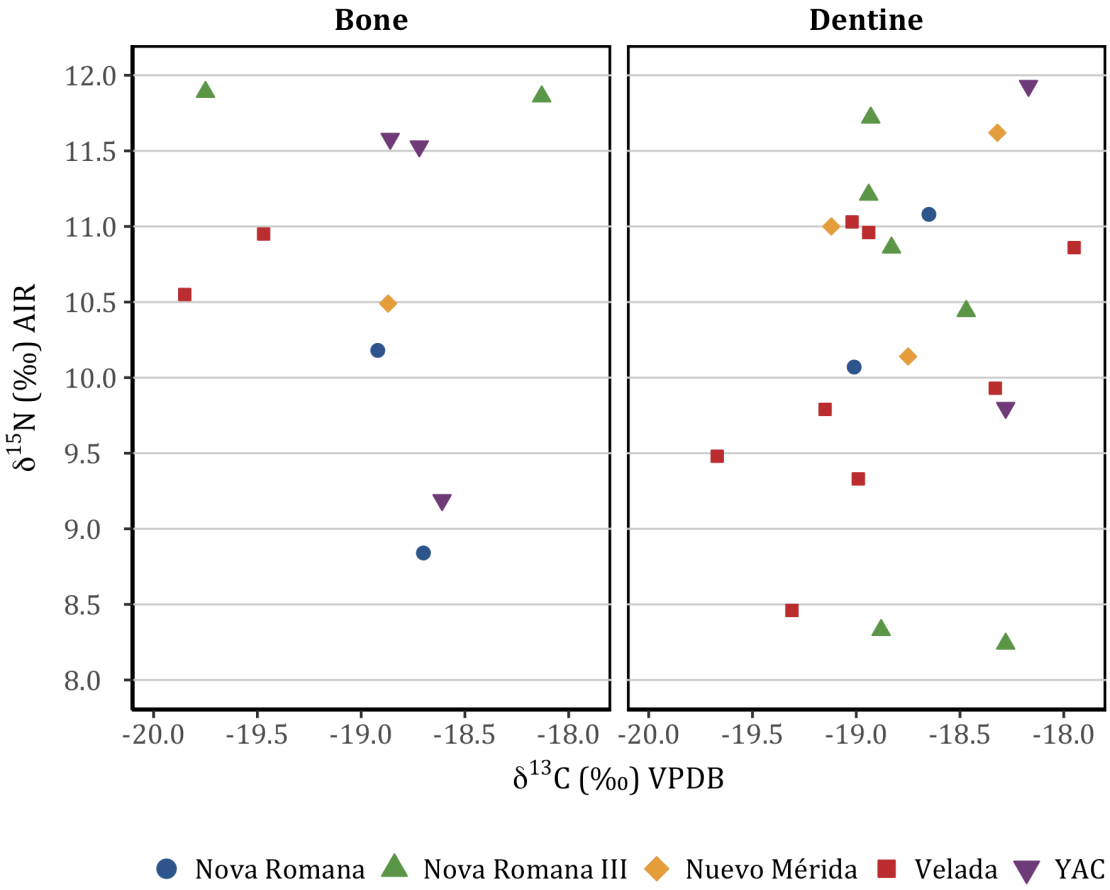


Figure 6.20: The $\delta^{13}C$ and $\delta^{15}N$ results of the human bone and dentine samples from Mérida plotted by necropolis, and faceted by material tested.

Table 6.14: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) by necropolis and material tested. For the dentine samples, if more than one sample was present for an individual, second molars were selected.

Site	Bone			Dentine		
	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
Nova Romana	2	-18.8 ± 0.2	9.5 ± 1.0	2	-18.9 ± 0.1	11.4 ± 0.3
Nova Romana III	2	-18.9 ± 1.2	11.9 ± 0.0	6	-18.7 ± 0.3	10.1 ± 1.5
Nuevo Mérida	1	-18.9	10.5	3	-18.7 ± 0.6	10.9 ± 0.9
Velada	2	-19.7 ± 0.3	10.8 ± 0.3	8	-18.7 ± 0.6	10.0 ± 1.0
YAC	3	-18.7 ± 0.1	10.8 ± 1.4	2	-18.2 ± 0.1	10.9 ± 1.5

lower $\delta^{15}N$ value than the other bone samples (on average over 2‰ less); however it did not stand out when the dentine samples were included, especially considering that the dentine from that same individual had a $\delta^{15}N$ of over 11‰. This would

indicate that the range of $\delta^{15}N$ values present in these sites was well within the range that one individual could have over their life time. This is discussed further in Chapter 7.

6.3.2.3.4 By Time Period

Another important variable to consider was the period during which these individuals lived. Individuals were divided into three time periods, the Low Empire or Roman period between the 3rd and 5th centuries AD, the Late Antique Era which covers the fall of the Roman Empire in the 5th century AD through to the rise of Islamic control in the 8th century AD, and the Early Medieval Period from the 8th through to the 10th centuries AD. The mean results for each time period are shown

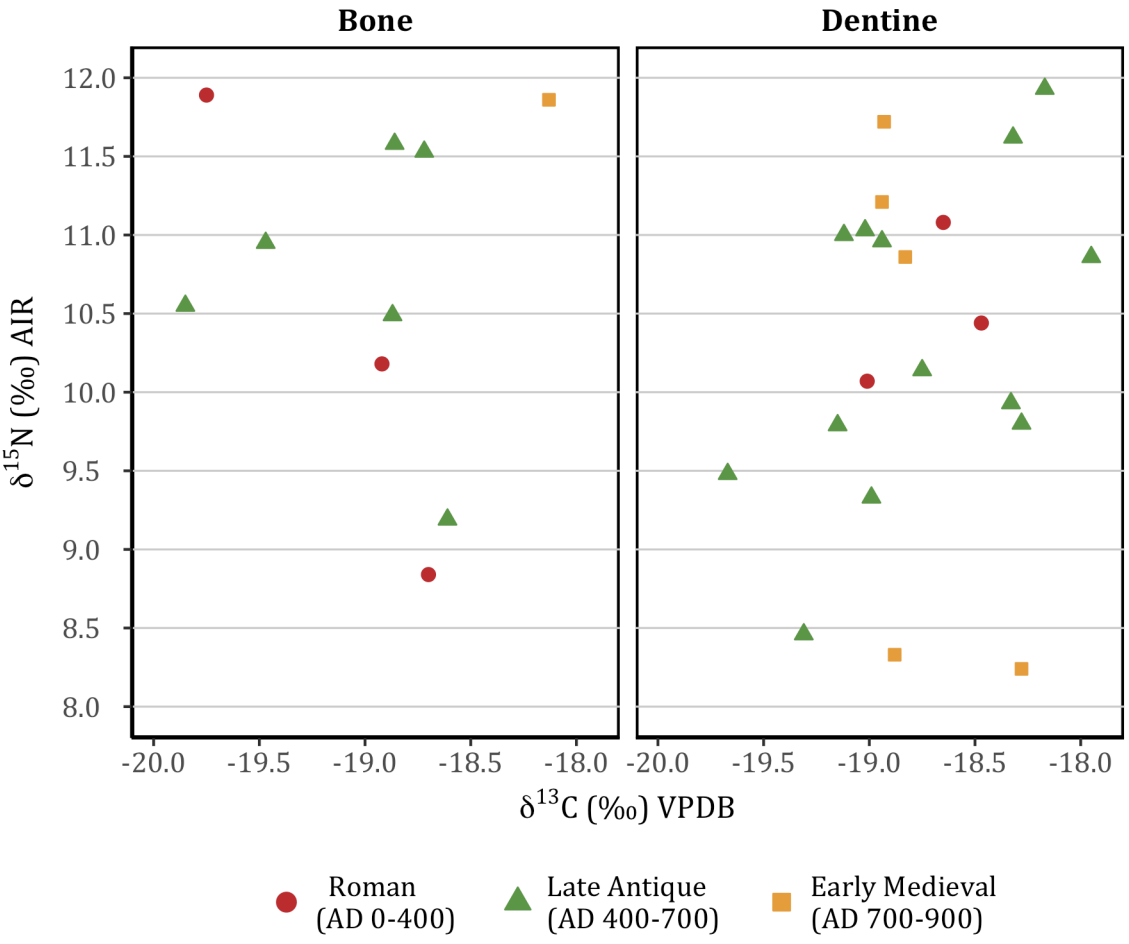


Figure 6.21: The $\delta^{13}C$ and $\delta^{15}N$ of human bone and dentine samples from Mérida plotted by time period and faceted by material tested.

in Table 6.15 and individual data are plotted in Figure 6.21. As Figure 6.21 makes clear, there was no consistent variation in carbon and nitrogen isotope values based on time period at these sites.

Table 6.15: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the individuals from Mérida based on the time period in which they were buried.

Time Period	Bone			Dentine		
	n	**$\delta^{13}C$ ± σ (‰)**	**$\delta^{15}N$ ± σ (‰)**	**n**	**$\delta^{13}C$ ± σ (‰)**	**$\delta^{15}N$ ± σ (‰)**
Roman (3rd-5th)	3	-19.1 ± 0.6	10.3 ± 1.5	3	-18.8 ± 0.3	11.1 ± 0.6
Late Antique (5th-8th)	6	-19.1 ± 0.5	10.7 ± 0.9	13	-18.7 ± 0.5	10.3 ± 1.1
Early Medieval (8th-10th)	1	-18.13	11.86	5	-18.8 ± 0.3	10.1 ± 1.7

6.4 Meta-Analysis Results

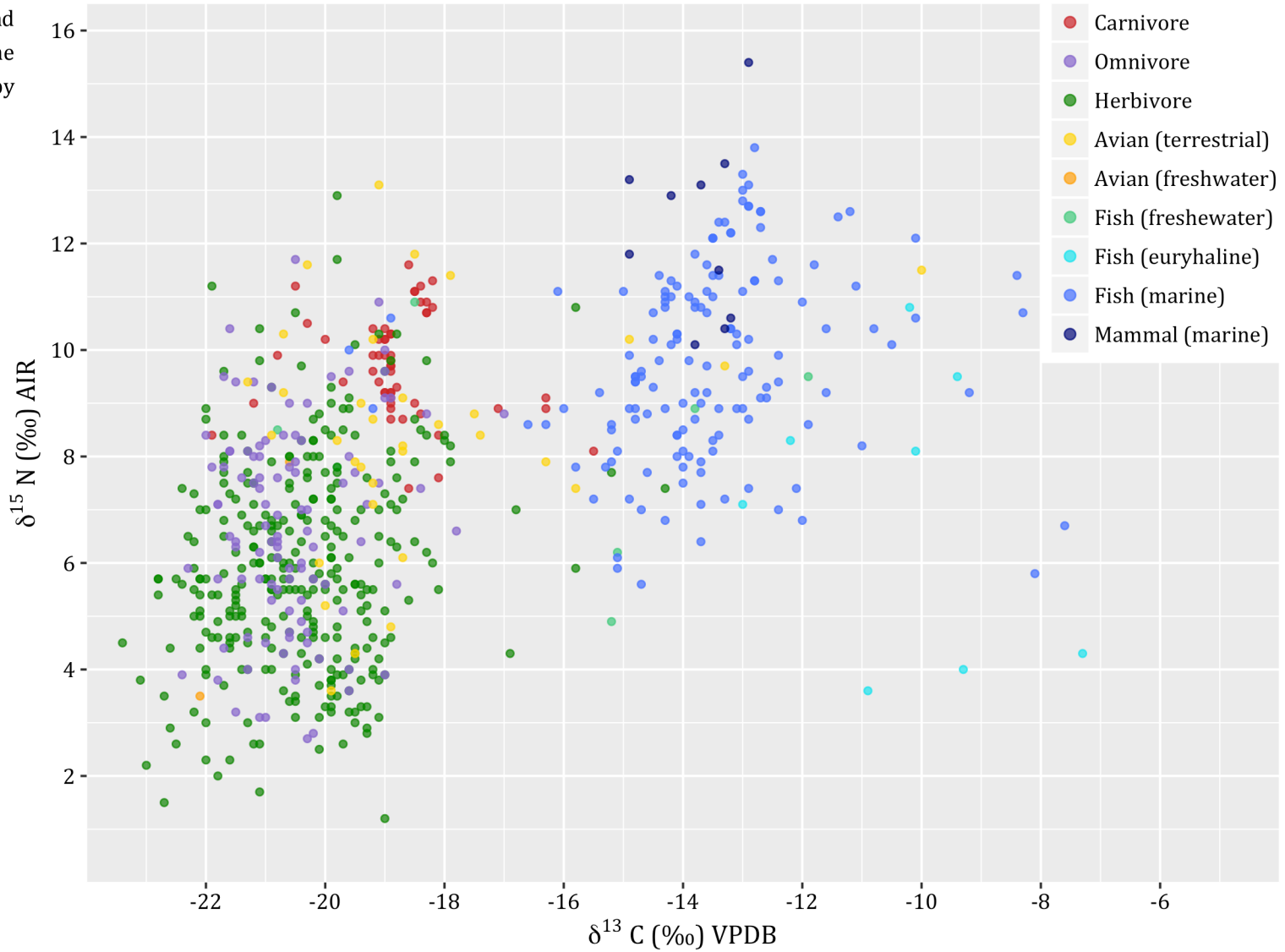
6.4.1 Faunal Analysis

The Meta-Data set contains 672 individual faunal samples from roughly 95 different species sourced from 36 different studies (for more detail see Chapter 5). The detail with which the fauna is described in each study varies from simply calling a sample 'fish' to including the full scientific name. With this in mind, the faunal data was first divided into nine broad categories based on their ecology. The categories are as follows: Carnivore, Omnivore, Herbivore and Marine (mammals); Terrestrial and Freshwater Avian (birds); Freshwater, Euryhaline and Marine Fish. All of the faunal data is shown in Figure 6.22. The number of samples from each category as well as a general summary of their carbon and nitrogen isotope results can be seen in Table 6.16.

Table 6.16: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each faunal category, and the p-value for the Shapiro-Wilk test of normality. An * indicates a normal distribution.

Faunal Category	n	$\delta^{13}C$		$\delta^{15}N$	
		mean ± σ	p-value	mean ± σ	p-value
Carnivore	53	-18.81 ± 1.05	0.000	9.72 ± 0.96	0.623*
Omnivore	104	-20.56 ± 0.97	0.000	6.67 ± 1.96	0.485*
Herbivore	309	-20.39 ± 1.30	0.000	5.92 ± 1.98	0.047
Avian (terrestrial)	33	-18.51 ± 2.29	0.000	8.47 ± 2.20	0.686*
Avian (freshwater)	2	-21.35 ± 1.06	-	5.70 ± 3.11	-
Fish (freshwater)	7	-16.44 ± 3.30	0.638*	8.10 ± 2.02	0.938*
Fish (euryhaline)	8	-10.30 ± 1.78	0.906*	6.96 ± 2.71	0.376*
Fish (marine)	145	-13.55 ± 1.74	0.000	9.77 ± 1.80	0.294*
Mammal (marine)	10	-13.76 ± 0.70	0.145*	12.25 ± 1.67	0.572*

Figure 6.22: The $\delta^{13}C$ and $\delta^{15}N$ of the fauna from the Meta-Data set grouped by faunal category.



The distribution plots of the $\delta^{13}C$ and $\delta^{15}N$ values for each category can be seen in Figure 6.23. The Freshwater Avian category had too small a sample size to be included in the normality test and therefore, was also excluded from the distribution plots.

What the Shaprio-Wilk test for normality (Table 6.16) and the distribution plot (Figure 6.23) made clear was that only the herbivores have a normally distributed 'population' ($p<0.05$), both in terms of $\delta^{13}C$ and $\delta^{15}N$. It was also the only group to have a normal distributions in terms of $\delta^{15}N$ values. In terms of $\delta^{13}C$, only freshwater fish, the euryhaline fish, and the marine mammals did not have normal distributions. Due to only six of sixteen distributions being normal, the faunal categories were only tested using non-parametric tests.

When means and standard deviations of each category are plotted, it is clear that the terrestrial fauna fit well within the theoretical model discussed in Chapter 3 (see Figure 6.24). This comes as no surprise, as the model was established using European sources. While there are no freshwater fish in the original model, their spread between the Terrestrial and Marine ecosystems was expected. The remaining fish categories, however, had noticeably different $\delta^{13}C$ and $\delta^{15}N$ values than the model. This was most likely due to the species used in each study, with the source material for the theoretical model originating from Western European Holocene, which was a substantially broader period of time, and most likely a spatially larger area of study (Müldner & Richards 2006; 229). This brings into question what exactly the $\delta^{13}C$ and $\delta^{15}N$ values of an individual from the Roman to Late Medieval Periods would be, as compared to individuals consuming species included in the theoretical model, and how practical such a broad theoretical model is for reconstructing the diets of individuals from more specific time periods.

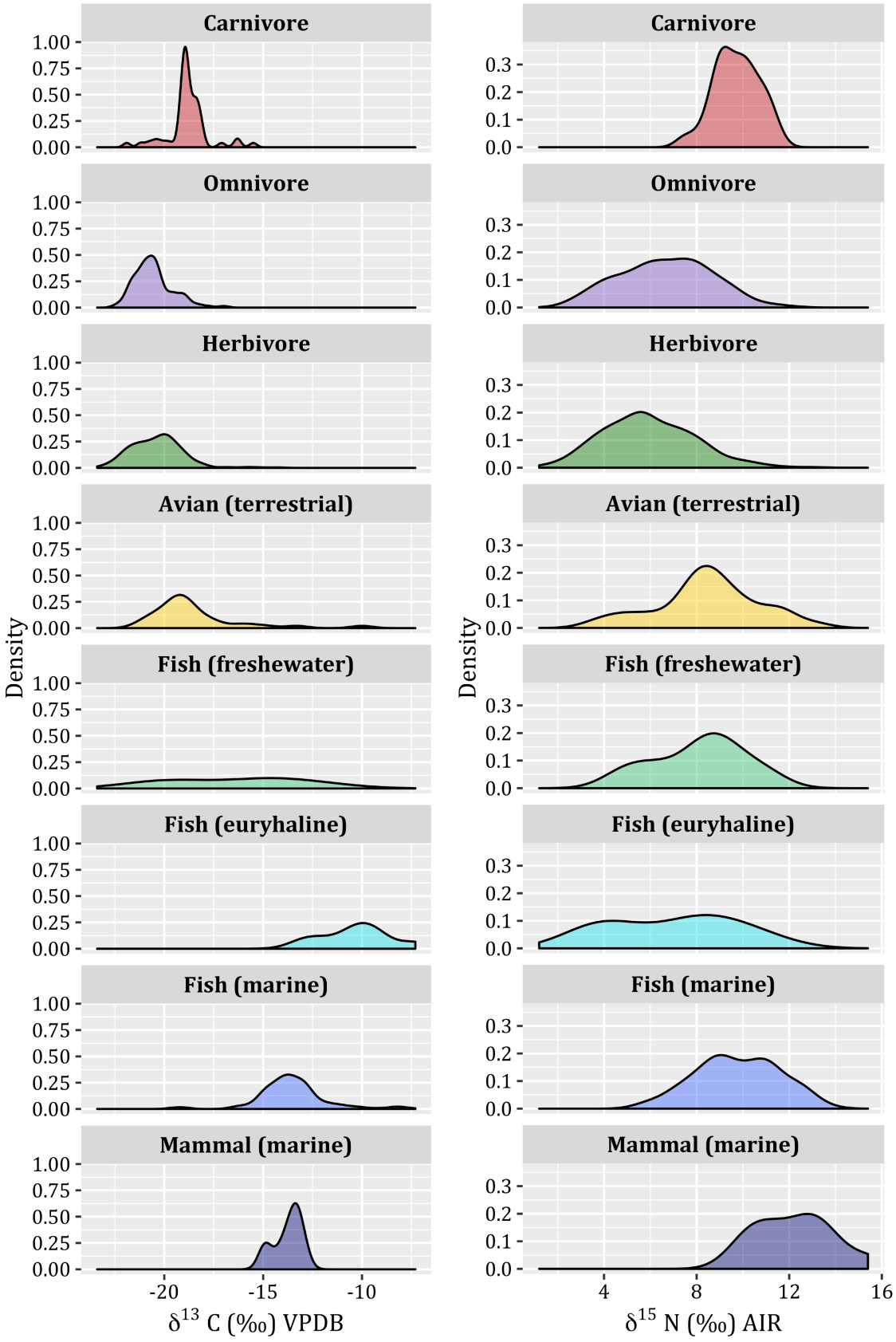


Figure 6.23: Distribution plots of the $\delta^{13}C$ and $\delta^{15}N$ of each faunal category.

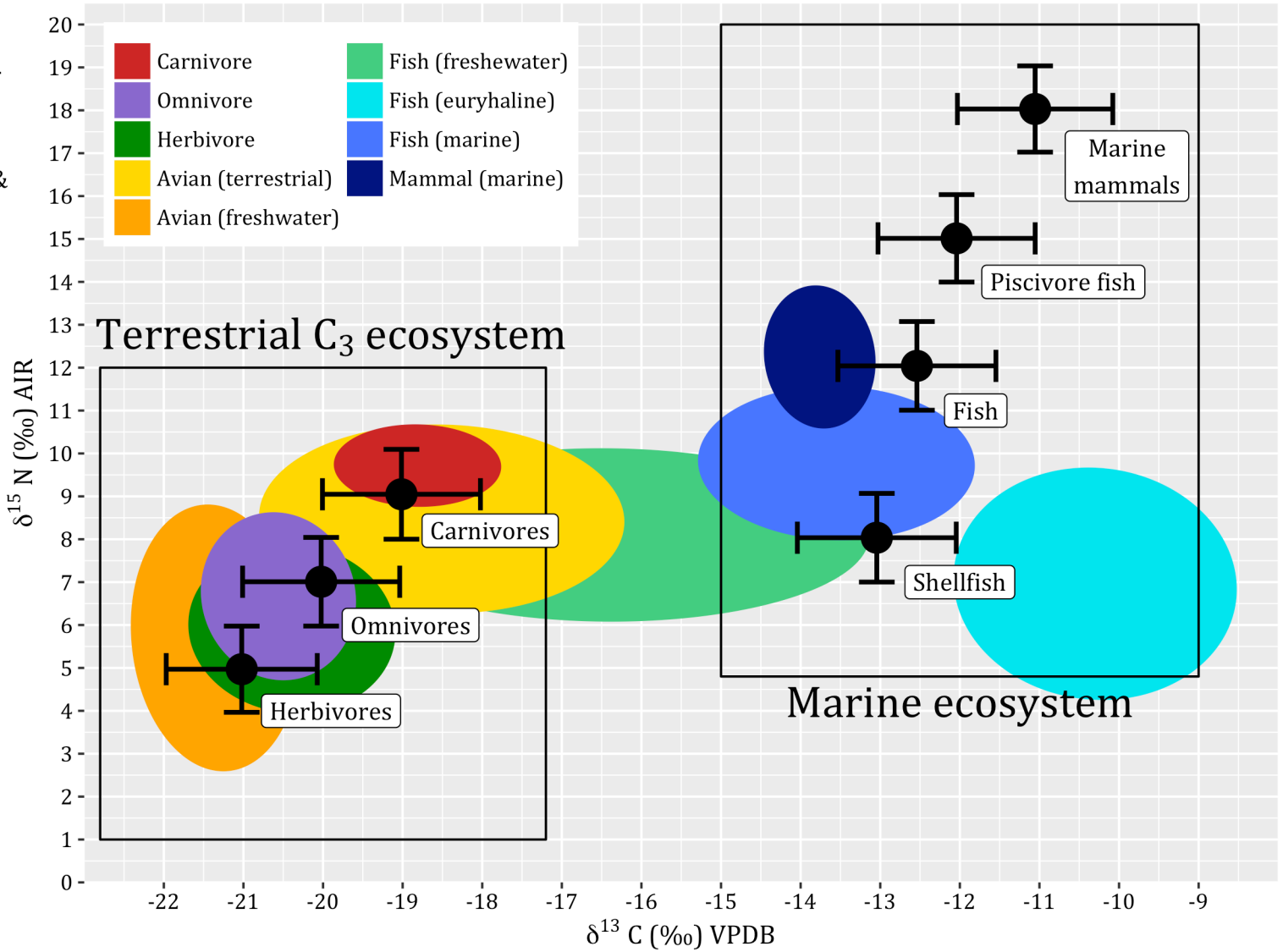


Figure 6.24: The mean $\delta^{13}C$ and $\delta^{15}N$ $\pm\sigma$ of each faunal type from the Meta-Data set (the colored ellipses), overlain with a theoretical plot of isotope values based on Müldner & Richards 2006, 229.

Also of interest were the euryhaline fish, or the fish that can live in salt, fresh or brackish water. The euryhaline fish in this dataset consist of mullet, and while red mullet were known to be kept in ponds during the Roman period (Andrews 1949), these samples range in date from the Mesolithic through to the Early Medieval Period (Mundee 2010, Vika & Theodoropoulou 2012, Alexander 2015). This suggests that the difference in carbon and nitrogen isotope values most likely had a physiological cause, rather than due to the animals kept in ponds.

To get a more comprehensive view of the terrestrial fauna, fish and the wild avian species were removed. This left 489 faunal samples from nine species. The number of samples for each species, as well as the mean and standard deviation for both carbon and nitrogen isotope analysis can be seen in Table 6.17.

Table 6.17: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for the faunal categories. Species with the same letter ($\delta^{13}C$) or number ($\delta^{15}N$) are not significantly different at the 5% level based on the Dunn's test (1964) for stochastic dominance.

Species	n	$\delta^{13}C \pm \sigma$	$\delta^{15}N \pm \sigma$	Groups by $\delta^{13}C$	Groups by $\delta^{15}N$
Cattle	103	-20.44 ± 1.51	6.14 ± 1.80	a	1
Pig	104	-20.56 ± 0.97	6.67 ± 1.96	a	2
Sheep/Goat	159	-20.06 ± 1.02	6.05 ± 2.08	b	1
Horse	28	-21.59 ± 0.95	5.60 ± 1.58	c	1 + 3
Cat	10	-18.11 ± 1.45	9.19 ± 0.53	d	4
Dog	43	-18.98 ± 0.88	9.84 ± 1.00	d	4
Chicken	23	-18.82 ± 1.97	8.70 ± 2.41	d	4
Deer	11	-21.25 ± 1.28	3.94 ± 1.39	a + c	5
Rabbit/Hare	8	-20.95 ± 1.36	4.23 ± 1.71	a + c	3 + 5

Figure 6.25 depicts the means of each species with the error bars outlining plus and minus two standard errors from the mean and from this plot groups of

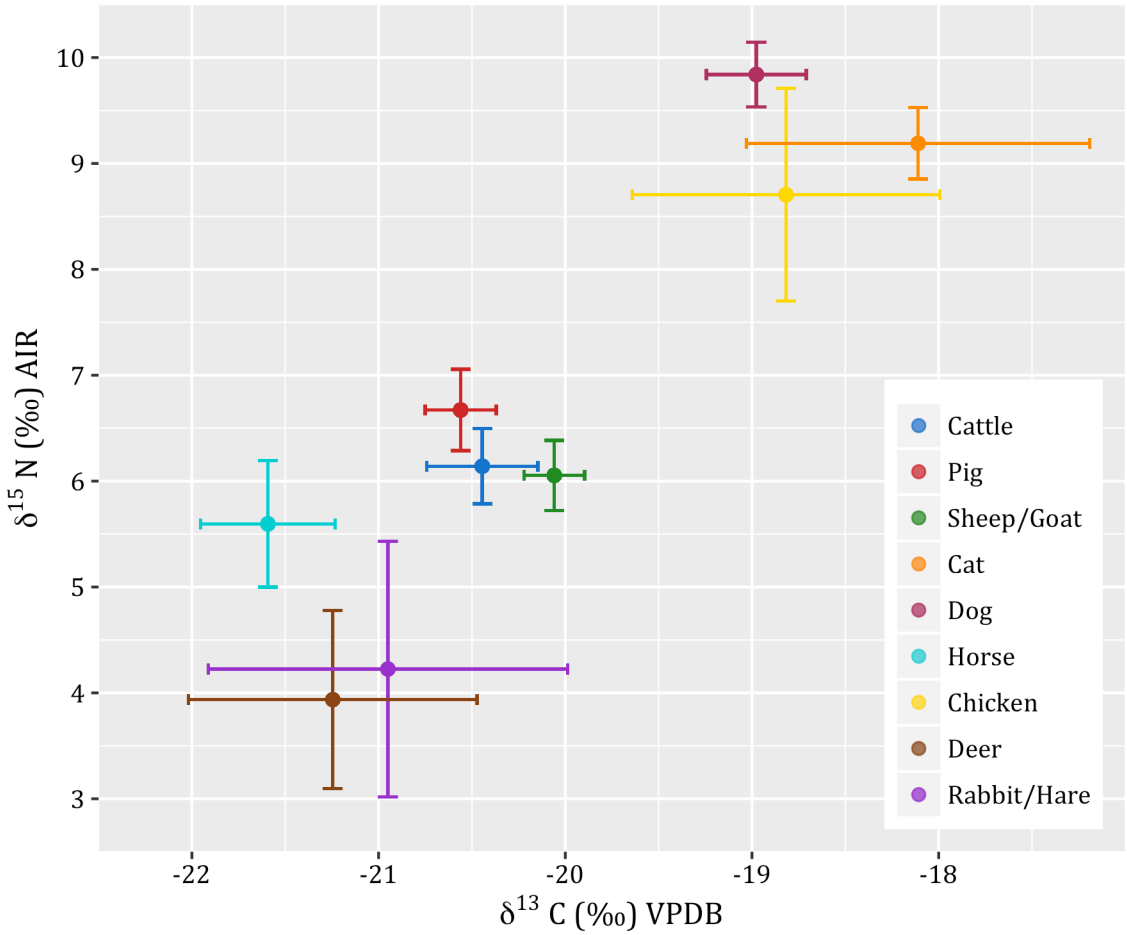


Figure 6.25: The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard error, of the most common terrestrial species in the Meta-Data set.

animals clearly emerge. Using Dunn's test (Dunn 1964) for stochastic dominance, as it pertains to non-parametric data, with an alpha value of 0.05, the fauna was divided into groups based on their carbon and nitrogen isotope values (see Table 6.17 and Table 6.18). Species that were not significantly different (at the $p < 0.05$ level) have been labeled with the same group letter ($\delta^{13}C$) or number ($\delta^{15}N$). The main insight that can be taken from these results is that the carnivorous mammals and the omnivorous chickens were distinct from the rest of the fauna both in terms of $\delta^{13}C$ and $\delta^{15}N$, and that while the pigs were statistically different in $\delta^{15}N$, they group with the majority of the herbivores in terms of their $\delta^{13}C$ values. The opposite was true for the sheep/goats as they had significantly different $\delta^{13}C$ values (see

Table 6.18) from the rest of the fauna, but have similar $\delta^{15}N$ to both the cattle and the horses.

Table 6.18: The p-values for the Dunn's test on the faunal $\delta^{13}C$ and $\delta^{15}N$ values. With p-value for carbon being on top and the p-value for nitrogen being on bottom and in grey. Values indicating statistically different groups are indicated with an * .

	Cat	Chicken	Cattle	Deer	Dog	Horse	Pig	Rabbit/ Hare
Sheep/ Goat	0.000*	0.004*	0.001*	0.004*	0.000*	0.000*	0.000*	0.019*
	0.000*	0.000*	0.293	0.002*	0.000*	0.192	0.008*	0.021*
Rabbit/ Hare	0.000*	0.000*	0.176	0.439	0.000*	0.117	0.209	
	0.000*	0.000*	0.014*	0.349	0.000*	0.082	0.002*	
Pig	0.000*	0.000*	0.374	0.122	0.000*	0.000*		
	0.000*	0.000*	0.044*	0.000*	0.000*	0.011*		
Horse	0.000*	0.000*	0.000*	0.127	0.000*			
	0.000*	0.000*	0.123	0.019*	0.000*			
Dog	0.238	0.131	0.000*	0.000*				
	0.330	0.021*	0.000*	0.000*				
Deer	0.000*	0.000*	0.096					
	0.000*	0.000*	0.001*					
Cattle	0.000*	0.000*						
	0.000*	0.000*						
Chicken	0.077							
	0.165							

In general, the deer and the rabbit/hare had by far the lowest $\delta^{15}N$ values and some of the larger ranges of both $\delta^{13}C$ and $\delta^{15}N$. This coincides with them being undomesticated and having to acquire food from a larger, less isotopically consistent array of sources. Meanwhile, the majority of the domesticated animals had much smaller standard errors indicating more consistent food sources, despite the samples originated from many different locations across Europe. With the exception of the chickens (who have drastically different means of digestion than the other species, all of which are mammals), the dogs and cats had distinctly more

carnivorous diets. They were, in fact, diets similar to those expected of humans. This is to be expected given that they are indeed mostly carnivorous animals, and coincides with them being kept as pets and fed similar diets to their masters. This phenomenon was previously noted to such an extent that dog $\delta^{13}C$ and $\delta^{15}N$ values were suggested as suitable substitutions for human values should none be available (Burleigh & Brothwell 1978, Murray & Schoeninger 1988, Guiry 2012).

6.4.1.1 Time Period

The faunal data set was divided into four time periods, Roman (AD 0-400), Late Antique (AD 400-800), Early Medieval (AD 800-1200) and Late Medieval (AD 1200-1500), to see if the intra-species variation was due to the cultural shifts that these periods represent. Figure 6.26 shows the distribution of faunal species across each of these time periods, and makes it clear that, at this point, most sites did not have the array of fauna necessary to compare all nine species. For this reason, only cattle, pigs, and sheep/goats were included in further analysis (see Table 6.19).

Outliers were removed from each species based on 1.5 times the Inter Quartile Range for each location. Any sample that fell outside this range was excluded. This brought the sample size to 91 cattle, 95 pigs, and 143 sheep/goats. The summary statistics of these three species by time period can be seen in Table 6.19 and Figure 6.27.

Tukey box plots of the $\delta^{13}C$ values (Figures 6.28 A and B) and Dunn's test (Table 6.20) indicate that there is a shift in $\delta^{13}C$ values for all species between the Late Antique and the Early Medieval periods (p=0.00 for all species). This most likely reflects the introduction of C_4 grains, as there is no accompanying shift in $\delta^{15}N$ values for pigs and sheep/goats. However, there was a significant difference between the Late Antique and Early Medieval cattle $\delta^{15}N$ values, with the mean increasing

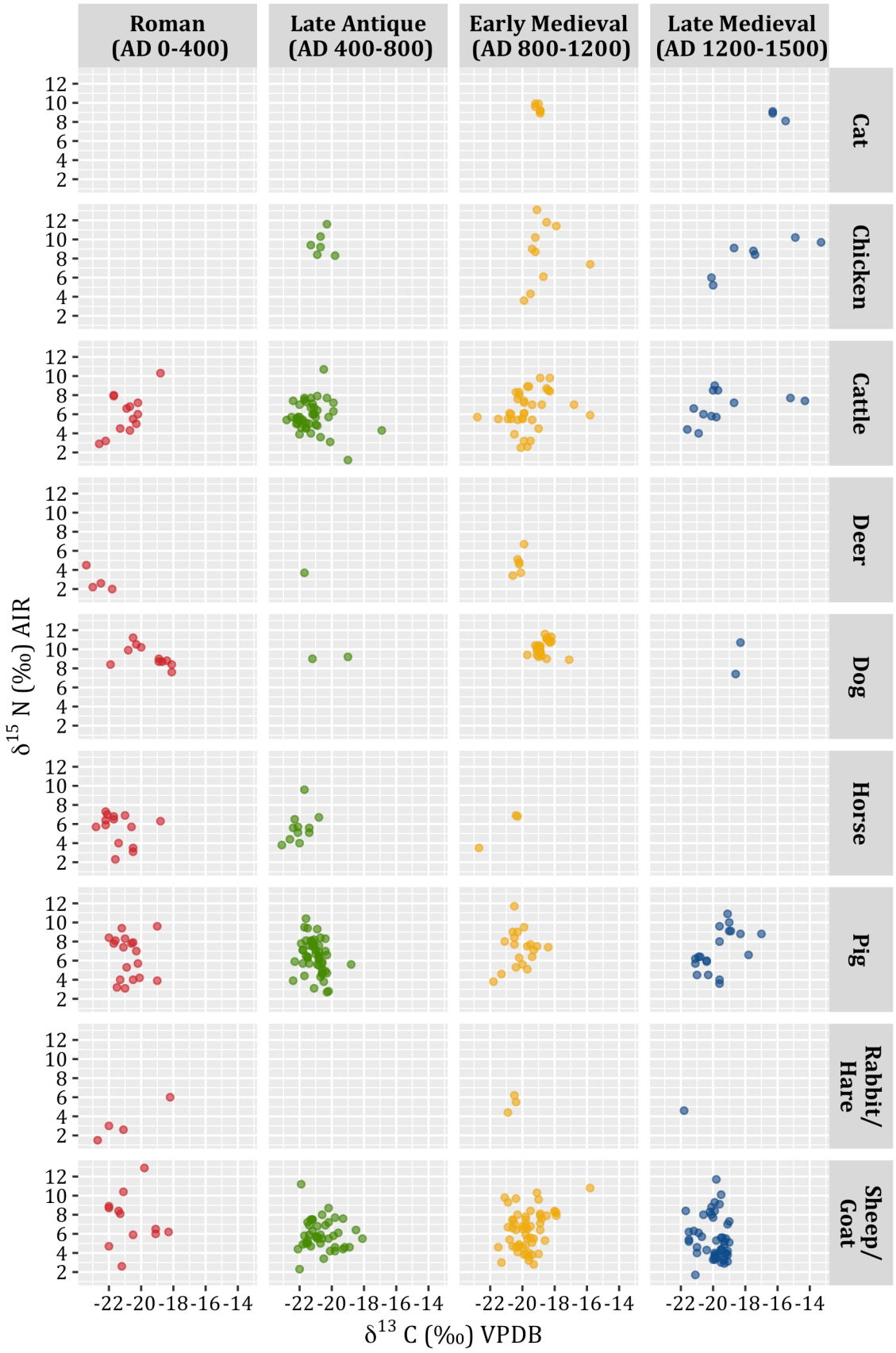


Figure 6.26: The $\delta^{13}C$ and $\delta^{15}N$ of the most common terrestrial species in the Meta-Data set, faceted by time period and species.

Table 6.19: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each species by time period.

Species	Time Period	n	$\delta^{13}C \pm \sigma$	$\delta^{15}N \pm \sigma$
Cattle	Roman	12	-20.80 ± 0.96	6.25 ± 2.00
	Late Antique	41	-21.23 ± 1.01	5.75 ± 1.61
	Early Medieval	29	-19.69 ± 1.35	6.69 ± 1.66
	Late Medieval	12	-19.33 ± 2.28	6.73 ± 1.61
Pig	Roman	17	-20.85 ± 0.73	6.54 ± 2.18
	Late Antique	46	-21.04 ± 0.52	6.47 ± 1.77
	Early Medieval	16	-20.24 ± 0.76	7.19 ± 1.95
	Late Medieval	18	-19.70 ± 1.18	6.94 ± 2.19
Sheep/Goat	Roman	10	-20.38 ± 1.23	7.17 ± 2.93
	Late Antique	39	-20.57 ± 0.99	5.80 ± 1.38
	Early Medieval	52	-19.67 ± 0.84	6.23 ± 1.90
	Late Medieval	45	-19.84 ± 0.67	5.46 ± 2.22

Table 6.20: The p-values for the Dunn's test on the difference between time periods of the faunal carbon and nitrogen isotope values. Values indicating statistically different groups are indicated with an * .

Species	Comparisons	$\delta^{13}C$	$\delta^{15}N$
		p-value	p-value
Cattle	Roman - Late Antique	0.075	0.204
	Late Antique - Early Medevial	0.000*	0.010*
	Early Medieval - Late Medieval	0.420	0.415
Pig	Roman - Late Antique	0.217	0.364
	Late Antique - Early Medevial	0.000*	0.234
	Early Medieval - Late Medieval	0.226	0.356
Sheep/Goat	Roman - Late Antique	0.234	0.083
	Late Antique - Early Medevial	0.000*	0.220
	Early Medieval - Late Medieval	0.269	0.012*

0.94‰. This may indicate an increase in the practice of keeping cattle in pens, or feeding them grain that had be fertilized with manure, both of which could lead to an increase in $\delta^{15}N$ values (Bogaard et al. 2007). Also significant is the shift in $\delta^{15}N$

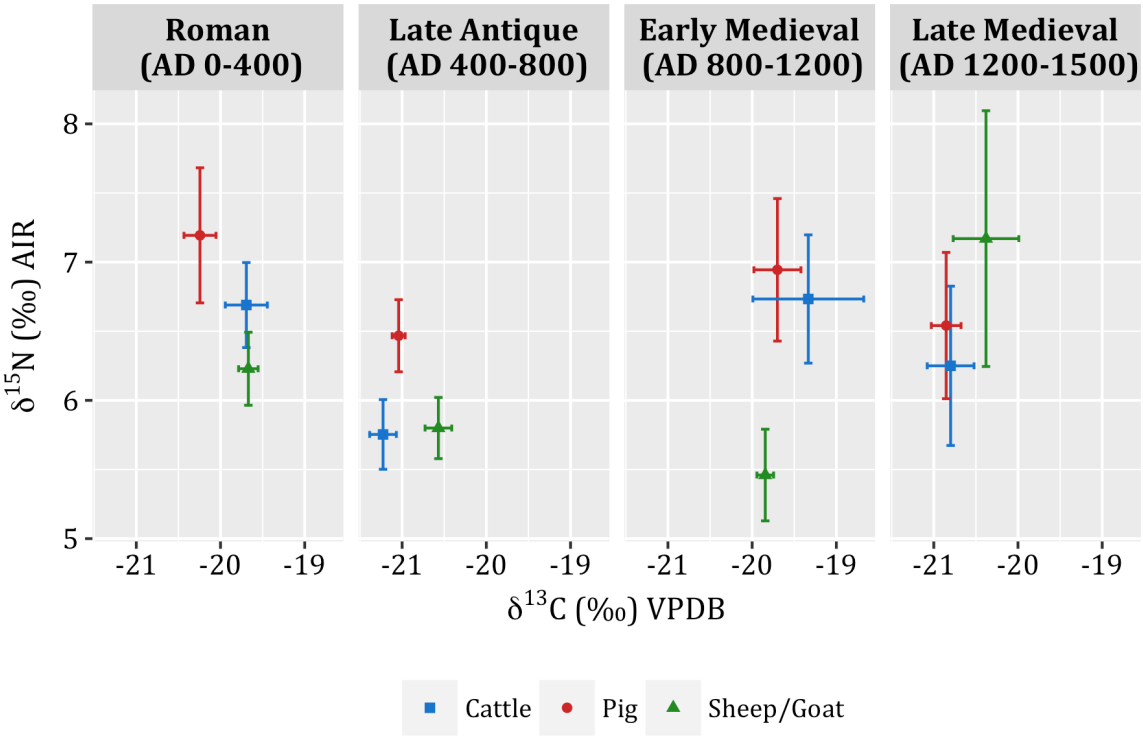


Figure 6.27: The mean $\delta^{13}C$ and $\delta^{15}N$ ± one standard error, of the most common terrestrial species in the Meta-Data set, faceted by time period.

values, between the sheep/goat populations from the Early Medieval and the Late Medieval period (p=0.012). The increase in mean $\delta^{15}N$ was due to a few individuals having higher $\delta^{15}N$, rather than a shift in the whole population. The reasoning behind it is most likely the same as for the shift in cattle $\delta^{15}N$ values; however, the lack of an overall shift in the population indicates that animal husbandry practices were more localized and less universal across the continent. While it is tempting to overgeneralize based on chronology, it is important to keep in mind that the samples in this study are spread across a large geographical range, and often not equally distributed across time periods. This will be addressed further in the next chapter.

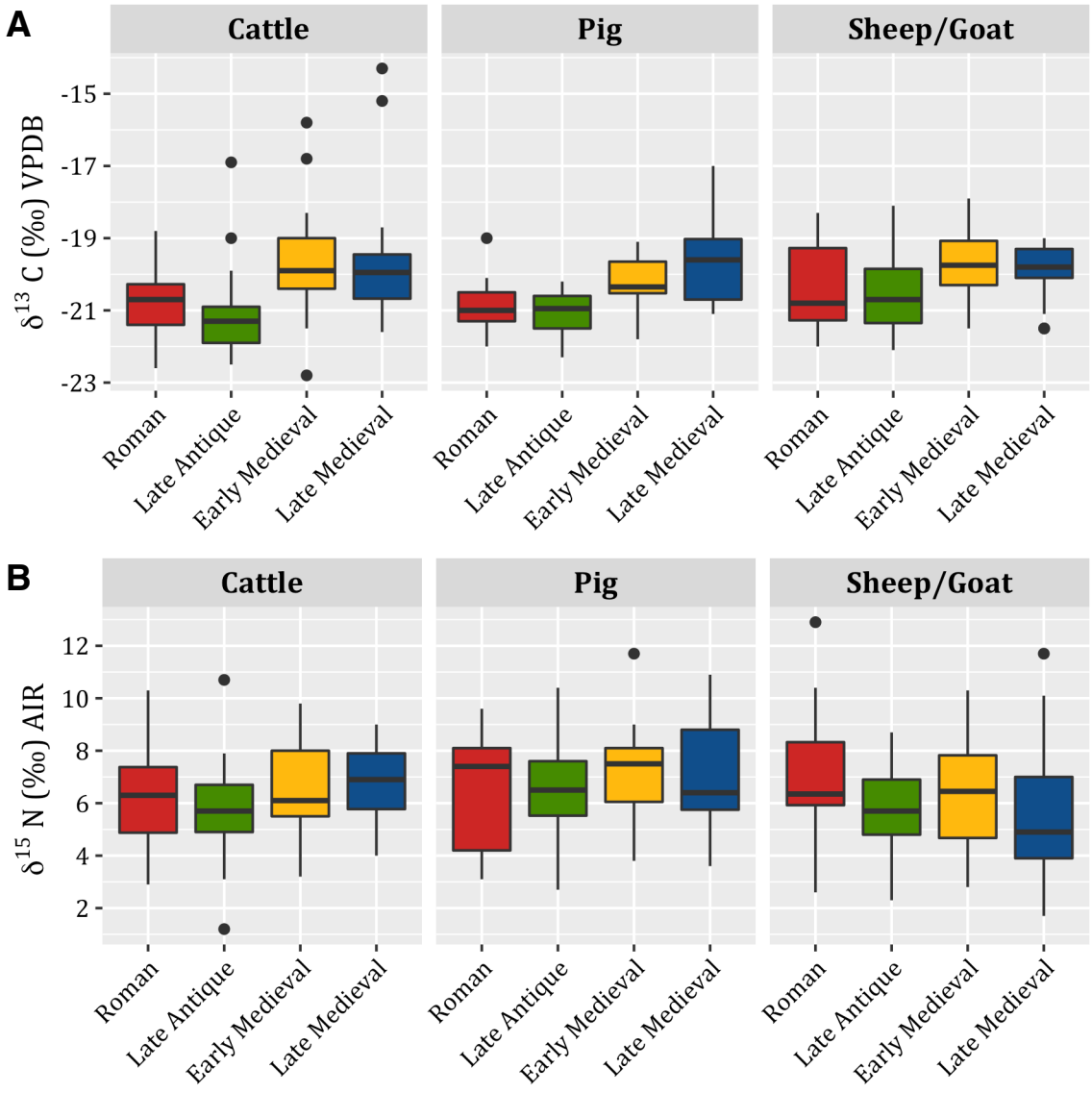


Figure 6.28 A & B: Tukey Boxplot (Tukey 1977) of the $\delta^{13}C$ (A) and $\delta^{15}N$ (B) for each species grouped by time period.

6.4.1.2 Coastal vs Inland

The results of the analysis between coastal and inland faunal species can be seen in Table 6.21 and Figure 6.29. The difference between coastal and inland populations is shown separately for each species. The coastal cattle population has significantly different carbon and nitrogen isotope values from the inland cattle populations (Mann-Whitney U p=0.00 and p=0.004, respectively). The coastal cattle had, on average, higher $\delta^{13}C$ and $\delta^{15}N$ (1.32‰ and 1.08‰), respectively. They had a wider range in $\delta^{13}C$ values, but a narrower range in $\delta^{15}N$ values (see Figure 6.29

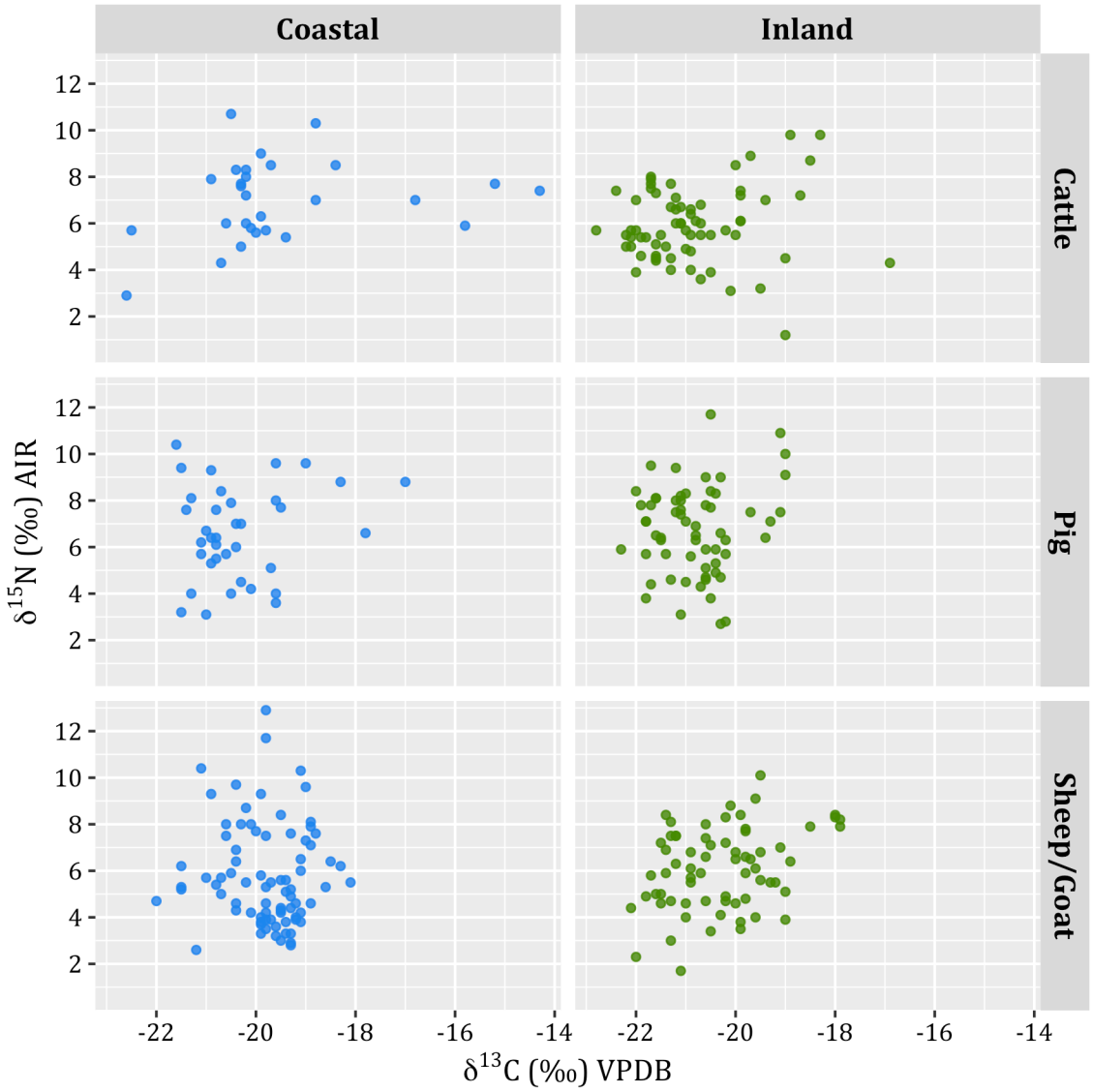


Figure 6.29: The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by species (coastal means less than 10km from the coast and inland means more than 10km).

below). In contrast to the cattle, the pigs from coastal and inland locations did not have carbon and nitrogen isotope values that were significantly different from each other. This indicates that their food source was not affected by the proximity to the ocean. The coastal and inland sheep/goat populations significantly differ only in their carbon isotope values (Mann-Whitney U p=0.00 for $\delta^{13}C$ and p=0.092 for $\delta^{15}N$). The coastal population also had a higher mean $\delta^{13}C$ (+0.51‰); however, it was generally lower in $\delta^{15}N$ (-0.31‰).

Table 6.21: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the coastal and inland groups of each species. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *.

Species	Location	n	$\delta^{13}C \pm \sigma$	$\delta^{13}C$ p-value	$\delta^{15}N \pm \sigma$	$\delta^{15}N$ p-value
Cattle	Coastal	28	-19.53 ± 1.91	0.000*	6.99 ± 1.73	0.004*
	Inland	66	-20.85 ± 1.14		5.91 ± 1.61	
Pig	Coastal	36	-20.34 ± 1.05	0.052	6.60 ± 2.01	0.748
	Inland	61	-20.80 ± 0.78		6.74 ± 1.92	
Sheep/Goat	Coastal	79	-19.78 ± 0.78	0.000*	5.80 ± 2.20	0.092
	Inland	67	-20.29 ± 1.03		6.11 ± 1.75	

When the data was further divided into the four time periods (Roman, Late Antique, Early Medieval and Late Medieval), the significant differences between coastal and inland groups becomes more nuanced. As can be seen in Table 6.22 and Figure 6.30, the only significant difference in $\delta^{13}C$ between coastal and inland groups was found in the sheep/goats during the Late Antique Period (Mann-Whitney U test, p=0.00). In terms of $\delta^{15}N$ there was a significant difference between the Late Antique cattle (p=0.001), the Roman pigs (p=0.030) and the Late Antique pigs (p=0.13). What is clear is that there is no uniform pattern of fauna having statistically different carbon and nitrogen isotope values due to their proximity to the ocean.

Table 6.22: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the coastal and inland groups of each species, for each time period. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *.

Species	Time Period	Location	n	$\delta^{13}C \pm \sigma$	p-value	$\delta^{15}N \pm \sigma$	p-value
Cattle	Roman	Coastal	6	-20.47 ± 1.23	0.108	5.95 ± 2.59	0.485
		Inland	6	-21.13 ± 0.51		6.55 ± 1.36	
	Late Antique	Coastal	5	-20.85 ± 1.01	0.135	7.66 ± 1.94	0.011*
		Inland	36	-21.28 ± 1.02		5.49 ± 1.40	
	Early Medieval	Coastal	10	-19.03 ± 1.60	0.206	7.16 ± 1.18	0.301
		Inland	19	-20.04 ± 1.08		6.44 ± 1.84	
	Late Medieval	Coastal	7	-18.51 ± 2.60	0.106	7.16 ± 1.35	0.371
		Inland	5	-20.48 ± 1.16		6.14 ± 1.90	
Pig	Roman	Coastal	9	-20.57 ± 0.75	0.083	5.37 ± 2.29	0.030*
		Inland	8	-21.18 ± 0.59		7.86 ± 1.06	
	Late Antique	Coastal	12	-20.98 ± 0.38	0.783	7.65 ± 1.55	0.013*
		Inland	34	-21.06 ± 0.57		6.05 ± 1.67	
	Early Medieval	Coastal	2	-19.60 ± 0.14	0.265	6.40 ± 1.84	0.633
		Inland	14	-20.34 ± 0.77		7.31 ± 2.01	
	Late Medieval	Coastal	13	-19.70 ± 1.30	0.728	6.51 ± 1.87	0.256
		Inland	5	-19.70 ± 0.94		8.08 ± 2.75	
Sheep/ Goat	Roman	Coastal	8	-20.14 ± 1.27	0.150	6.90 ± 3.25	0.400
		Inland	2	-21.35 ± 0.07		8.25 ± 0.21	
	Late Antique	Coastal	16	-19.81 ± 0.90	0.000*	5.56 ± 1.29	0.166
		Inland	23	-21.10 ± 0.65		5.97 ± 1.45	
	Early Medieval	Coastal	24	-19.81 ± 0.90	0.679	6.43 ± 2.28	0.607
		Inland	28	-20.10 ± 0.65		6.05 ± 1.53	
	Late Medieval	Coastal	31	-19.76 ± 0.63	0.201	5.15 ± 2.05	0.158
		Inland	14	-20.03 ± 0.73		6.14 ± 2.52	

6.4.1.3 By Climate Classification

The faunal data was next grouped according to the Köppen-Geiger Climate Classification of their location (outlined in Tables 5.7 and 5.8 in Chapter 5). The results of the analysis of the three main faunal species (cattle, pigs, and sheep/goats) can be seen in Table 6.23 as well as in Figure 6.31.

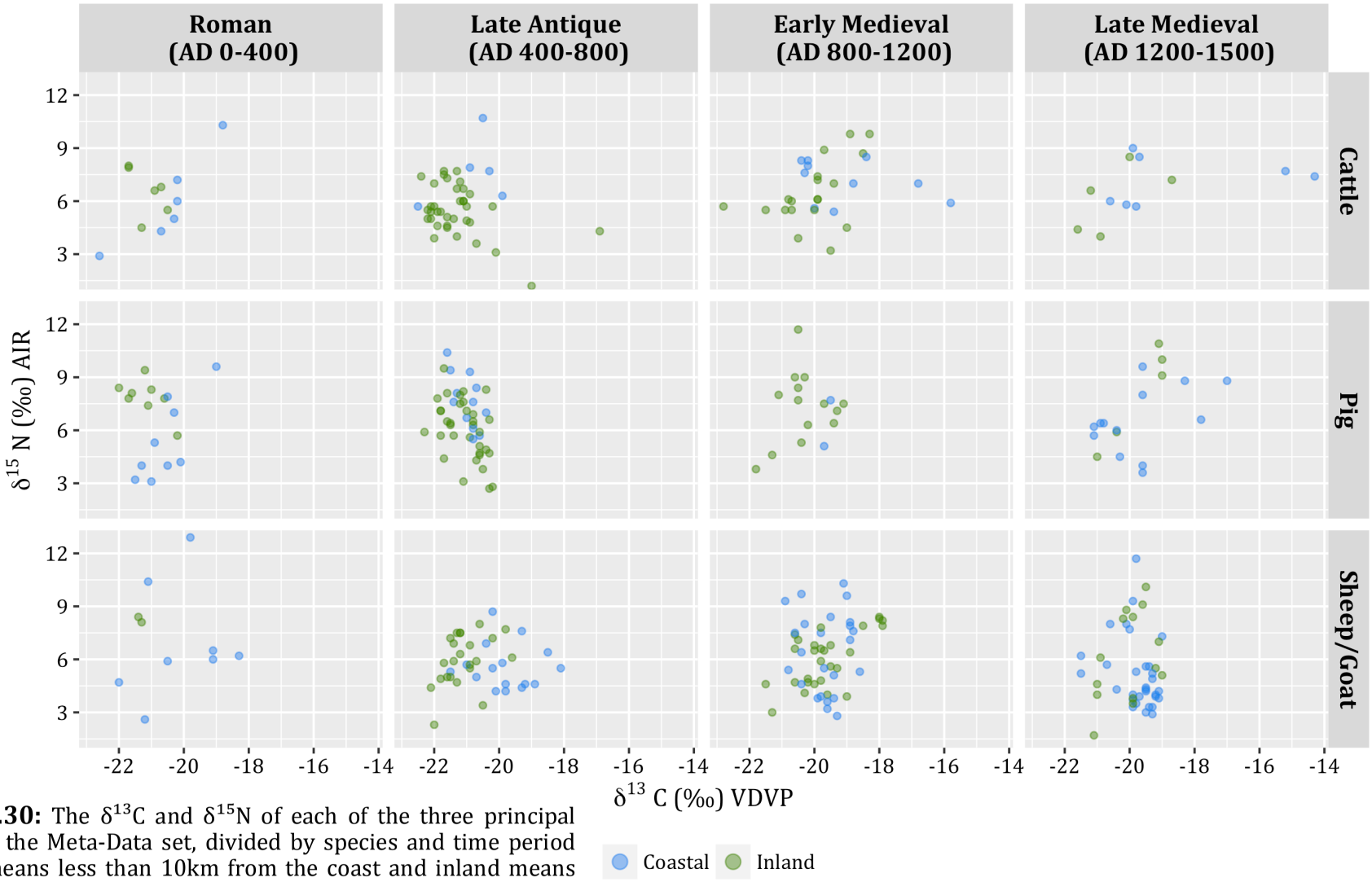


Figure 6.30: The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by species and time period (coastal means less than 10km from the coast and inland means more than 10km).

Table 6.23: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each of the three main faunal species (cattle, pigs, and sheep/goats), grouped by Köppen-Geiger Climate Classification.

Species	Climate Classification	n	$\delta^{13}C \pm \sigma$	$\delta^{15}N \pm \sigma$
Cattle	BSh	1	-18.80	10.30
	BSk	4	-18.93 ± 0.49	6.83 ± 3.48
	Csa	29	-19.52 ±1.88	7.00 ± 1.65
	Csb	3	-20.90 ± 0.40	5.53 ± 1.05
	Cfb	50	-20.95 ± 1.04	5.85 ±1.43
	Dfc	7	-21.74 ±0.60	5.16 ± 0.83
Pig	BSh	1	-19.00	9.60
	Csa	35	-20.38 ± 1.03	6.51 ± 1.97
	Cfb	56	-20.70 ±0.74	6.70 ± 1.99
	Dfc	5	-21.88 ± 0.26	7.20 ± 0.85
Sheep/Goat	BSh	4	-19.58 ± 1.19	8.88 ± 3.36
	BSk	9	-19.28 ± 0.83	7.70 ± 1.57
	Csa	77	-19.81 ± 0.76	5.63 ± 2.02
	Cfb	52	-20.34 ± 0.95	5.95 ± 1.68
	Dfc	4	-21.80 ± 0.22	5.03 ± 0.58

There is a general pattern of decreasing $\delta^{13}C$ and $\delta^{15}N$ values as climate classifications progress from hot and arid climates to colder more wet climates that is very clear in the cattle, slightly less clear with the sheep/goat, and completely lacking in terms of the pigs. The p-values from Dunn's Test (Dunn 1964) can be seen in Table 6.24. The sample size for some of the climate classifications are fairly small, making any firm conclusions difficult. However, as can be seen in Table 6.24, the significant differences, where, $p<0.05$, are between the warmer, more arid climate classifications like BSh and BSk and the colder, wetter climate classifications like Cfb and Dfc; and that this is true for all three species. Of special interest is the manner in which the data, when plotted in box plots by isotope, follows a similar pattern to that of the humans (discussed further below and in Chapter 7).

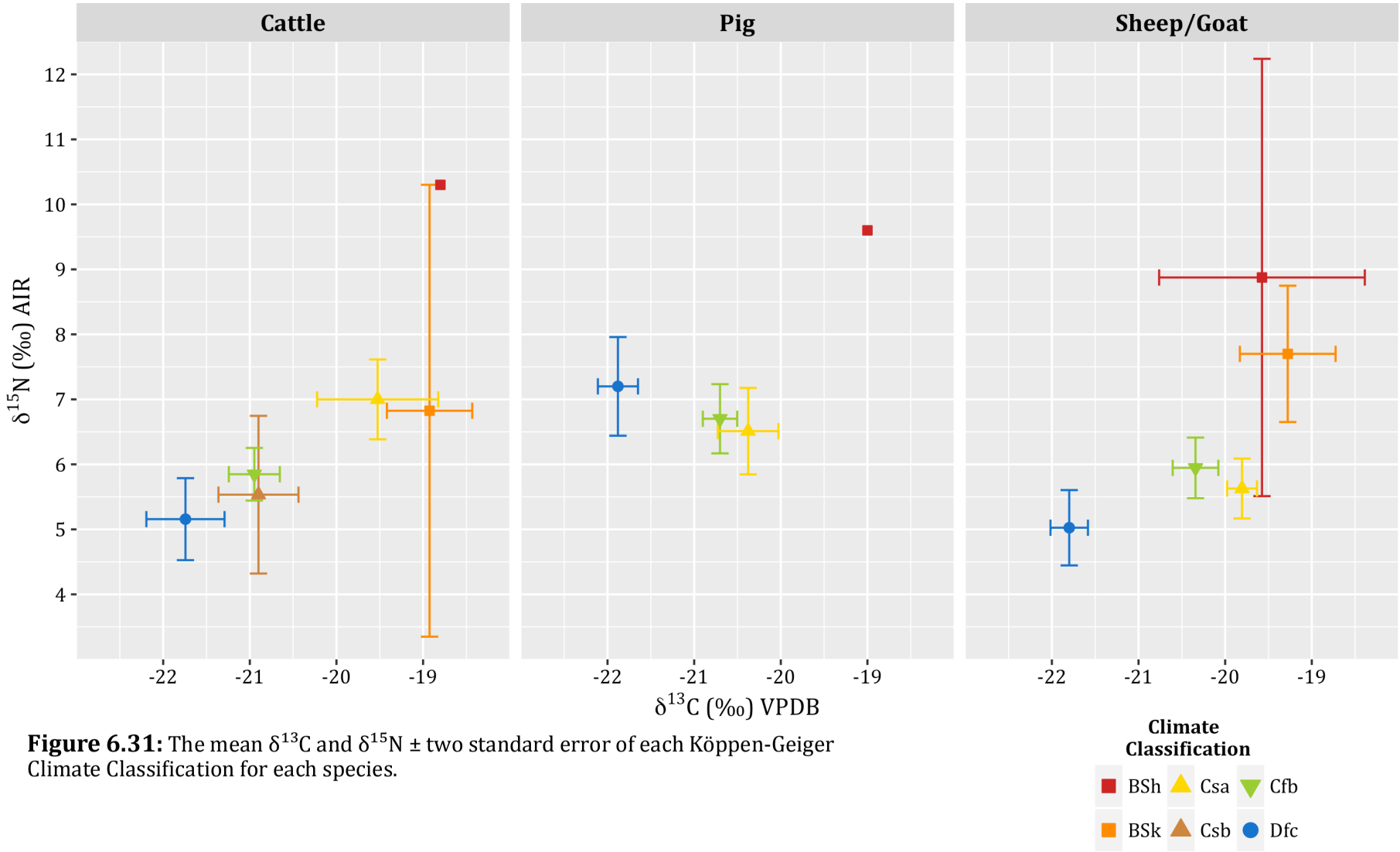


Figure 6.31: The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard error of each Köppen-Geiger Climate Classification for each species.

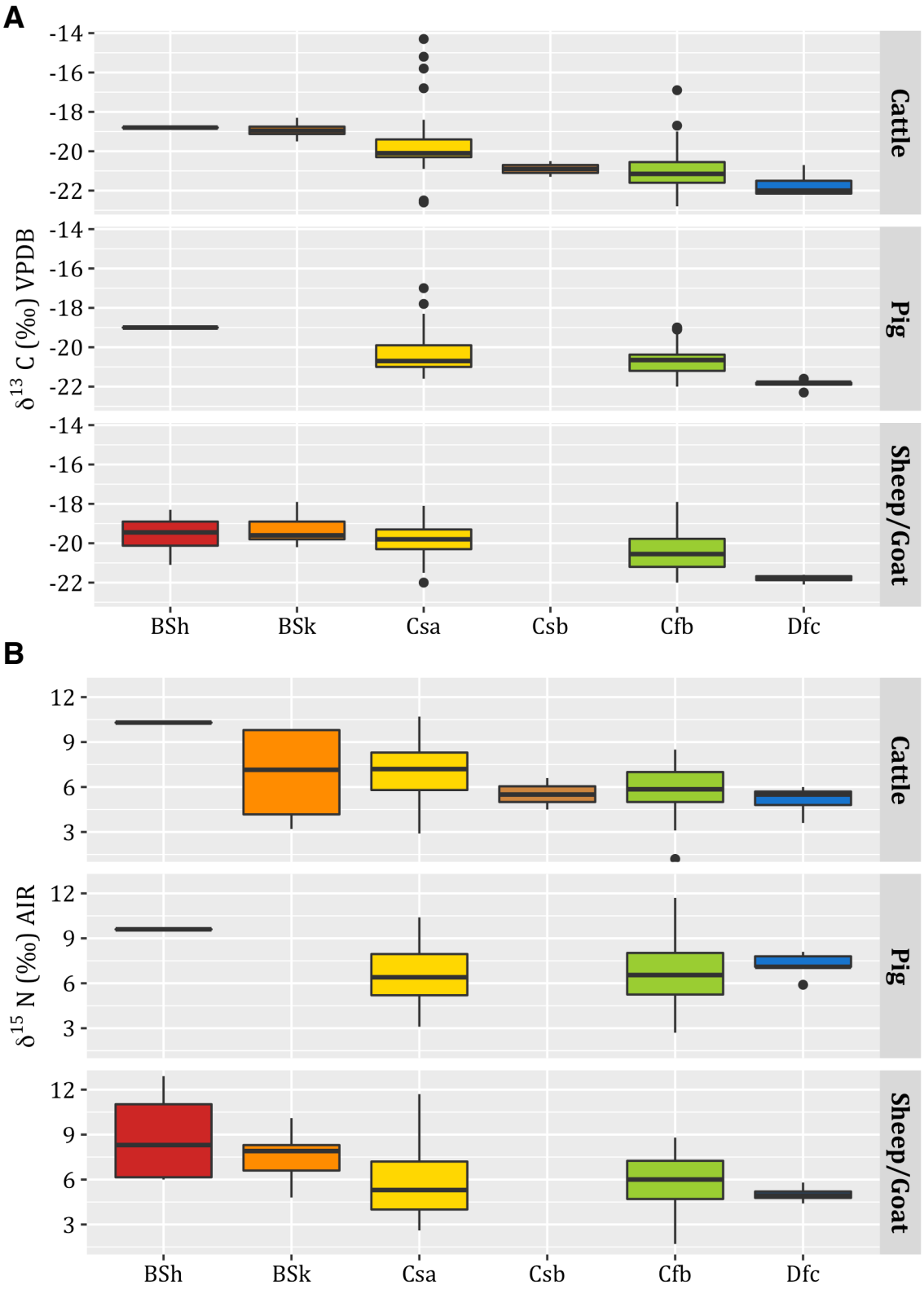


Figure 6.32 A & B: Tukey Boxplot (Tukey 1977) of $\delta^{13}C$ (A) and $\delta^{15}N$ (B) for each species grouped by Köppen-Geiger Climate Classification.

Table 6.24: The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classification of the faunal carbon and nitrogen isotope values. Statistically different values are indicated with an *.

Species	Comparison	$\delta^{13}C$ p-value	$\delta^{15}N$ p-value	Species	Comparison	$\delta^{13}C$ p-value	$\delta^{15}N$ p-value
Cattle	BSh - BSk	0.479	0.080*	Pig	BSh - Cfb	0.057	0.063
	BSh - Cfb	0.047*	0.032*		BSh - Csa	0.092	0.054
	BSh - Csa	0.239	0.122		BSh - Dfc	0.002*	0.129
	BSh - Csb	0.084	0.030*		Cfb - Csa	0.125	0.340
	BSh - Dfc	0.011*	0.014*		Cfb - Dfc	0.001*	0.257
	BSk - Cfb	0.001*	0.284		Csa - Dfc	0.000*	0.205
	BSk - Csa	0.107	0.236	Sheep/ Goat	BSh - BSk	0.357	0.461
	BSk - Csb	0.022*	0.218		BSh - Cfb	0.051	0.042*
	BSk - Dfc	0.000*	0.102		BSh - Csa	0.334	0.011
	Cfb - Csa	0.000*	0.002*		BSh - Dfc	0.001*	0.023
	Cfb - Csb	0.436	0.307		BSk - Cfb	0.002*	0.010*
	Cfb - Dfc	0.032*	0.108		BSk - Csa	0.106	0.001*
	Csa - Csb	0.075	0.053		BSk - Dfc	0.000*	0.012
	Csa - Dfc	0.000*	0.003*		Cfb - Csa	0.000*	0.063
	Csb - Dfc	0.111	0.386		Cfb - Dfc	0.008*	0.162
					Csa - Dfc	0.000*	0.322

6.4.2 Human Analysis

As stated in Chapter 5, the Meta-Data set was established using published studies approximately contemporary with Sanisera and Mérida. The resulting database contains 1,511 human individuals from 53 sites. For simplicity, sites from the same city were grouped together yielding 31 locations. Of the human samples, 1381 were identified as adults, either by their original publication or by methods described in Chapter 5. To avoid the effects of nursing signals, the 130 subadults were removed from the analysis. Figure 6.33 shows the isotopic results for the 1,381 remaining adults.

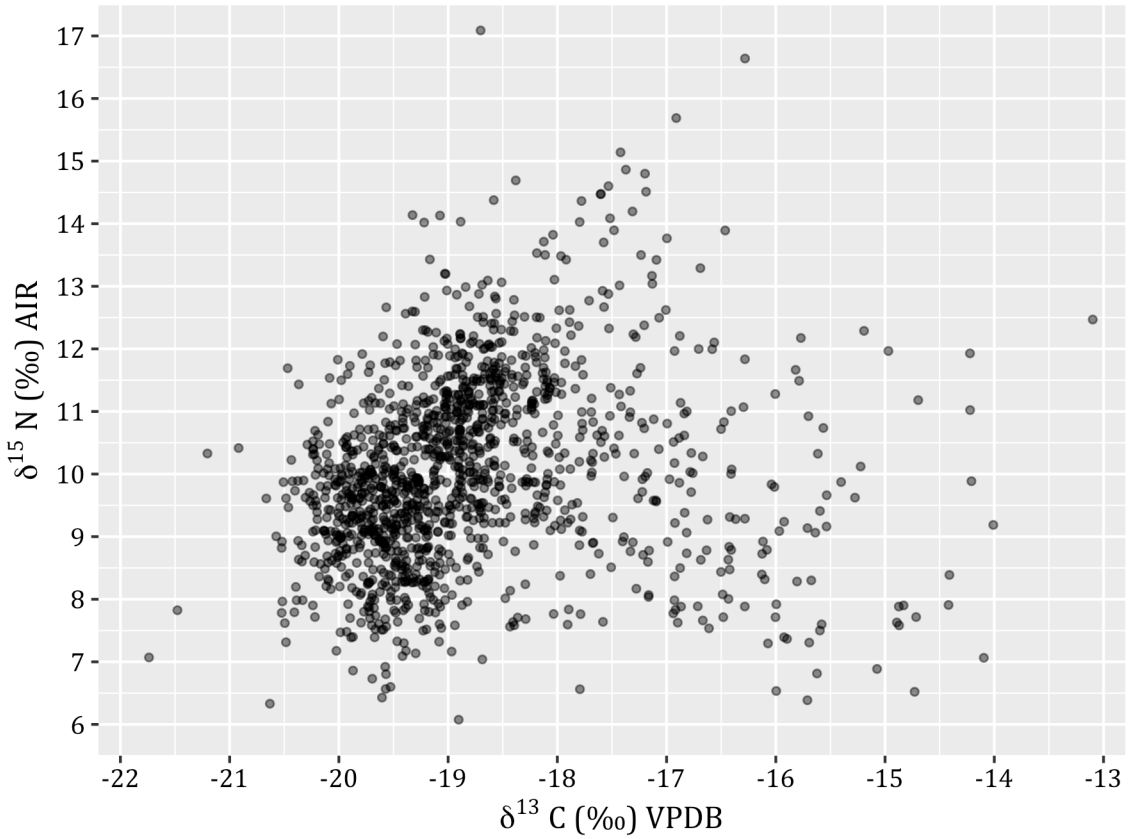


Figure 6.33: The $\delta^{13}C$ and $\delta^{15}N$ of every adult human (n=1381) in the Meta-analysis. Points jittered and at 1/2 transparency to make them more visible.

Below, in Table 6.25 are the summary statistics for each of the 31 locations included in this analysis[1]. Ten of the locations have normally distributed $\delta^{13}C$ and $\delta^{15}N$ values (Shapiro-Wilk test $p>0.05$). While fifteen of the locations have exclusively $\delta^{13}C$ values distributed normally and twenty-one have normal distributions exclusively for their $\delta^{15}N$ values. With the populations all having such

[1] For information as to the study the data was taken from see Table 5.5.

Table 6.25: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of each location. Also included is the p-value of the Shapiro-Wilk test of normality (p>0.05 indicates that a distribution is normal).

Location	n	$\delta^{13}C$ (‰) VPDB			$\delta^{15}N$ (‰) AIR		
		mean	σ	p-value	mean	σ	p-value
Austria							
Volders	90	-20.0	0.4	0.002	10.0	0.8	0.195
Belgium							
Antwerp	2	-19.4	0.0	-	11.2	0.4	-
Namur	5	-20.2	0.3	0.006	8.9	0.7	0.625
Tongeren	2	-19.8	0.1	-	11.7	0.1	-
Czech Republic							
Mikulčice	28	-17.8	0.6	0.443	10.0	0.9	0.000
France							
Grenoble	34	-20.0	0.4	0.268	8.7	0.9	0.581
Germany							
Munich	75	-19.4	0.5	0.000	9.6	0.7	0.022
Naumburg	32	-19.8	0.3	0.160	9.5	0.6	0.017
Straubing	94	-19.7	0.3	0.000	9.6	0.5	0.093
Weingarten	37	-19.8	0.7	0.000	8.7	0.7	0.244
Greece							
Corinth	16	-19.0	0.8	0.000	8.7	0.6	0.970
Crete	4	-18.7	1.2	1.115	9.4	1.4	0.519
Sourtara	23	-18.2	0.2	0.812	9.5	0.3	0.221
Messene	19	-19.2	0.3	0.135	8.8	1.2	0.017
Hungary							
Szolád	25	-19.0	0.7	0.000	9.6	0.8	0.542
Italy							
Civitanova Marche	21	-19.6	0.6	0.003	9.5	1.3	0.010
Cosa	26	-17.8	0.7	0.070	8.8	1.1	0.316
Friuli V.G.	75	-16.4	1.1	0.391	8.2	0.8	0.571
Pompeii	22	-18.9	0.4	0.016	10.3	0.8	0.350

Location	n	δ^{13}C (‰) VPDB			δ^{15}N (‰) AIR		
		mean	σ	p-value	mean	σ	p-value
Rome	254	-18.8	0.5	0.000	10.8	1.2	0.000
Velia	117	-19.4	0.3	0.070	8.6	1.3	0.000
Portugal							
Bragança	9	-19.2	0.3	0.650	9.1	1.0	0.671
Spain							
A Lanzada	53	-16.1	1.6	0.047	12.4	0.8	0.291
Albarracín	31	-19.0	0.2	0.113	10.8	0.7	0.881
Gandía	44	-16.8	1.1	0.564	10.4	0.7	0.985
Jaca	25	-18.4	1.1	0.000	10.0	0.8	0.090
Ibiza	60	-18.7	0.9	0.000	10.9	0.9	0.111
Mérida	25	-18.4	1.5	0.000	10.5	1.1	0.216
Sanisera	34	-18.7	0.7	0.647	11.5	1.1	0.000
Valencia	57	-17.9	1.2	0.001	11.3	1.6	0.000
Zaragoza	41	-18.9	0.4	0.182	10.8	1.4	0.499
Tunisia							
Leptiminus	54	-17.8	0.6	0.696	12.9	1.3	0.963

varied distributions, a non-parametric method was used to determine and remove outliers. Outliers were defined as individuals falling outside 1.5 times the interquartile range for each location (1.5 × IQR) as is normally done in the construction of Tukey Boxplots (Tukey 1977). The distribution and outliers of both δ^{13}C and δ^{15}N values for each location can be seen in Figures 6.34 and 6.35.

Using this method, 113 individuals (8.18% of the total) were determined to be outliers for their location and were removed from further analysis. Figure 6.36 shows the new means with twice the standard error of the mean, colored by country. What can be interpreted from this graph is that the majority of the locations consist of individuals with terrestrial C_3-based diets with variable amounts of meat, fish and C_4 plants being integrated into the diet. Of particular interest is Friuli Venezia Giulia

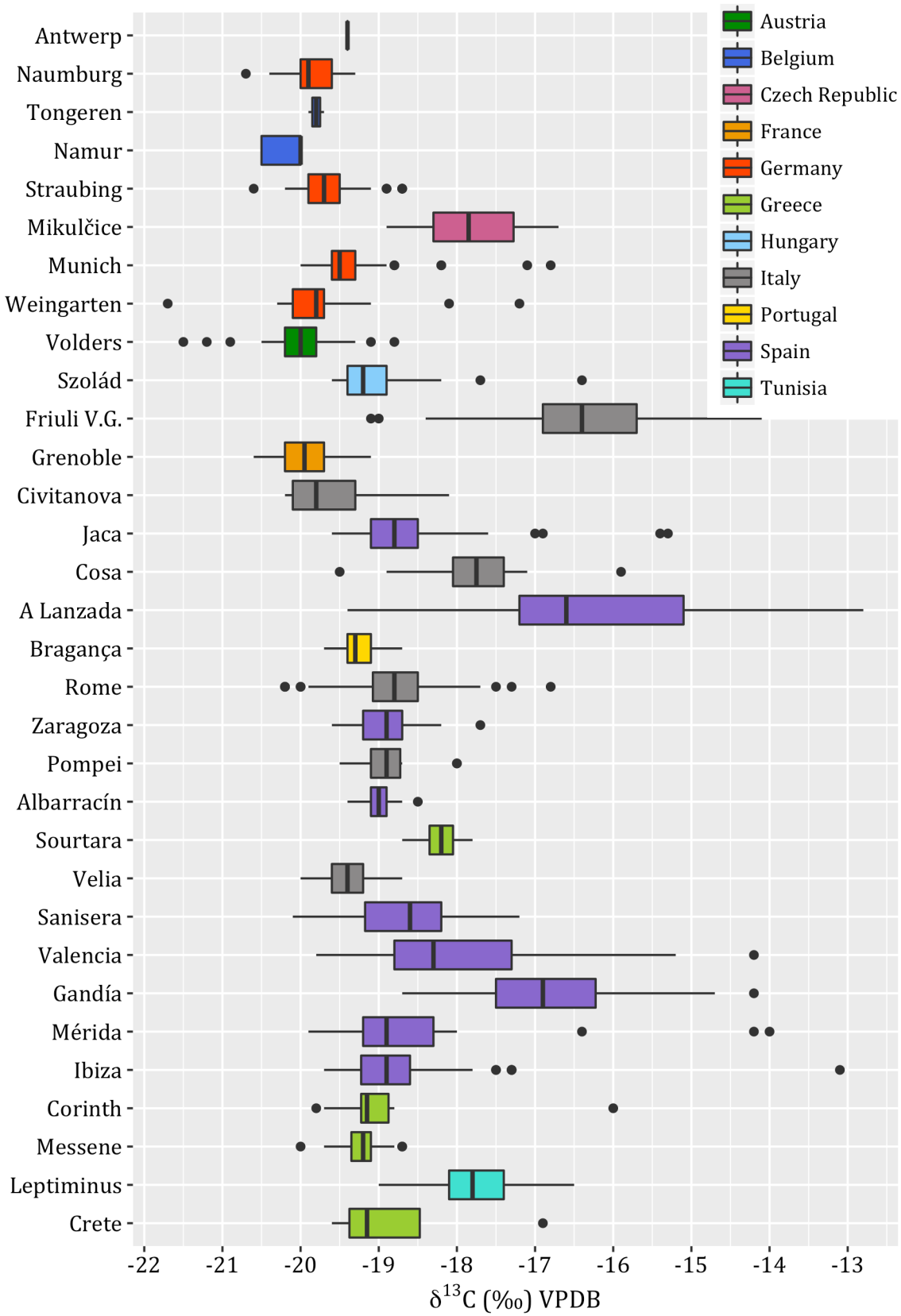


Figure 6.34: Tukey box-plot (Tukey 1977) showing the distribution of $\delta^{13}C$ by location on the left vertical axis. The box represents the interquartile range, while the lines represents 1.5 times that. The division in the box is the population median, and the dots are the outliers. Locations are colored according to their country (listed in the key on the right) and ordered North to South.

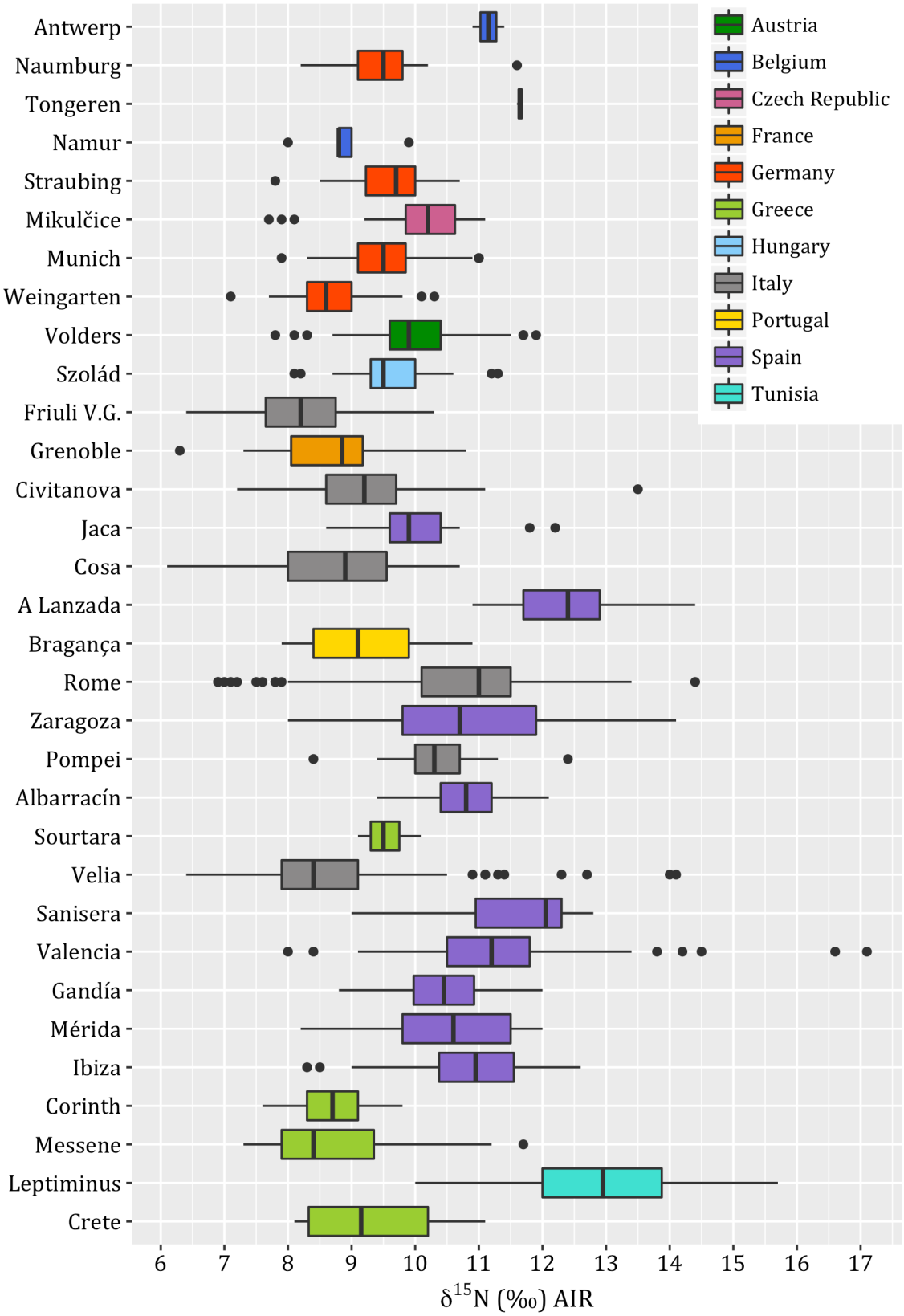


Figure 6.35: Tukey box-plot (Tukey 1977) showing the distribution of $\delta^{15}N$ by location along the left vertical axis. The box represents the interquartile range, while the lines represents 1.5 times that. The division in the box is the population median, and the dots are the outliers. Locations are colored according to their country (listed in the key on the right) and ordered North to South.

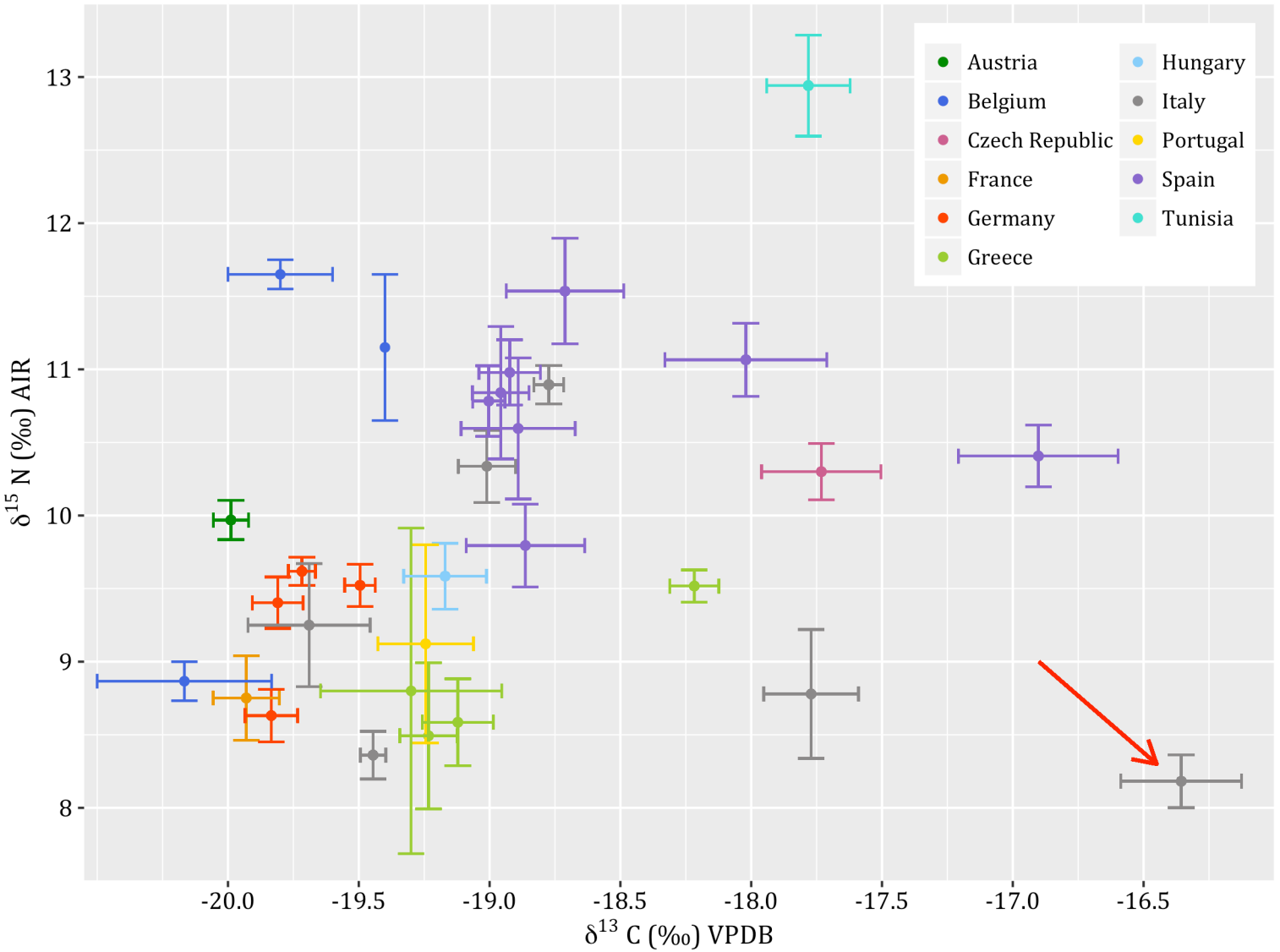


Figure 6.36: The mean $\delta^{13}C$ and $\delta^{15}N$ ± two standard errors, for each location in the Meta-analysis. The points are colored by country as can be seen in the legend. The site of Friuli V.G. is indicated by the red arrow.

(here after referred to as Friuli V.G.) in Italy, with exceptionally high $\delta^{13}C$ values and relatively low $\delta^{15}N$ (as can be seen indicated with the red arrow in Figure 6.36), as well as Leptiminus (in Tunisia). The isotope values at Friuli V.G. have been attributed to a C_4 based diet (Iacumin *et al.* 2014). For this reason, it will be excluded from the statistical analysis below, but it will be included in the discussion later. As demonstrated by the faunal data, the two major factors to consider in the comparison of multiple populations, is *when* and *where*. What follows are the results of considering those variables in terms of the human samples from the Meta-Data set.

6.4.2.1 Time Period

The Meta-Data set also includes individuals dating from the 1st century AD through to the 16th century AD. With such a large number of studies, it is not surprising that the dates reported range from radiocarbon dates and more general time spans. As with the faunal data, dates were assigned to four time spans: (AD 0-400, AD 400- 900, AD 900- 1300, and AD 1300 to 1500). These time spans will be referred to as "Roman", "Late Antique", "Early Medieval", and "Late Medieval"

Table 6.26: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of each time period. Also included is the p-value of the Shapiro-Wilk test of normality (p>0.05 indicates that a distribution is normal).

Time period	n	$\delta^{13}C$ (‰) VPDB		$\delta^{15}N$ (‰) AIR	
		mean ± σ	p-value	mean ± σ	p-value
Roman (1st-4th cen. AD)	429	-18.9 ± 0.6	0.000	10.3 ± 1.6	0.000
Late Antique (5th-8th cen. AD)	470	-19.4 ± 0.7	0.000	10.0 ± 1.2	0.000
Early Medieval (9th-12th cen. AD)	183	-18.5 ± 0.9	0.000	10.5 ± 1.3	0.200
Late Medieval (13th - 16th cen. AD)	113	-18.4 ± 1.5	0.001	9.9 ±1.1	0.232

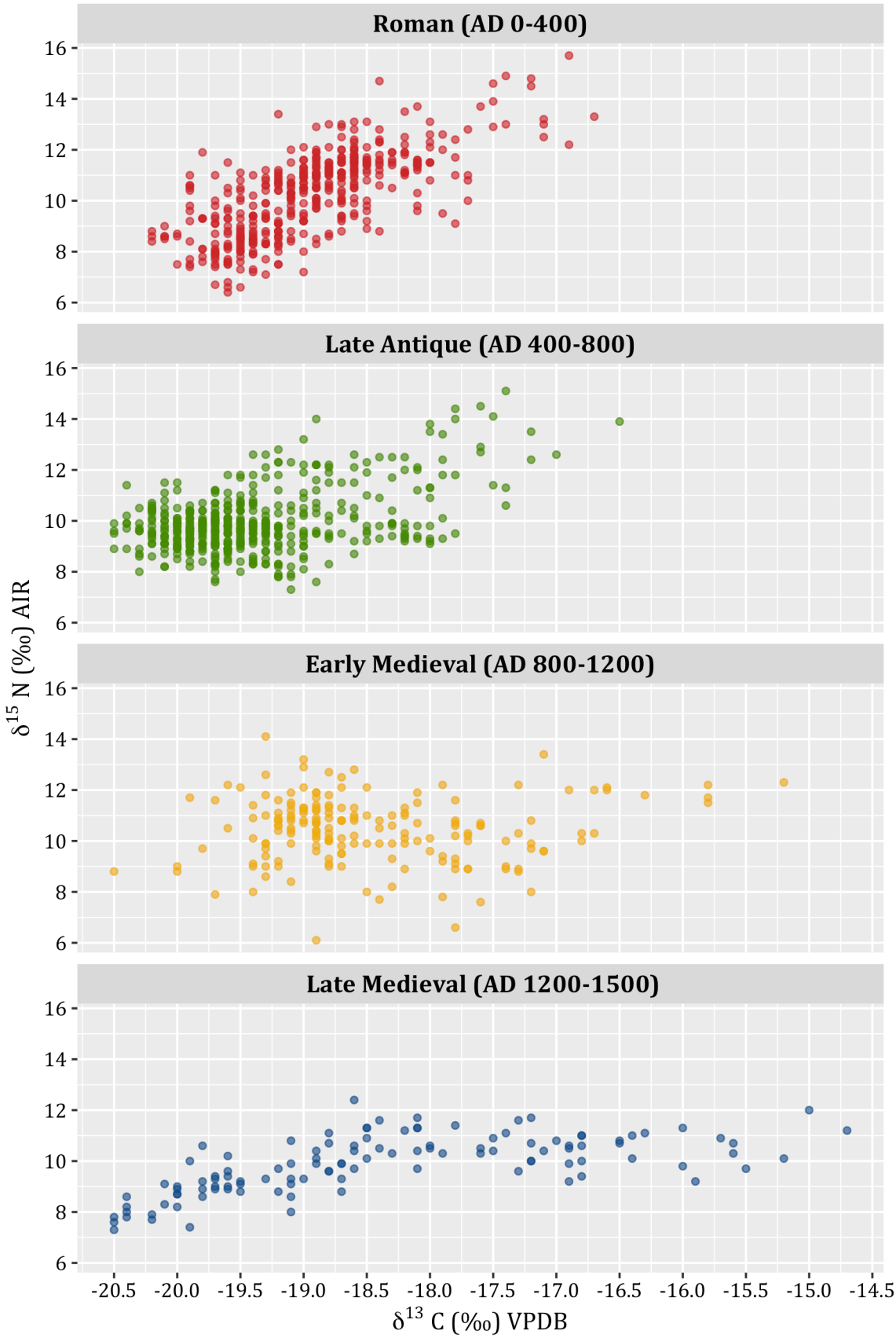


Figure 6.37: The $\delta^{13}C$ and $\delta^{15}N$ of the individuals from the Meta-Data set divided by time period.

respectively. When the Meta-Data set was divided by time period, it became clear that there was a marked difference in distributions among the four time periods (See Figure 6.37 and Table 6.26). The increased range of $\delta^{13}C$ values after the 9th century AD could be attributed to the spread of C_4 plants such as millet and sorghum (Braudel 1972, Glick 1982, Mundee 2010), but could also be due to an increase in the consumption of marine resources. While there also appears to be a decrease in $\delta^{15}N$ values over time, this can be attributed to the Tunisian location of Leptiminus only having individuals dating to the first two periods.

6.4.2.2 Location

Location is key to interpreting the isotopic results. There are many ways in which to define location. The most basic of variables, latitude, longitude, and altitude (or meters above sea level) were considered first before moving on to other more complex definitions.

While none of these three variables had a direct effect on carbon and nitrogen isotope values or how they were passed up the food chain, it was important to, at least, consider them as proxies for other environmental factors that did affect staple isotopes (Van Klinken *et al.* 1994, 2002). The results of univariate regression analysis on these three variables of location are presented in Table 6.27.

Table 6.27: The results of uni-variate regression analysis on $\delta^{13}C$ and $\delta^{15}N$ by the location variables of altitude, latitude and longitude.

Variable	Isotope	p-value	R^2	Slope Coefficient
Altitude	$\delta^{13}C$	0.000	0.103	-0.001
	$\delta^{15}N$	0.000	0.034	-0.001
Latitude	$\delta^{13}C$	0.000	0.265	-0.113
	$\delta^{15}N$	0.000	0.104	-0.111
Longitude	$\delta^{13}C$	0.000	0.048	-0.030
	$\delta^{15}N$	0.000	0.084	-0.062

While the p-values for these regressions appeared promising, the coefficient values indicated that they were more likely a Type I error, or false positive results; probably due to the large size of the data set (Field *et al.* 2012). The squared correlation coefficient (R^2) of these equations gave a clearer picture as to the strength of the relationship between carbon and nitrogen isotope values and these variables. Latitude had the strongest relationship (i.e., the largest R^2), for both carbon and nitrogen isotope results, accounting for up to 26.5% and 10.4% of the variance, respectively. The further north the location, the less enriched the $\delta^{13}C$ value or $\delta^{15}N$ value, though this was only by approximately 0.1‰ per degree of latitude for either isotope (assuming a linear relationship). In this data set, latitude's effect on $\delta^{15}N$ was not as strong as the effect on $\delta^{13}C$ values. This was likely due to greater fish consumption at coastal versus inland locations combined with the relatively greater frequency of coastal locations than inland locations at more southern latitudes. As noted above, this would make individuals more enriched in ^{15}N. A further discussion of this is included in the multi-variate analysis below, which allows the effect of coastal-inland location to be controlled for when assessing the impact of latitude.

It is also important to keep in mind that the percent of variation 'explained' by R^2 can be misleading. As can be seen in Figure 6.38, any relationship between $\delta^{13}C$ values and latitude was not very robust. What is more likely was that additional variables, which also change with latitude, were responsible. For example, the difference could be the result of the lower temperatures of higher latitudes affecting fractionation during CO_2 uptake in plants resulting in lower $\delta^{13}C$ (Van Klinken *et al.* 2002).

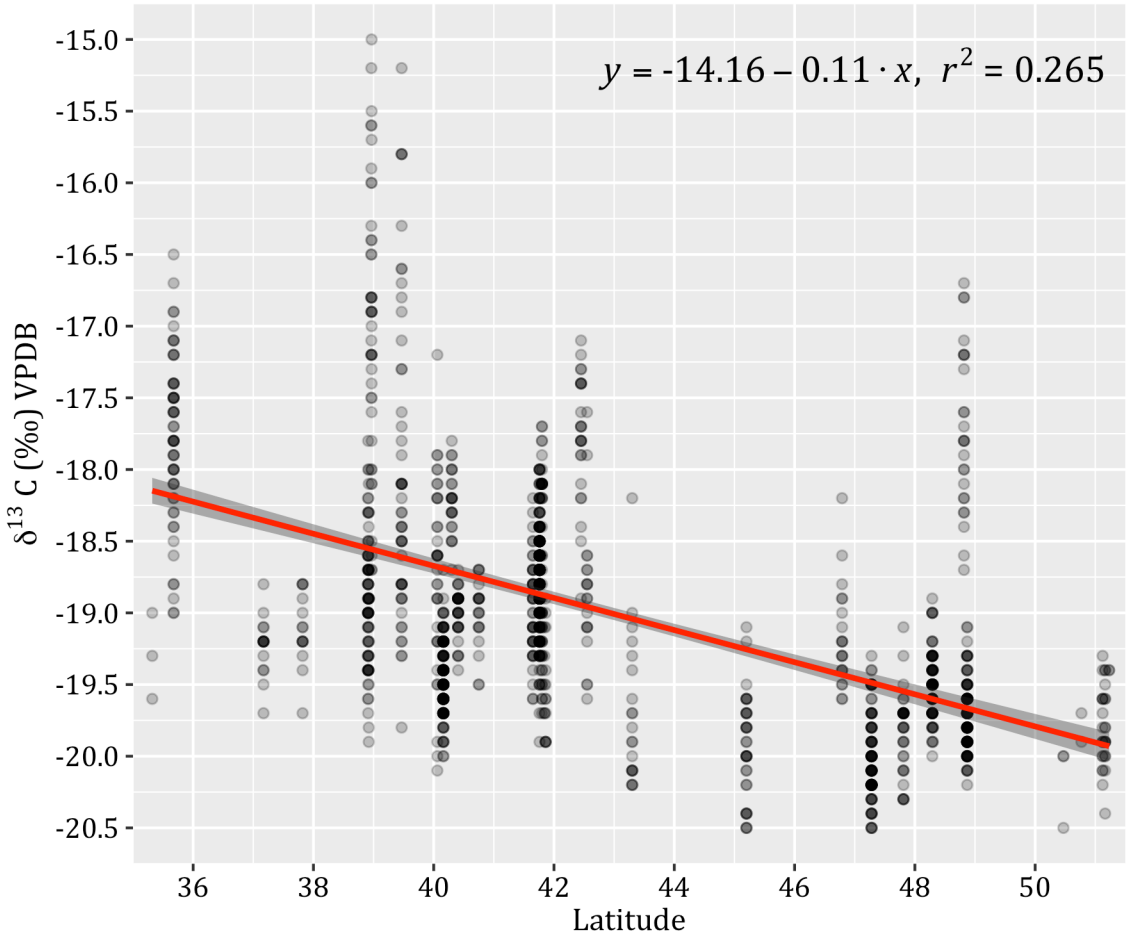


Figure 6.38: The $\delta^{13}C$ values found at each latitude, with linear regression line in red and 95% confidence variable in grey. The points are at 3/4 opacity, so darker points indicate more samples.

6.4.2.2.1 Coastal vs Inland

While the effect on diet of coastal versus inland location might at first seem obvious, with coastal populations consuming more marine resources, a closer look at the data revealed that there was a considerable overlap between coastal locations (defined here as locations within ten kilometers of the coast) and locations further inland (see Figure 6.39).

Regressing both measures, $\delta^{13}C$ and $\delta^{15}N$, individually on the binary indicator variable for coastal and inland locations, there was a significant difference

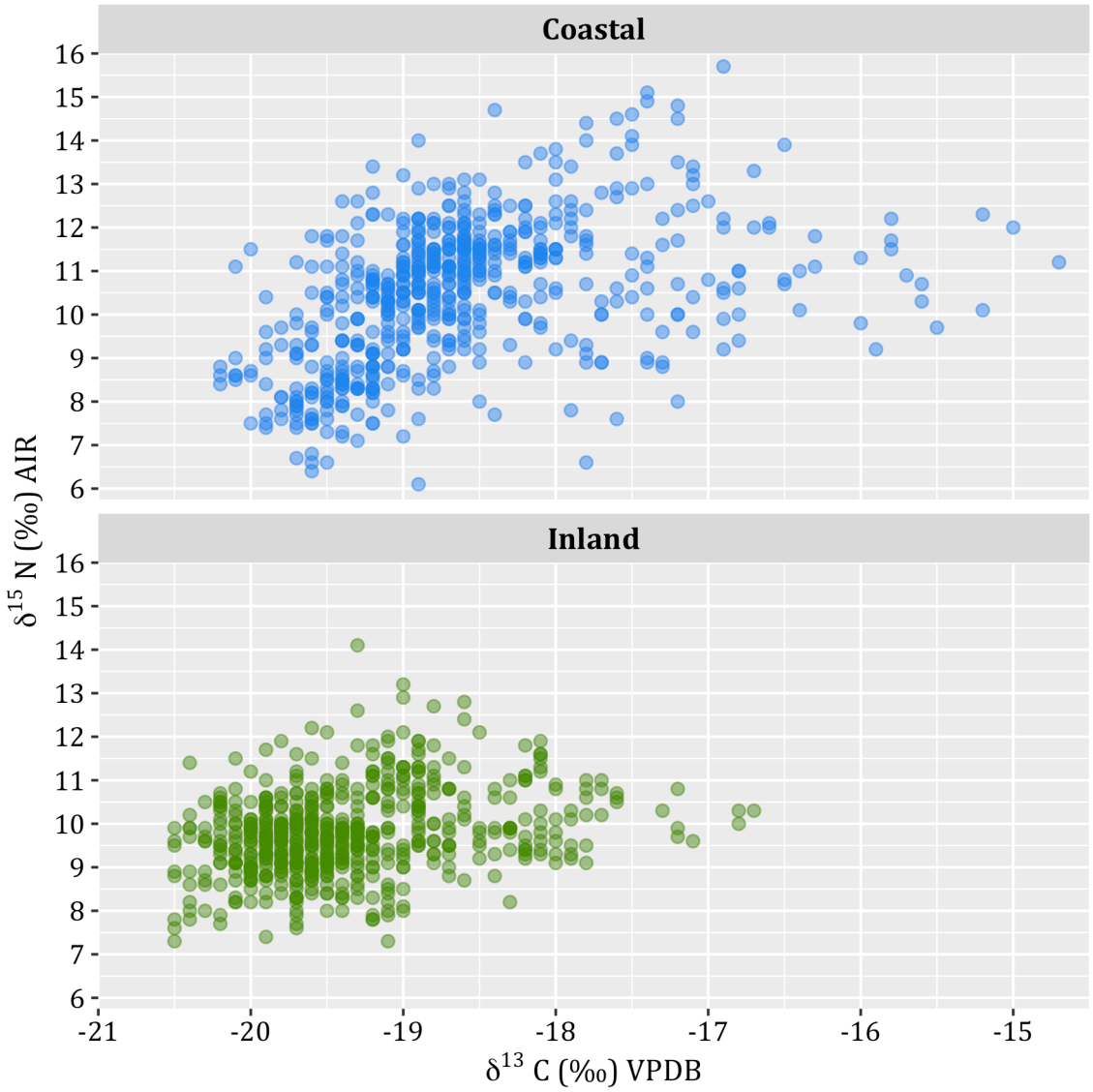


Figure 6.39: The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast. Within 10 kilometers of the coast (Coastal) versus farther inland (Inland).

between the two types of locations both in terms of $\delta^{13}C$ ($p<0.00$) and $\delta^{15}N$ ($p<0.00$) values (see Table 6.28).

Table 6.28: The results of regressing $\delta^{13}C$ and $\delta^{15}N$ values, individually on the binary indicator variable for coastal and inland locations.

Isotope	p-value	R^2	coefficient
$\delta^{13}C$	<0.00	0.174	-0.736
$\delta^{15}N$	<0.00	0.061	-0.691

The average individual from an inland population would be expected to be around 0.74‰ lower in $\delta^{13}C$ and around 0.69‰ lower in $\delta^{15}N$ compared to the typical coastal individual. Elevated $\delta^{15}N$ at coastal locations was expected, for

reasons that could reflect a more dominant marine diet, and/or the cooler closed forests at inland locations might also lower $\delta^{15}N$ values in those populations. Conversely, the salinity at coastal environments could help to explain higher $\delta^{15}N$ values (Heaton 1987, Britton *et al.* 2008). The canopy effect could also help to explain lower $\delta^{13}C$ values at inland locations with plants growing in shade being less enriched in ^{13}C (Bonafini *et al*. 2013). Nevertheless, the most likely explanation is the consumption of marine resources, though the increase in isotope values was smaller than expected for populations more heavily reliant on marine resources (DeNiro & Epstein 1981, Minagawa & Wada 1984, Sealy *et al.* 1987, Fry 1988, Richards & Hedges 1999, Lee-Thorp 2008, Schulting *et al.* 2008). The R^2 values indicate that the variation between coastal and inland locations only accounted for 17.4% of the variation in carbon isotope values and only 6.1% of the variation in nitrogen isotope values. If individuals from Leptiminus are excluded from this analysis, the difference between the trend holds true, but only accounts for 14.6% of the carbon isotope variation and 3.1% of the nitrogen isotope variation. Also important to note is the difference between the marine sources, with the Mediterranean ecosystem being different from that of the North Sea.

Since the time period could have a substantial effect on the level of trade, travel, and even dietary preferences (see Chapter 2 for a description of chronological variations in diet in Spain), corresponding effects on the distribution of $\delta^{13}C$ and $\delta^{15}N$ values would also be expected. Similarly, geographic location, in this case coastal versus inland location, could also expect to be differentially affected by time period, since coastal areas were relatively more accessible to travelers, as means of travel developed. As can be seen in Figure 6.40 and Table 6.29, the relation between coastal and inland isotope values changed rather substantially throughout history.

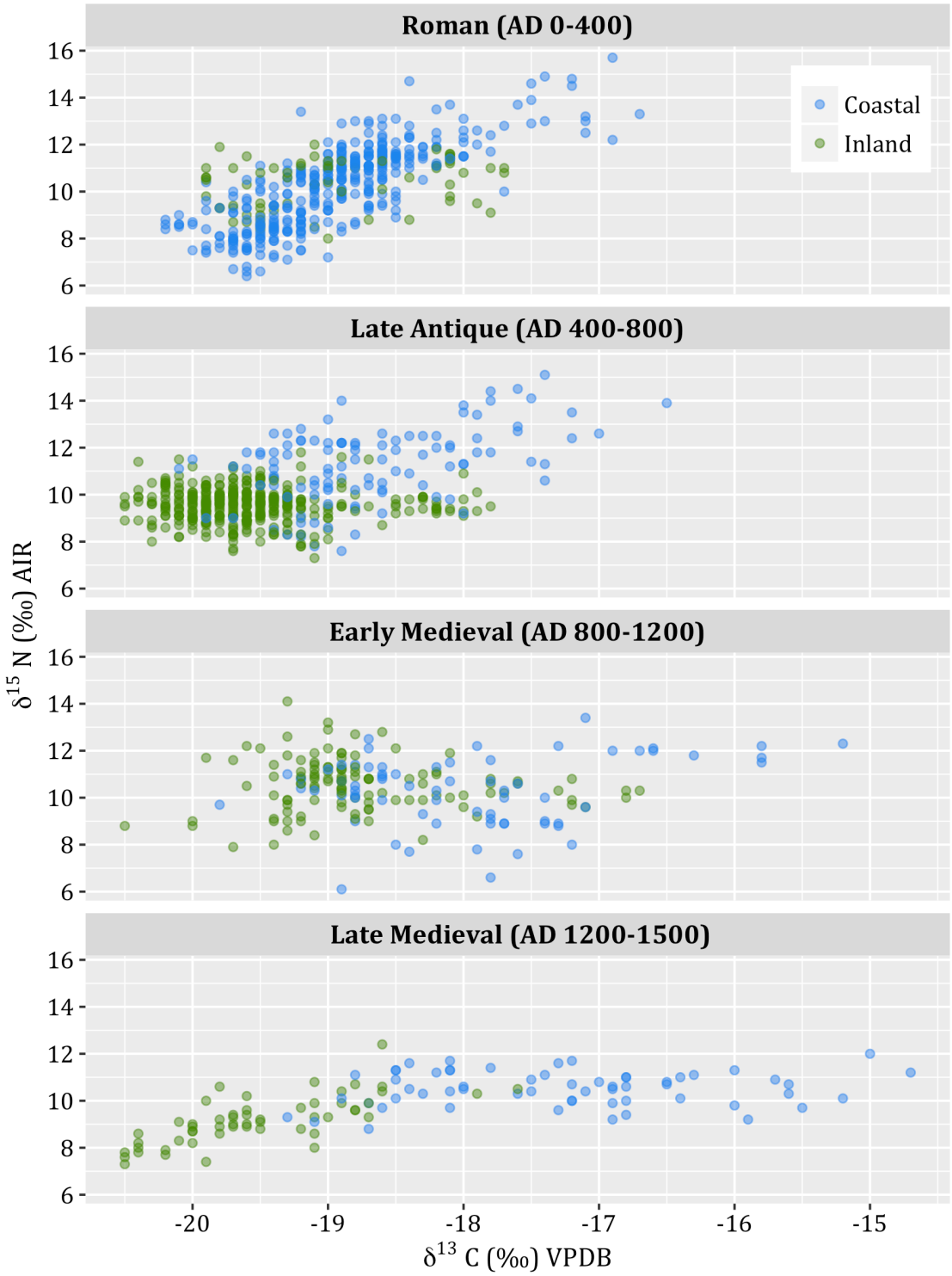


Figure 6.40: The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast, faceted by Time Period. Within 10 kilometers of the coast (Coastal) versus farther inland (Inland).

Table 6.29: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each time period in the Meta-Data set. Also included is the p-value for the Mann-Whitney U Test with values indicating a significant difference between coastal and inland groups marked with an *.

Period	Location	n	R^2	$\delta^{13}C$ (‰) VPDB		$\delta^{15}N$ (‰) AIR	
				mean ± σ	p-value	mean ± σ	M-W p
Roman	Coastal	365	0.61	-18.93 ± 0.61	0.388	10.27 ± 1.71	0.995
	Inland	64	0.07	-18.98 ± 0.68		10.28 ± 1.05	
Late Antique	Coastal	109	0.21	-18.68 ± 0.71	0.000*	11.27 ± 1.58	0.000*
	Inland	361	0.00	-19.58 ± 0.53		9.55 ± 0.72	
Early Medieval	Coastal	69	0.04	-17.99 ± 0.94	0.000*	10.30 ± 1.48	0.522
	Inland	114	0.00	-18.76 ± 0.70		10.55 ± 1.12	
Late Medieval	Coastal	59	0.01	-17.29 ± 1.11	0.000*	10.52 ± 0.74	0.000*
	Inland	54	0.53	-19.51 ± 0.66		9.17 ± 1.01	

During the Roman Period (AD 0-400), the coastal and inland groups did not significantly differ by $\delta^{13}C$ or $\delta^{15}N$ values (Mann-Whitney U p=0.388 and p=0.995, respectively). However, the relationship between $\delta^{13}C$ or $\delta^{15}N$ values did, with the correlation between carbon and nitrogen isotope values being much stronger for the coastal population (R^2=0.61) than for the inland population (R^2=0.07). This changed during Late Antiquity (AD 400-800) with both carbon and nitrogen isotope values differing significantly (p=<0.00 for both $\delta^{13}C$ and $\delta^{15}N$), while the relationship between carbon and nitrogen isotope values was not strong for the coastal population and nonexistent for the inland populations (R^2=0.21 and R^2=0.00 respectively). In the subsequent Early Medieval period (AD 800-1200), only $\delta^{15}N$ values differed significantly (p=0.00), with $\delta^{13}C$ values remaining similar (p=0.522). However, there was little to no relation between $\delta^{13}C$ and $\delta^{15}N$ values for either the coastal (R^2=0.04) or inland populations (R^2=0.00). The Late Medieval period (AD 1200-1500) coastal and inland populations again had significantly different carbon and nitrogen isotope values with p=0.00 for both $\delta^{13}C$ and $\delta^{15}N$. It was the inland

population that had the stronger correlation between carbon and nitrogen isotope values (R^2=0.53), while there was practically none for the coastal population (R^2=0.01). As can be seen in Figure 6.40, when $\delta^{13}C$ and $\delta^{15}N$ values significantly differed, it was always the coastal individuals who had the higher values. This supports the notion of coastal populations having greater access to marine resources, and therefore, consuming them on a more regular basis than individuals farther inland. For time periods where variation between individual isotope values cannot be explained by distance to the coast, other explanations must be considered, such as the introduction of C_4 grains during the Early Medieval period. Other considerations will be discussed further in Chapter 7.

6.4.2.3 Climate Variation

While there was a clear variation between locations based on their geographic location, it is not enough to simply note this variation. To truly understand the difference in diet, it is important to understand *why* this variation occurs. Aside from the variables previously discussed, one of the most likely candidates for variation, in carbon and nitrogen isotope values, is small-scale climate variation (Hamilton *et al.* 2013). For the purposes of determining environmental contributions to isotopic variability, local climate provides the proper control needed to begin characterizing the contribution of diet. While there are many climactic variables that can affect $\delta^{13}C$ and $\delta^{15}N$, temperature and precipitation are two factors which provide reasonable initial proxies for local climate variation with readily available data. The climate data were taken from the nearest weather station to the location, as found in the G.N.I.P. Network[2].

[2] IAEA/WMO (2016). Global Network of Isotopes in Precipitation. The GNIP Database. Accessible at: http://www.iaea.org/water

6.4.2.3.1 Temperature and Precipitation

Linear regressions were run for both $\delta^{13}C$ and $\delta^{15}N$ values by the following temperature related variables: mean monthly temperature for each month, mean seasonal temperature by each season, and mean annual temperature. The results can be seen in Table 6.30. As was the case with the location variables, the p-values may be misleading. They indicate that there is a statistically significant relationship between carbon and nitrogen isotope values and temperature; however the R^2 values and the slope coefficients for these relationships indicate that the relationships accounted for between 27% to 37% of the variance in $\delta^{13}C$ and between 11% to 17% of the variance for $\delta^{15}N$.

Table 6.30: The results of linear regressions of local climate variables (temperature - monthly, seasonal and annual mean (± σ) and precipitation- monthly, seasonal and annual total (± σ) on both $\delta^{13}C$ and $\delta^{15}N$ values for each location.

	$\delta^{13}C$			$\delta^{15}N$		
	Coefficient	**R^2**	**p-value**	**Coefficient**	**R^2**	**p-value**
Temperature						
January	0.095	0.325	0.000	0.100	0.144	0.000
February	0.098	0.319	0.000	0.091	0.112	0.000
March	0.116	0.313	0.000	0.117	0.128	0.000
April	0.164	0.364	0.000	0.185	0.184	0.000
May	0.150	0.271	0.000	0.163	0.128	0.000
June	0.128	0.269	0.000	0.138	0.124	0.000
July	0.137	0.342	0.000	0.153	0.169	0.000
August	0.130	0.333	0.000	0.136	0.147	0.000
September	0.132	0.369	0.000	0.136	0.156	0.000
October	0.094	0.292	0.000	0.106	0.150	0.000
November	0.085	0.287	0.000	0.092	0.133	0.000
December	0.100	0.330	0.000	0.107	0.152	0.000
Winter	0.099	0.331	0.000	0.102	0.140	0.000
Spring	0.145	0.335	0.000	0.157	0.157	0.000
Summer	0.135	0.327	0.000	0.148	0.156	0.000
Fall	0.100	0.332	0.000	0.111	0.165	0.000
Annual	0.125	0.351	0.000	0.126	0.142	0.000
January σ	-0.552	0.128	0.000	-0.235	0.009	0.001
February σ	-0.231	0.040	0.000	0.134	0.005	0.013
March σ	0.041	0.001	0.215	-0.111	0.004	0.033
April σ	-0.677	0.123	0.000	-0.231	0.006	0.011
May σ	-0.311	0.062	0.000	-0.474	0.058	0.000
June σ	-0.300	0.021	0.000	0.761	0.055	0.000
July σ	-0.504	0.104	0.000	-0.218	0.008	0.003
August σ	-0.629	0.055	0.000	-0.217	0.003	0.085

	$\delta^{13}C$			$\delta^{15}N$		
	Coefficient	**R^2**	**p-value**	**Coefficient**	**R^2**	**p-value**
September σ	-0.415	0.055	0.000	-0.354	0.016	0.000
October σ	-0.498	0.036	0.000	-0.005	0.000	0.965
November σ	0.297	0.007	0.005	1.160	0.042	0.000
December σ	0.143	0.009	0.002	0.749	0.094	0.000
Annual σ	0.002	0.000	0.933	0.170	0.025	0.000
Precipitation						
January	-0.014	0.087	0.000	-0.009	0.014	0.000
February	-0.020	0.143	0.000	-0.027	0.099	0.000
March	-0.018	0.139	0.000	-0.017	0.048	0.000
April	-0.011	0.061	0.000	-0.007	0.009	0.000
May	0.000	0.002	0.160	0.000	0.003	0.050
June	-0.009	0.224	0.000	-0.006	0.048	0.000
July	-0.010	0.293	0.000	-0.007	0.053	0.000
August	-0.015	0.310	0.000	-0.013	0.088	0.000
September	0.001	0.001	0.220	-0.003	0.004	0.040
October	0.006	0.028	0.000	-0.004	0.004	0.030
November	-0.007	0.053	0.000	-0.005	0.014	0.000
December	-0.011	0.085	0.000	-0.021	0.136	0.000
Winter	-0.006	0.119	0.000	-0.008	0.089	0.000
Spring	0.000	0.003	0.050	0.000	0.004	0.020
Summer	-0.004	0.286	0.000	-0.003	0.063	0.000
Fall	0.000	0.001	0.280	-0.002	0.010	0.000
Annual	-0.001	0.183	0.000	-0.001	0.072	0.000
Annual σ	0.003	0.046	0.000	0.005	0.055	0.000

The standard deviation for monthly and annual mean temperatures for each location were also compared to the $\delta^{13}C$ and $\delta^{15}N$ values and the results of these linear regressions can be seen in Table 6.30. What is clear from these results is that the amount of temperature variation in each month has even less of an effect on carbon and nitrogen isotope values than the temperature itself.

Similar to temperature, linear regressions were run against both $\delta^{13}C$ and $\delta^{15}N$-based on the precipitation related variables such as mean monthly and seasonal precipitation, as well as long term annual mean precipitation. The results of this analysis can be seen in Table 6.30. From these results, it can is evident that while precipitation did affect carbon and nitrogen isotope values in humans, the effect was very slight for carbon and negligible for nitrogen. The strongest correlation between isotope values and a precipitation variable was the relationship between $\delta^{13}C$ and the total precipitation during August (in mm), with an R^2 of 0.31.

The above presented results rely on individual regressions of both carbon and nitrogen for each temperature variable. This, however, likely results in biased estimates of the effects given the likelihood that they co-vary. The next step was to expand the univariate regression models estimated in the above section to a multivariate analysis which allows analysis of the effect of a single variable while controlling (holding constant) the effect of others. This will be further discussed in Chapter 7. What is important to understand from the bivariate analyses above is that temperature clearly had an effect on carbon and nitrogen isotope results in humans (more so carbon than nitrogen), but that it was clearly only one of many factors that played a part.

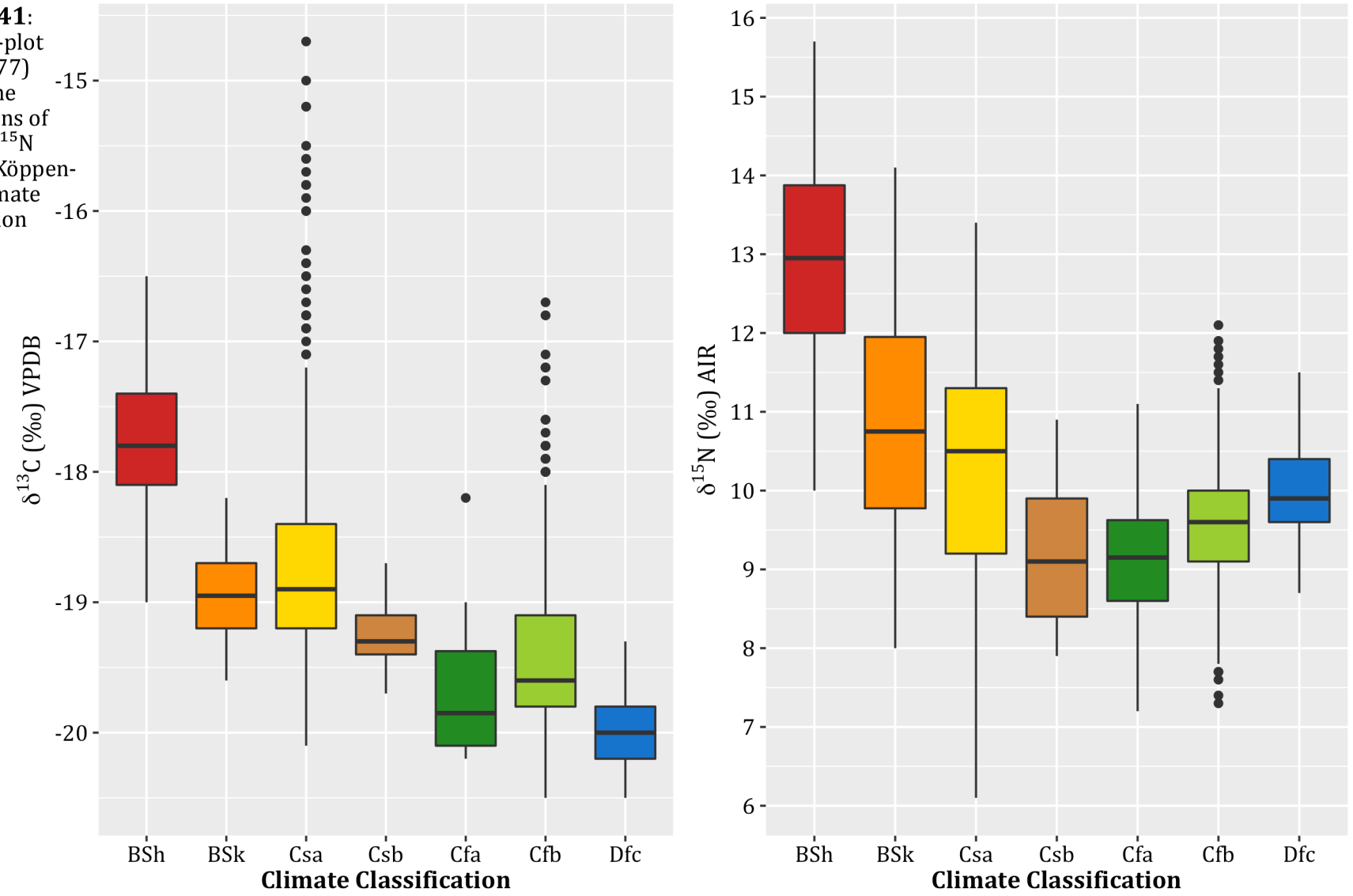


Figure 6.41: Tukey box-plot (Tukey 1977) showing the distributions of $\delta^{13}C$ and $\delta^{15}N$ values by Köppen-Geiger Climate Classification

6.4.2.3.2 Climate Classification

The sites from the Meta-Data set were from seven different climate classifications (see Figure 5.7, Materials and Methods), two arid (the hot and cold steppes), four temperate (hot and warm dry summers as well as hot and warm summers without a dry season) and one cold (without a dry season and a warm summer). The mean carbon and nitrogen isotope values for these climate classifications can be seen in Table 6.31 and Figure 6.41.

Table 6.31: The number, mean, and standard deviation values for $\delta^{13}C$ and $\delta^{15}N$ for each of the Köppen-Geiger Climate Classification.

Climate Classification	Description			n	$\delta^{13}C \pm \sigma$	$\delta^{15}N \pm \sigma$
	1st	2nd	3rd			
BSh	Arid	Steppe	Hot (annual)	49	-17.78 ± 0.52	12.97 ± 1.15
BSk	Arid	Steppe	Cold (annual)	181	-18.18 ± 1.13	10.72 ± 1.19
Csa	Temperate	Dry Summer	Hot Summer	527	-18.89 ± 0.65	10.12 ± 1.50
Csb	Temperate	Dry Summer	Warm Summer	9	-19.24 ± 0.27	9.12 ± 1.02
Cfa	Temperate	w/o dry season	Hot Summer	91	-16.84 ± 1.12	8.49 ± 0.89
Cfb	Temperate	w/o dry season	Warm Summer	320	-19.53 ± 0.64	9.41 ± 0.74
Dfb	Cold	w/o dry season	Cold Summer	80	-19.99 ± 0.30	9.95 ± 0.58

There was clear relation between the climate classifications and carbon and nitrogen isotope values. Dunn's test for stochastic dominance (Dunn 1964) showed that all but seven of the comparisons between climate classifications and $\delta^{13}C$ and $\delta^{15}N$ had statistically significant differences ($p<0.05$), both in terms of $\delta^{13}C$ and $\delta^{15}N$ (see Table 6.32). When the data were divided by time period, the analysis becomes more difficult as not every time period had every climate classification. Overall the trend of decreasing $\delta^{13}C$ values accompanying decreasing temperatures remained the same, although it becomes less prominent in the Early Medieval and Late Medieval Periods. The introduction of C_4 grains during this time is the most likely explanation.

Table 6.32 The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classifications of the $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically different groups are indicated with an * .

	BSh	BSk	Csa	Csb	Cfa	Cfb
Dfc	0.000*	0.000*	0.000*	0.001*	0.053	0.000*
	0.000*	0.002*	0.023*	0.027*	0.007*	0.002*
Cfb	0.000*	0.000*	0.000*	0.211	0.026*	
	0.000*	0.000*	0.000*	0.167	0.125	
Cfa	0.000*	0.000*	0.000*	0.037*		
	0.000*	0.000*	0.000*	0.438		
Csb	0.000*	0.106	0.000*			
	0.000*	0.000*	0.003*			
Csa	0.000*	0.201				
	0.000*	0.024*				
BSk	0.000*					
	0.000*					

The climate classifications clearly outline how temperature, precipitation and vegetation, when considered together, strongly correlated to carbon and nitrogen isotope values in humans. The most striking conclusion that can be reached from this analysis was that individuals from arid environments (BSh and BSk) particularly those from the hot arid environment (BSh), have higher $\delta^{13}C$ and $\delta^{15}N$ values than individuals from the cold and temperate environments. The variations between climate classifications should be taken into account when comparing the carbon and nitrogen isotope values of populations, particularly in terms of dietary comparisons.

Also of note is the similar trends in the human and faunal data as they relate to climate classification. This indicates that the carbon and nitrogen isotope values from the humans in the meta data set, are subject to similar controlling variables as the fauna, and are reacting in a similar manner. This will be explored further in Chapter 7

Chapter 7: Osteological, Isotopic and Faunal Model Discussion

7.1 Sanisera

The stable carbon and nitrogen isotope analysis for Necropolis 6 presented in Chapter 6 are the first for a Late Antique site on the island of Menorca. In terms of Late Antique burial sites, Necropolis 6 is relatively homogenous. The vast majority of tombs were oriented East-West, and were built using the same materials and methods (locally sourced simple stone tombs lined with cement). The tombs also had similar profiles; commingled remains of mixed sexes and ages with little to no grave goods. Osteologically, the sample group for this study has a similar profile to that of the population taken from the Necropolis, as well as that of contemporary populations (Hurst *et al.* 2011). The radiocarbon dates were determined for two of the samples, S-86 and S-106, and these coincide with the dates derived from the tomb styles and the meager artifact assemblage (Hurst *et al.* 2011).

An analysis of the isotopic results for Sanisera revealed additional information, specifically the isotopic difference between dentine and bone samples, whether age at death was a factor, an interpretation of the outliers, and how the individuals from Sanisera compare to other populations.

7.1.1 Dentine

The relationship between age at death and the isotopic data from the dentine samples is not as straightforward as that of bone. The $\delta^{13}C$ and $\delta^{15}N$ of dentine represents childhood diet, and when combined with the age at which an individual died, it becomes possible to speculate on the affect that childhood diet had on

longevity. As expressed previously, Sandberg *et al.* 2014 proposed that low-quality diets, isotopically represented by lower $\delta^{13}C$ and $\delta^{15}N$ values, are related to shorter life spans.

Table 7.1: The mean of $\delta^{13}C$ and $\delta^{5}N$ values (± σ) of the dentine from Necropolis 6 at Sanisera, (excluding outliers), sorted by age at death category (as defined by the methods outlined in Brothwell 1989).

Age at Death	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
<17	4	-18.69 ± 0.43	12.08 ± 0.40
17-25	14	-18.84 ± 0.37	11.91 ± 1.01
25-35	5	-18.87 ± 0.40	12.18 ± 1.15
33-45	6	-18.57 ± 0.26	11.80 ± 0.39

The data from Sanisera was consolidated into four age groups based on dental attrition (<17, 17-25, 25-35, and 33-45). While there was no significant difference in $\delta^{13}C$ and $\delta^{15}N$ of the dentine values based on age, all but one (S-62) of the older individuals (ages 25-35 and 33-45) have $\delta^{15}N$ values above 11‰. In fact, it is the oldest group of individuals (aged 33-45) that have the lowest standard deviations for both $\delta^{13}C$ and $\delta^{15}N$ as can be seen in Table 7.1 and the lowest means for both $\delta^{13}C$ and $\delta^{15}N$.

7.1.2 Dentine to Bone

Age, and the influence it has on societal roles, is a popular topic of archaeological study (Roveland 1997, Perry 2005, Lewis 2007). Breastfeeding and weaning practices of a culture are also age related factors that are favored by archeologists (Schurr 1998, Sandberg *et al.* 2014). Specifically, when breastfeeding is not the topic of the study, data from infants and children are commonly excluded to avoid any interference that breastfeeding might have on the overall interpretation of a populations' diet. The inclusion of children in isotopic studies emphasizes a prominent concern for osteological studies, the "osteological paradox" (Wood *et al.,*

1992). The remains of individuals, especially those of less than a mature age, are not representative of that society at large because they did not survive to maturity and, as such, are not a true representation of that society as a whole (Waldron 1994). While this is of greatest concern for children and infants, the same can be said for any remains from other than mature adults.

In the case of adults, carbon and nitrogen isotope values taken from collagen are representative of the years prior to death. In the case of children, the turnover rate of their bones is more rapid and therefore more likely to reflect a diet associated with an ailing individual than are samples from their more mature counterparts. The osteological paradox is commonly overlooked in isotopic studies, as there is no easy way around the issue.

Primary dentine, once developed, does not turn over throughout an individual's life as bone does. This means that dentine developed during childhood is a direct reflection of childhood diet. One means of escaping the paradox is to use the dentine from adult individuals as a representation of what was probably a relatively healthy childhood diet. Even more promising is that the dentine for each tooth is laid down at very specific ages, making it possible to more clearly pinpoint isotopic values for specific ages (Moorrees *et al*. 1963, Ubelaker 1979). This also makes it possible to study a single individual at several ages. Another benefit of sampling from dentine instead of juvenile bones, is that dentine is more resistant to the taphonomic process, and will likely be better preserved. Finally, using the dentine from an adult, as a representation of childhood diet, as compared to the bone from a juvenile, means that the comparison of childhood diet to adult diet is an actual assessment of the dietary differences between the two time periods within a single individual's life, rather than a comparison between those individuals who

survived childhood, and those who did not. Thus escaping the archeological paradox. The following section shows the application of this theory to the sites of Sanisera.

Sixteen individuals from Sanisera had acceptable samples from both bone and dentine. Three of the sixteen individuals were identified as outliers, all three due to their bone samples (S-40, S-106, and S-107), and two of the three were outliers due to their dentine samples as well (S-40 and S-107). The average carbon and nitrogen isotope values for each material, excluding the three outliers, can be seen in Table 7.2.

Table 7.2: The mean $\delta^{13}C$ and $\delta^{5}N$ values (± σ) of the bone and dentine sampled from individuals from Necropolis 6 at Sanisera, excluding outliers.

Material	n	$\delta^{13}C$ ± σ (‰)	$\delta^{15}N$ ± σ (‰)
Bone	13	-18.26 ± 0.52	11.68 ± 0.71
Dentine	13	-18.64 ± 0.34	12.05 ± 0.86

When grouped by material, this subset of the population has a similar difference between dentine and bone samples as when all of the samples were compared in Chapter 6 (see Figure 6.9 and Table 6.5). In the selected data there is a lack of a significant difference in terms of $\delta^{15}N$. In terms of $\delta^{13}C$, on the other hand, the two materials do significantly differ (see "Dentine/Bone Comparison" in Section 6.2.1.1 Human).

The only real difference between adult and juvenile diets described in the literature for the Late Antique Period is generally that juveniles consumed less meat than their adult counterparts (Bradley 1998, Garnsey 1999). Isotopically, this would be reflected by the dentine of an individual having lower $\delta^{13}C$ and $\delta^{15}N$ values than the bone of an individual, as an increased consumption of meat leads to an increase in both $\delta^{13}C$ and $\delta^{15}N$, but most prominently $\delta^{15}N$. Instead, what is seen with this

group of individuals is that there is, on average, an increase in $\delta^{13}C$ values (0.38‰), but a decrease in $\delta^{15}N$ values (-0.37‰). These differences are negligible and support the notion that there is no substantial dietary difference between adults and juveniles unlike other studies (Tuross & Fogel 1994, Richards *et al.*. 2002, Fuller e*t al.* 2006). However, at the individual level, the comparisons between childhood $\delta^{13}C$ and $\delta^{15}N$ values and adult values are more dramatic.

Figure 7.1 shows the $\Delta^{13}C$, or the $\delta^{13}C$ value of the dentine sample subtracted from the $\delta^{13}C$ value of the bone sample, for each individual. As can be seen, the majority of the individuals have a relatively uniform shift in $\delta^{13}C$ values from dentine to bone (positive, but small), while two (S-64 and S-107) stand out as being outliers in the negative direction.

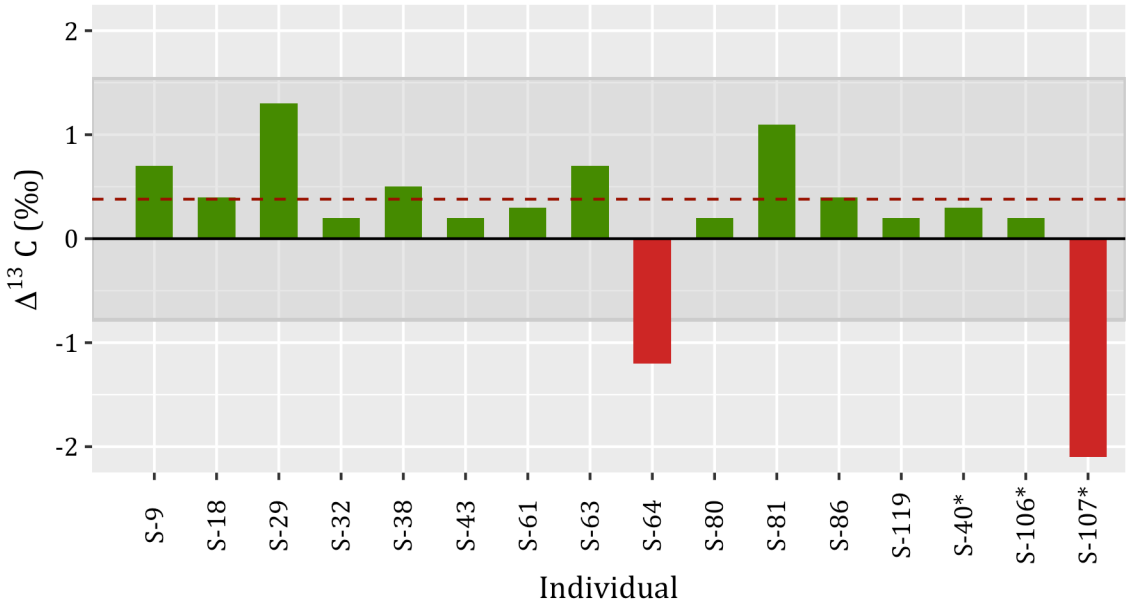


Figure 7.1: The $\Delta^{13}C$ (dentine $\delta^{13}C$ subtracted from the bone $\delta^{13}C$) of each individual from Sanisera Necropolis 6. The dashed red line and shaded area indicates the average $\Delta^{13}C \pm 2\sigma$ (calculated excluding outliers). Bars colored red indicate individuals whose values fall outside this range. Individuals previously determined to be outliers are indicated with an *.

Figure 7.2 depicts the $\Delta^{15}N$ of each individual (calculated using the same method as $\Delta^{13}C$) . The variation in $\Delta^{15}N$ values is greater than with the $\Delta^{13}C$ values. Of the sixteen individuals, eleven have negative $\Delta^{15}N$, four have positive $\Delta^{15}N$, and

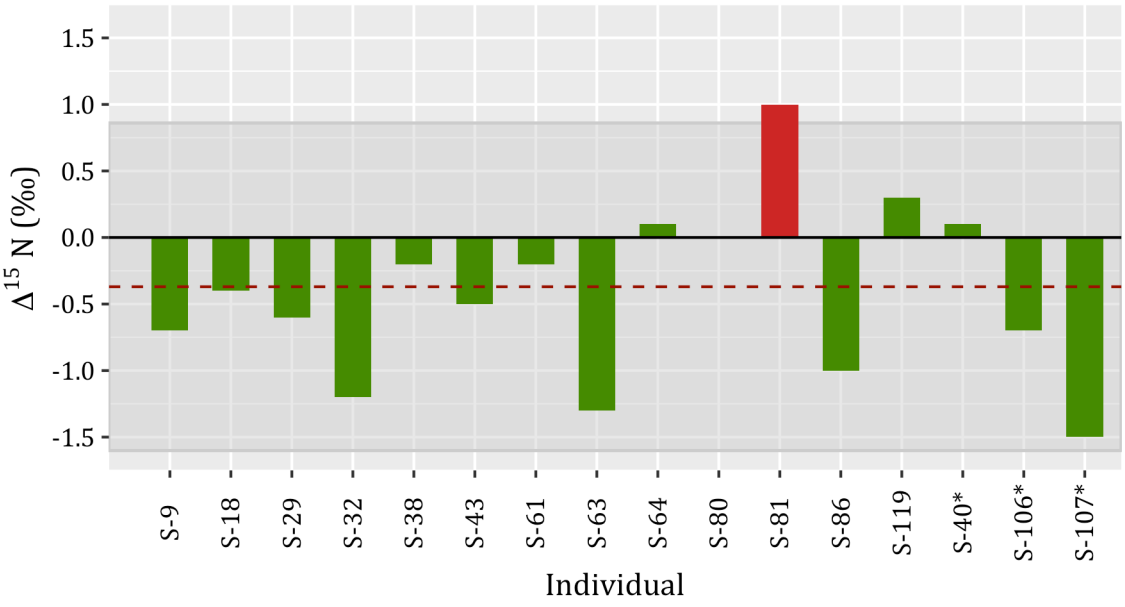


Figure 7.2: The $\Delta^{15}N$ (dentine $\delta^{15}N$ subtracted from the bone $\delta^{15}N$) of each individual from Sanisera Necropolis 6. The dashed red line and shaded area indicates the average $\Delta^{15}N \pm 2\sigma$ (calculated excluding outliers). Red bars indicate individuals whose value falls outside this range. Individuals previously determined to be outliers are indicated with an *.

one has a no shift in $\delta^{15}N$ values (S-80). Also of note is that two of the three outliers (based on the $\delta^{15}N$ values from their bones) have $\Delta^{13}C$ and $\Delta^{15}N$ values that fall within the normal range for the general population.

Overall, these two graphs show that a simple increases in meat or marine food consumption cannot explain the majority of the variation found within these individuals. If this were the case, $\delta^{13}C$ and $\delta^{15}N$ would increase with age, leading to positive $\Delta^{13}C$ and $\Delta^{15}N$ values; with $\Delta^{15}N$ increasing more, because $\delta^{15}N$ is more a reflection of trophic level than $\delta^{13}C$ (van Klinken e*t al.* 2002).

When looking at such nuanced data, it is important to keep the relative size of the shift in isotopic values in perspective. Based on standards analyzed along with the samples, the analytical error of the mass spectrometer was found to be around ±0.2‰ for $\delta^{13}C$ and ±0.1‰ $\delta^{15}N$. This means that any $\Delta^{13}C$ value less than or equal to 0.4‰ and any $\Delta^{15}N$ value less than or equal to 0.2‰ could be due solely to precision error. It is also important to consider what amount of variation between

the two materials being tested is due to factors outside of diet, such as the difference between the two skeletal materials, or variations in climate. It is for this reason that only differences outside two standard deviations of the mean variance will be discussed below.

Individuals S-64 and S-107 both have a substantial difference between their childhood (dentine) and adult (bone) $\delta^{13}C$ values. Individual S-64 has a decrease in $\delta^{13}C$ as they age, accompanied by a negligible shift in $\delta^{15}N$. A change in the amount of C_4 plant consumption is the easiest explanation for change in $\delta^{13}C$ without any change to $\delta^{15}N$, however, the $\delta^{13}C$ values themselves are solidly reflective of C_3 plant consumption. The variation found in individual S-64 is more likely a result of a combination of factors which affected both $\delta^{13}C$ and $\delta^{15}N$ values, but the effects on their $\delta^{15}N$ was canceled out. For example, increased legume consumption (which lowers $\delta^{15}N$ values) would counter the increase in $\delta^{15}N$ values that would accompany a switch from C_3 terrestrial animal food sources, to lower trophic level marine food sources. Individual S-107 has an even more drastic shift between their childhood and adult carbon and nitrogen isotope values. With a decrease in both $\delta^{13}C$ and $\delta^{15}N$ values as they aged, the most likely explanation is a decline in the consumption of animal protein, probably marine. The difference between the bone and dentine $\delta^{15}N$ values of individual S-81 may not be the largest, but as it is the only increase in $\delta^{15}N$ with age, it stands out. As opposed to individual S-107, it is likely due a larger marine contribution to the diet.

7.1.3 Outliers

7.1.3.1 Dentine

The $\delta^{13}C$ and $\delta^{15}N$ results for dentine sampled from the general population as well as the outliers (defined as being greater than two standard deviations from the mean) can be seen in Table 6.5.

There are four outliers. Two are from individuals whose bone samples were also outliers (S-107 and S-40) and two are samples that did not have bone associated with them to be tested. None of the outliers stand out relative to both carbon and nitrogen isotopes. Two of the samples have lower $\delta^{13}C$ (S-21B and S-52) values than the mean and one, S-107, has a higher value. The remaining sample (S-40) has relatively lower $\delta^{15}N$. All of the outlying samples were taken from second molars, and should, therefore, not be affected by nursing or weaning.

Similar to the bone sample values, the dentine results for $\delta^{13}C$ and $\delta^{15}N$ indicate a terrestrial C_3-based diet supplemented with marine resources. The variation in $\delta^{13}C$ values between the outliers and the general sample population may be due to varying consumption of C_4 plants, with the values more enriched in $\delta^{13}C$ (such as S-107) as a result of the consumption of more C_4 plants than was average, and for those sample values depleted of $\delta^{13}C$ (S-21B and S-52) consuming less. However, the $\delta^{13}C$ values (all lower than -17.5‰) are such that consumption of C_4 plants was likely limited and the variation being the result of differences in the degree.

Also of note is that the outliers S-21B, S-52 and S-107 were only defined as such based on their $\delta^{13}C$ values. Their $\delta^{15}N$ values are in the lower third of the overall population indicating that the lower $\delta^{13}C$ values of outliers S-21B and S-52

are likely due to less animal protein in their diet, though this is the most simplistic explanation. Along this vein the higher $\delta^{13}C$ values of outlier S-107, relative to the general population, could be indicative of C_4 plant consumption. If this were to be attributed to poverty there would be an expected decrease in the consumption of animal protein and therefore the lower $\delta^{15}N$ values. C_4 grains such as millet, were often used as backup for when more temperamental crops failed (Murphy 2016). The failure of a crop would likely lead to more austere measures, and possibly a decline in meat consumption.

The dentine from individual S-40 is consistent with the bone outliers in that it has lower $\delta^{15}N$ values, but similar $\delta^{13}C$ as compared to the general population. As discussed above, there are likely many explanations. Suffice it to say that the lower $\delta^{15}N$ value is likely due to the absence of animal protein, be it terrestrial or marine. This, however, does not take into account the possibility that this individual was an immigrant to Sanisera. Fortunately, individual S-40 had acceptable results for both bone and dentine. This makes it possible to interpret the childhood diet (dentine) as well as the diet in the years leading up to their death (bone). This will be further explored in Section 7.1.3.3.

7.1.3.2 Bone

Three bone samples were identified as outliers, being two or more standard deviations from the mean. These individuals and their carbon and nitrogen isotope values as well as the population mean plus or minus one standard deviation can be

seen in Table 7.3.

Table 7.3: The $\delta^{13}C$ and $\delta^{15}N$ values of the bone outliers. With the mean $\delta^{13}C$ and $\delta^{15}N$ values (± σ) of the bone and dentine, excluding outliers.

Individual	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	General $\delta^{13}C \pm \sigma$ (‰)	General $\delta^{15}N \pm \sigma$ (‰)
S-40	-18.6	9.2	-18.26 ± 0.52	11.68 ± 0.71
S-106	-18.0	9.2		
S-107	-19.9	9.0		

Among the bone samples, the most prominent variation was the approximate 2‰ difference between the $\delta^{15}N$ of the populations' average and the outliers, and the 1.25‰ difference between the highest $\delta^{15}N$ value of an outlier and the lowest $\delta^{15}N$ value from the general population. Such a pronounced shift is a good indication of different diets, with the lower $\delta^{15}N$ values suggesting a diet with consistently less animal protein.

The lower $\delta^{13}C$ value of sample S-107 (-19.9‰), as compared to the general population average (-18.26‰), is an indication of a different type of dietary variation than the other two outliers (whose $\delta^{13}C$ values fell within the normal range for the general population). Coupled with the $\delta^{15}N$ values, there are three main ways in which the diet of these outliers could be interpreted, assuming that these variations in carbon and nitrogen isotope values are solely based in dietary variation. First, the approximate decrease of 1.6‰ in $\delta^{13}C$ and 2.7‰ in $\delta^{15}N$ of the bone sample of individual S-107 is close to fitting within the general definition of a trophic level shift, 0-2‰ for $\delta^{13}C$ (Bocherens and Drucker 2003) and 3-5‰ for $\delta^{15}N$ (Bocherens *et al.* 1994a, Vogel *et al.* 1990, DeNiro and Epstein 1981, Hare *et al.* 1991). This suggests that S-107's diet more closely resembles that of the fauna the

general population is consuming in its diet. A similar interpretation could be applied to the remaining bone outliers since the variation in $\delta^{13}C$ values between S-40 and S-106 outliers and the population average does fall within the given 0-2‰ range. However, with a gap of over 1‰ between the carbon values of S-107 and the other two outliers there are more variables to consider.

The second interpretation takes into account the higher levels of ^{13}C found in S-40 and S-106 as compared to S-107. The more enriched carbon values of these two samples are an indication that they had a diet which included more C_4 plants than that of S-107. C_4 plants such as millet and sorghum, were considered food for the poor (Semple *et al.* 1935) and were more widely consumed in times of famine (Adamson 2013). Poverty could explain why S-40 and S-106 have lower $\delta^{15}N$ values, as impoverished individuals would likely have had less access to meat.

A third interpretation for the diet of the outliers concerns the consumption of marine resources versus terrestrial resources. The decreased $\delta^{13}C$ and $\delta^{15}N$ values of S-107, as stated above, is very close to a whole trophic level difference between S-107 and the general population. It is known that grains made up the majority of the Late Antique diet (Rickman 1980, Garnsey and Whitaker 1983, White 1988, Killgrove 2010), and since most terrestrial fauna that was available during the period would have also been fed similar grains, a population who consumes grains and terrestrial fauna should not be a whole trophic level above an individual who only consumed grains (i.e. S-107). In fact, individuals who simply consumed less animal protein would likely present with $\delta^{13}C$ and $\delta^{15}N$ values similar to S-40 and S-106. $\delta^{15}N$ reflects the protein portion of the diet, while $\delta^{13}C$, though heavily influenced by dietary protein, can be a reflection of multiple macronutrients (Jim *et al.* 2004, Jim *et al.* 2006). This leaves S-107. In this interpretation, the lower $\delta^{13}C$ and

$\delta^{15}N$ values compared to the general population is likely due to a lack of marine foodstuffs in their diet. While the terrestrial food web in this instance is relatively straightforward and small, the marine food web is the opposite. The fish being consumed in Late Antiquity generally had higher trophic levels than the terrestrial fauna (see Figure 6.22). Therefore the consumption of marine animals in comparison to terrestrial animals would likely lead to a larger increase in both $\delta^{13}C$ and $\delta^{15}N$. This harkens back to the general interpretation that the $\delta^{13}C$ and $\delta^{15}N$ values of all three outliers are due to a decreased consumption in animal protein in comparison to the general population. The only difference being which ecosystem that animal protein originated from, terrestrial in the cases S-40 and S-106 and marine in the case of S-107.

All of these explanations are based on the assumption that the variations in $\delta^{13}C$ and $\delta^{15}N$ values in this population are singularly due to diet. This is probably not the case with every individual sampled, as carbon and nitrogen isotope ratios found in humans are subject to a multitude of variables, be they social, locational, chronological, or climatological. While it is not possible to investigate every possible variable, a good starting point is to analyze the dentine of the population with the aim of gathering information about both the later and earlier periods of life.

7.1.3.3 Dentine to Bone

The importance of comparing the outlying dentine samples to that of the outlying bone samples is to determine if individuals that had significantly different isotope values during childhood, maintained those differences into adulthood. Were the factor or factors leading to their different values, simply related to their childhood, or were they permanent? If their outlying $\delta^{13}C$ and $\delta^{15}N$ values were due to something along the lines of not originally being from Sanisera, it would be

expected that their isotope values would become more like the general population the longer they lived there.

Of the four dentine outliers, two remained outliers in terms of their bone values (S-40 and S-107). The other two, unfortunately, did not have associated bone to test. Individual S-40 had a shift so slight ($\Delta^{13}C$ of 0.3‰ and $\Delta^{15}N$ of 0.1‰) that it suggests there was no change in diet. This is not surprising since, the age at death for both individuals S-40 and S-107 was assessed to be less than seventeen and the dentine, taken from their second molars, was formed between the ages of eight and fifteen (Moorrees *et al*. 1963; Ubelaker 1979).

Individual S-107 had the most drastic difference between childhood and adulthood with a $\Delta^{13}C$ of -2.1‰ and a $\Delta^{15}N$ of -1.5‰. While the isotope values found for the dentine of S-107 was only outside the population mean in terms of $\delta^{13}C$ the values taken from their bone was the most dramatically different in terms of both $\delta^{13}C$ and $\delta^{15}N$. As this individual aged their isotope values shifted even farther away from the general population. Which raises interesting questions not only as to why their isotope values differed, but also why they became more divergent from the population with age. Individuals S-40 and S-106, both of whom have markedly low $\delta^{15}N$ values, also raise similar questions.

All three of these individuals were buried in Zone 1 of the necropolis. Even with them included, there is no statistically significant difference between the $\delta^{13}C$ and $\delta^{15}N$ values of the two zones either in terms of bone (Mann-Whittney U for $\delta^{13}C$, $p=0.562$ and $\delta^{15}N$, $p=0.395$) or in terms of dentine (Mann-Whittney U for $\delta^{13}C$, $p=0.726$ and $\delta^{15}N$, $p=0.912$). This suggests that whatever factor led to their outlying isotope values, it did not play a role in their burial location within Necropolis 6.

The three bone outliers originated from two different tombs (S-40 is from Tomb 26 and S-106 and S-107 are from Tomb 5). While there were no other samples from Tomb 5, there was another sample from Tomb 26, S-43. The bone and dentine sampled from individual S-43 was on the other end of the spectrum in terms of $\delta^{15}N$ values having some of the higher $\delta^{15}N$ values of the entire population (13.07‰ for dentine and 12.53‰ for bone).

The lack of any real archaeologically based distinction between these individuals might not be as much of a hinderance to analysis if there were more individuals to compare them to. The inclusion of more samples from the site of Sanisera, not only from Necropolis 6, but also from the other necropoles, would help to more clearly define the relation between the Zones and might help to uncover how individuals were divided into the different tombs.

7.2 Mérida

7.2.1 Dentine

Analyzing the dentine of individuals based on their age at death makes it possible to explore how diet, during their developmental years, affects longevity. The mean dentine value for each individual from Mérida and their age at death can be found in Table 7.4 and Figure 7.3.

Table 7.4: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on their age at death (as defined by the methods outlined in Brothwell 1989).

Age at Death	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
17-25	13	-18.82 ± 0.36	10.26 ± 1.06
25-35	5	-18.78 ± 0.38	10.21 ± 1.24
33-45	2	-18.06 ± 0.16	11.40 ± 0.76

The mean dentine values hint at the possibility that those with higher carbon and nitrogen isotope ratios may have lived longer. Unfortunately there are only two

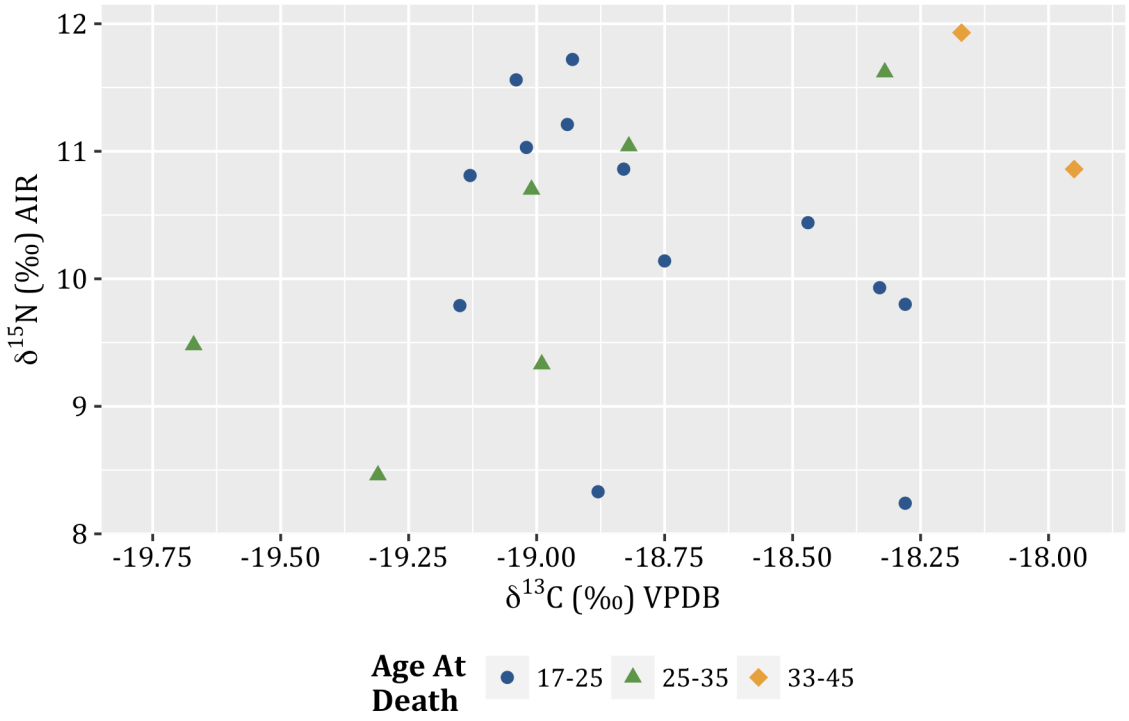


Figure 7.3: The mean $\delta^{13}C$ and $\delta^{15}N$ analysis on the human dentine samples from Mérida plotted by age at death.

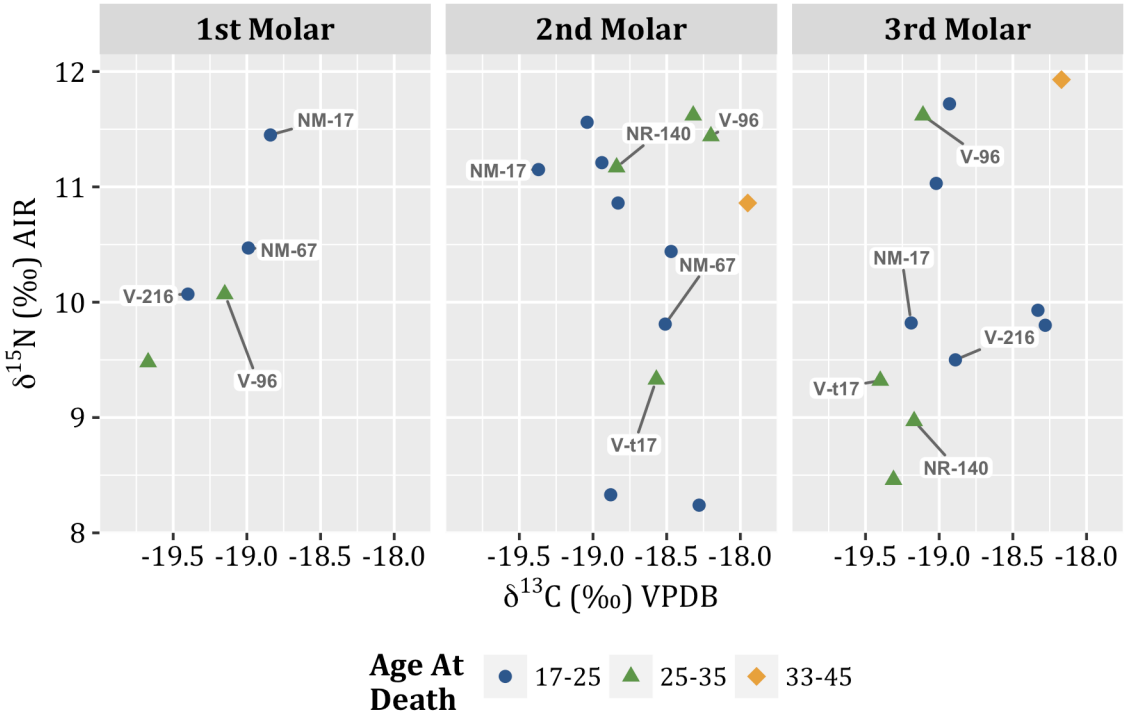


Figure 7.4: The $\delta^{13}C$ and $\delta^{15}N$ analysis on the human dentine samples from Mérida plotted by age at death and divided by the molar the sample was taken from. Samples from the same individual are labeled.

individuals in the oldest age group, making statistical tests suspect. There is also very little variation to be found between the younger age groups ($\delta^{13}C$: p=0.53 and $\delta^{15}N$: p=0.74).

What makes this analysis even more difficult is that the dentine samples were taken from different teeth depending on the individual. For example, some individuals only had a second molar, some had all three. When age at death is plotted by molar the pattern becomes less defined (see Figure 7.4 and Table 7.5).

Table 7.5: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on their molar and age at death (as defined by the methods outlined in Brothwell 1989).

Molar	Age at Death	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
1st	17-25	3	-19.08 ± 0.29	10.66 ± 0.71
	25-35	2	-19.41 ± 0.37	9.78 ± 0.42
2nd	17-25	8	-18.79 ± 0.35	10.20 ± 1.30
	25-35	4	-18.48 ± 0.28	10.89 ± 1.06
	33-45	1	-17.95	10.86
3rd	17-25	6	-18.77 ± 0.38	10.30 ± 0.87
	25-35	4	-19.25 ± 0.13	9.59 ± 1.40
	33-45	1	-18.17	11.93

When using dentine data to get a true sense of the role that age played in diet, the individuals need to be sorted according to which tooth was analyzed as well as age at death. This allows a more nuanced understanding of how diet affected longevity. The results of this analysis can be seen in Table 7.6 and Figure 7.5. From

Table 7.6: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) of the dentine from individuals from Mérida based on the age at formation of the tooth tested and age at death. In this table "longevity" is defined by the average difference between the age of formation of the tooth tested and age at death of the bone sample.

Molar	Age at Formation in years	Age at Death in years	Longevity in years	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
2nd	8-15	17-25	9.5	5	-18.87 ± 0.28	9.68 ± 1.21
		25-35	18.5	2	-18.48 ± 0.08	11.96 ± 0.13
		33-45	27.5	1	-18.18	11.26
3rd	13-21	17-25	4.5	2	-18.52 ± 0.04	10.25 ± 0.09
		33-45	22.5	1	-18.39	12.36

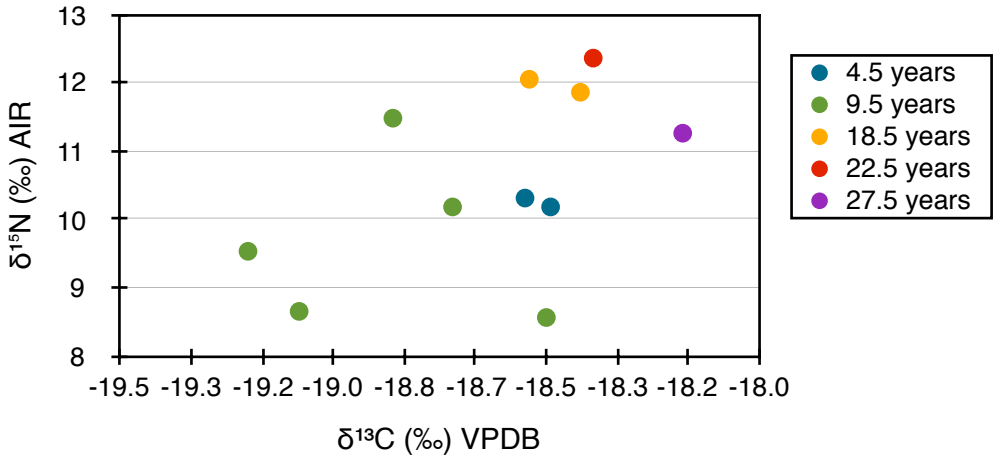


Figure 7.5: The $\delta^{13}C$ and $\delta^{15}N$ of human dentine samples from Mérida plotted by longevity (defined by the average difference between the age of formation of the tooth tested and age at death of the bone sample).

these data, it is clear that the individuals with higher $\delta^{15}N$ lived longer. In fact, the individual who lived the longest (YAC-31) had the highest $\delta^{15}N$ value (12.36‰) of the whole population.

7.2.2 Multiple Materials

Of the 36 individuals from Mérida analyzed, fifteen had acceptable samples taken from more than one material (between two and five samples per individual). These materials included bone (from the mandible or maxilla), first (M1), second (M2) and third molars (M3). In the case of the molars, some were bisected along the root creating the Cervical section, or that closest to the enamel, and the Apical section, or the tip (see diagram in Chapter 5). The $\delta^{13}C$ and $\delta^{15}N$ results for each individual can be seen in Figure 7.6. The second molar (M2) from individual V-nn has a $\delta^{13}C$ value more than two standard deviations from the population mean, which would have skewed the scale of the other samples, obscuring their smaller shifts in $\delta^{13}C$ values. The progression of isotope values for V-nn can be seen in Figure 7.7.

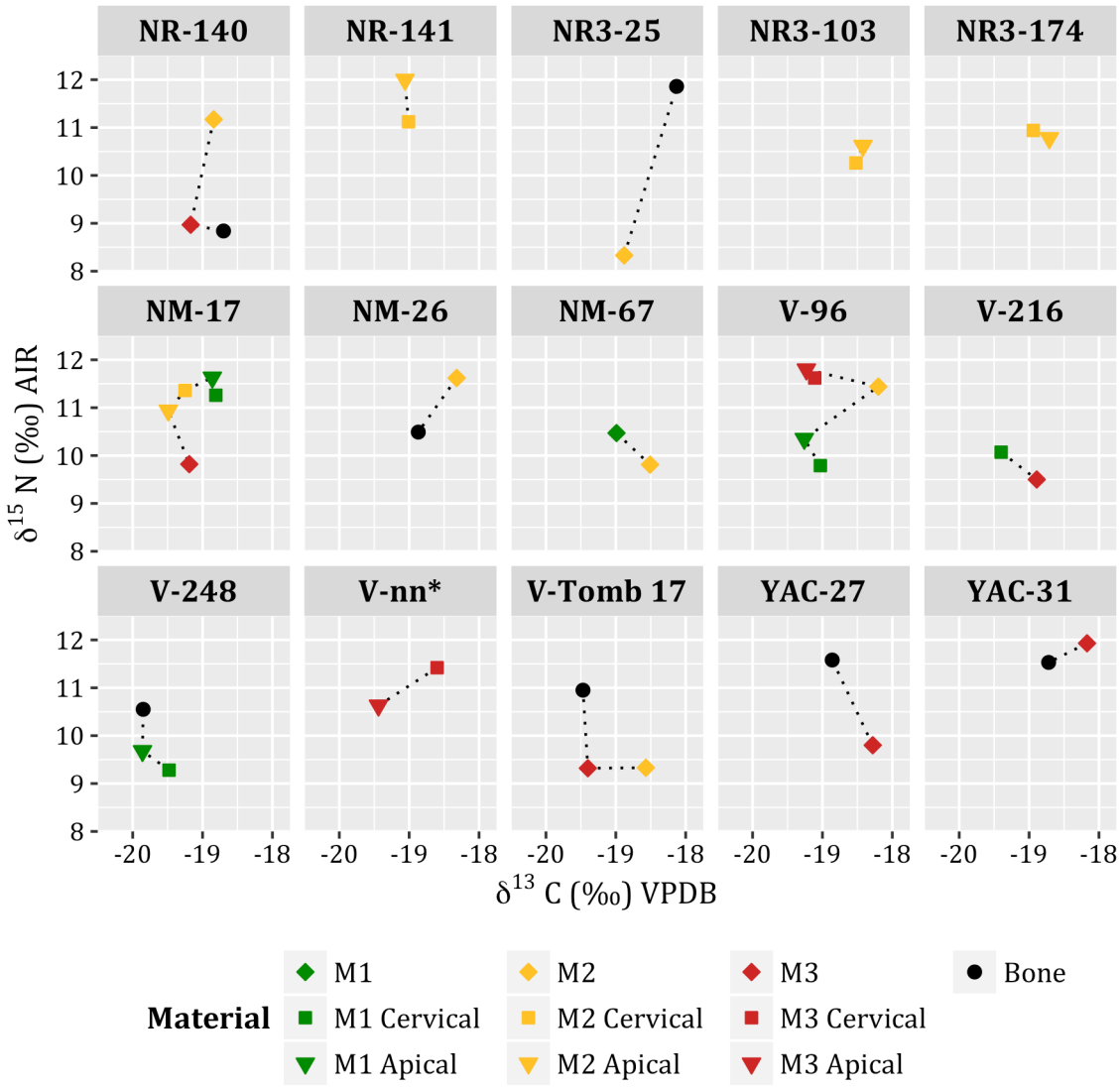


Figure 7.6: The $\delta^{13}C$ and $\delta^{5}N$ isotopic values of the bone and dentine samples for each individual. The color and shape denotes the material sampled. Dentine sampled from whole molars are labeled simply as that molar, while bisected samples are labeled by the part of the root they were taken from. The * indicates a missing sample.

As can be seen, the variation between individuals does not follow a uniform pattern. However, distinct differences are visible as individuals age, which are greater than can be attributed to precision error (±0.1‰ for $\delta^{13}C$ and ±0.3‰ for $\delta^{15}N$) of the mass spectrometer. While this particular study cannot draw any definitive conclusions, it demonstrates the potential inherent in sampling more than one type of material per individual. There is distinct variability within the

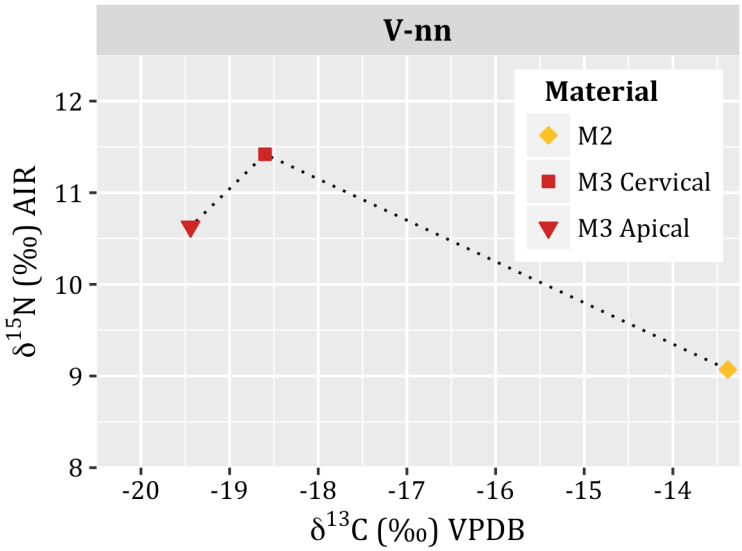


Figure 7.7: The $\delta^{13}C$ and $\delta^{5}N$ isotopic values of the different materials from individual nn from the Velada necropolis in Mérida. Dentine sampled from whole molars are labeled simply as that molar, while bisected samples are labeled by the part of the root they were taken from.

individuals of Mérida, but the sample size makes it so that it cannot be definitely incorporated or discarded without further study.

7.2.3 Human Outliers

7.2.3.1 Low $\delta^{13}C$ Values

There are four individuals from Mérida that are considered outliers due to their elevated $\delta^{13}C$ values as compared to the rest of the population (value is greater than plus or minus two standard deviations from the mean). The isotopic data for these individuals can be seen in Table 7.7.

Table 7.7: The $\delta^{13}C$, $\delta^{15}N$, and material sampled of the isotopic outliers from Mérida (based on being greater than two standard deviations from the mean dentine values).

Individual	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
NR3-144	M2 Cervical	-14.2	9.9
NR3-140	M3 Cervical	-14.0	9.2
YAC-16	M2	-16.4	9.3
V-nn	M2	-13.4	9.1

The two individuals from Nova Romana III date between the 3rd and 5th centuries AD and were two of the eleven Roman burials found at this site. They are both male, between the ages of 17 and 25, and their skeletons were described as "robust" (Alba Calzado 2005; 336). Both individuals were buried in a supine position with their faces oriented to the West. They were interred in pit tombs oriented East-West (NR3-140) and East (NR3-144) with grave goods (though the grave goods from NR3-144 had been looted) that were indicative of humble origins (Alba Calzado 2005; 336). NR3-144 was located inside of a funerary structure near a well, while NR3-140 was located just outside the same structure and was found to be overlapping another burial (Tomb 33). The only other identifiable difference between these individuals and the rest of the population from Nova Romana III is their height. NR3-140 is the tallest of all the individuals sampled from Nova Romana III at 173.31 ± 3.27cm, while NR3-144 was found to be the shortest at 149.51 ± 3.27cm tall[1] . With their heights being at opposite ends of the range of heights for the population, there is little to be concluded at this time.

Neither of the two outliers from Nova Romana III or the outlier from Y.A.C have other associated samples. While there is plenty of information regarding the samples from Nova Romana III, the data from the Y.A.C. site has yet to be published, so all that is known about individual YAC-16 is that they were a female (based on the prominence of their mental eminence), aged between 25 and 35 years old (based on dental attrition), and dated to the Visigothic Period (5th-8th century AD).

The outlier from Velada (V-nn) is not from a known tomb, has a radiocarbon date of 1352 ± 23 BP, which is between 641-690 AD (p = 94.1%). This fits with the

[1] Based on the length of his femur and the formula for white males found in Owsley *et al.* 1995

Visigothic dates of the Necropolis of Velada. There were three acceptable samples associated with V-nn: the dentine from the second molar (formed between 8-15 years), the dentine from the cervical section of the third molar (formed between 13-17 years old), and also from apical section of that same molar (formed between 17-21 years). The samples taken from the third molar have $\delta^{13}C$ and $\delta^{15}N$ values consistent with the general population of Mérida, and with other third molars. As individual V-nn aged, their $\delta^{15}N$ value increased then slightly decreased, while their $\delta^{13}C$ value decreased drastically at first, then decreased slightly more. What is interesting is how distinct the $\delta^{13}C$ and $\delta^{15}N$ values of the two molars are from each other, especially considering that some portion of the development of the M2 and M3 roots would have happened simultaneously.

7.2.3.2 Interpretation of Isotope Values

The high $\delta^{13}C$ values of the outlying individuals, combined with their relatively low $\delta^{15}N$ values, suggest consumption of C_4 foods. The C_4 grains present during this time period were millet and sorghum, are grains that are commonly associated with poverty or famine. Given that famine was very common when these individuals lived (5th-8th centuries AD), and crop failure even more so (McCormick e*t al.* 2012). Consumption of C_4 foods would be a reasonable assumption as it was a more robust and easy to store crop (Murphy 2016). The lower $\delta^{15}N$ values are consistent with this interpretation, since animal protein would also be less available during times of famine or poverty. A "poor" diet, resulting from famine or social status, and leading to sorghum or millet consumption, also coincides with the "humble" burials of the two individuals from Nova Romana. The higher $\delta^{15}N$ value of NR3-144 suggests that this individual did consume a typical amount of animal protein as compared to the rest of the individuals from Mérida (being less than 0.5 a

standard deviation away from the mean). This could mean either that this individual had access to animal products, but not the more desirable grains, or that their starvation was sufficiently sever to lead to elevated $\delta^{15}N$ (Fuller e*t al.* 2005, Haubert e*t al.* 2005, Mekota e*t al*. 2006), though this is less likely as there are no pathologies to support this theory.

Based on their carbon and nitrogen isotope ratios, Individual V-nn went through a period consuming C_4 plants coupled with less animal protein consumption. This could be an indication that they survived a period of famine in which they were forced to turn to the less desirable grains of sorghum or millet, rather than they were a lower class individual forced to subsist on the less desirable grains. Unfortunately, none of the other individuals have related samples, but in the case of NR3-144 and YAC-16, both survived past the age at which the tooth being tested would have finished developing. Leaving the possibility that their diet changed later in life. In the case of individual NR3-140, he would have been very near the age at which his third molar finished developing, between 17 and 25 years old, (Moorrees *et al.* 1963, Ubelaker 1979) suggesting that his consumption of C_4 plants could possibly be an indication of the poor diet that led to his demise.

Another interpretation of the unusually high $\delta^{13}C$ values is that these individuals migrated. One possible origin for these individuals is from places such as the Friuli region in Italy, where C_4 grain consumption was common (Iacumin *et al.* 2014). Individual V-nn, would also fit well into the argument for migration, as their isotope values became more like those of the general population as they aged/lived in Mérida. Definitively proving this hypothesis would require further testing, such as a strontium and oxygen isotope analysis on dental enamel.

7.2.3.3 Low $\delta^{15}N$ Values

As with Sanisera, there are a number of individuals who have low $\delta^{15}N$ values but have $\delta^{13}C$ values consistent with the rest of the population. Unlike Sanisera, the distribution of $\delta^{15}N$ values is such that these individuals are not as noticeably set apart. Three of the four are outliers in terms of their $\delta^{15}N$ values though, while the fourth does group with them. These individuals are listed in Table 7.8. Individuals NR-140 and NR3-153 have $\delta^{15}N$ values that are more than two standard deviations from the mean of their material. Individuals NR3-25 and V-99 have $\delta^{15}N$ values within two standard deviations of the mean dentine value, but their values are borderline, and they are below the $\delta^{15}N$ of the bone sample NR-140; so they should likely be discussed with the first two.

Table 7.8: The $\delta^{13}C$, $\delta^{15}N$, and material sampled of the isotopic outliers from Mérida (based on being greater than two standard deviations from the mean dentine values). *V-99 is just under 2σ (1.84); however, since it is below the bone value (NR-140) and over 0.5‰ less than the next highest $\delta^{15}N$ value, it has been included.

Individual	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
NR-140	Bone	-18.7	8.8
NR3-153	M2	-18.3	8.2
NR3-25	M2	-18.9	8.3
V-99*	M3	-19.3	8.5

Similar to Sanisera, there is no clear indication as to why these individuals have such low $\delta^{15}N$ values, as compared to the rest of the samples. While their carbon and nitrogen isotope values would suggest that they consumed a terrestrially based C_3 diet, similar to the rest of the population, what is clear is that these individuals consumed less animal protein. Whether there is little to no trophic level shift in $\delta^{13}C$ accompanying the consumption of animal protein in this situation (thus

leading to $\delta^{13}C$ values being independent of the amount of animal protein consumed) or if the consumption of small amounts of C_4 grains such as sorghum and millet, increased these individuals $\delta^{13}C$ enough to mimic the values of the rest of the population cannot be determined.

7.2.4 Faunal Outlier

Samples were taken from two *Bos taurus* from the site of Casa Herrera just outside Mérida. Three of the samples were deemed acceptable; from Cow A, a bone sample and a sample from a second molar, and from Cow B, a sample from a second molar. The bone from Cow A and the dentine from Cow B had generally similar results (suggesting a terrestrial C_3-based diet). The dentine sample from Cow A had an unusually high $\delta^{13}C$ value (-15.3‰); coupled with a $\delta^{15}N$ value of 8.7‰, similar to that of the other two samples). It can be assumed that Cow A consumed C_4 grains while it was young but shifted to solely consuming C_3 grains later in life. Since the other dentine sample from this site has a $\delta^{13}C$ similar to that of the bone, it is unlikely that the C_4 in Cow A's juvenile diet was associated with its age, and more likely that cows were not fed the more desirable C_3 grains during times of famine or shortage.

7.3 Contemporary Comparisons

7.3.1 Background

To best understand the results presented above it is necessary to compare the individuals from Sanisera and Mérida to nearby, contemporary sites. The larger the scale of the comparisons, the better chance of gaining an understanding of inter-population dietary variation and intra-population variation.

The nature of the data from Sanisera and Mérida presents an issue in terms of comparisons to contemporary sites. To avoid over representation, only one sample was chosen from each individual. Since most other carbon and nitrogen isotope studies take their samples from bone, the sample selected for each individual from Sanisera and Mérida was the one that was developed closest to time of death. If bone were available, it would be bone; third molars were preferable over second, and apical sections were taken over cervical sections. In addition, any outliers were removed from the sample pool.

For Sanisera the comparison population consists of 33 individuals, 13 with bone samples, and 16 dentine samples (all second molars, with the exception of 1 third molar). It has a mean $\delta^{13}C$ of -18.7 ± 0.7‰ and a mean $\delta^{15}N$ of 11.6 ± 1.0‰.

For Mérida, this led to a population consisting of 22 samples, 8 from bone, 7 from third molars (4 whole roots and 3 apical sections) and 7 from second molars (3 whole roots and 4 apical sections). The population is made up of individuals from all 5 necropoles from the city and covers the Roman (3rd-5th century AD), Late Antique (5th-8th century AD) and Islamic/Early Medieval (8th-10th century AD) time periods. As covered in Chapter 6, there is no significant difference between time periods at Mérida. It has a mean $\delta^{13}C$ of -18.9 ± 0.5‰ and a mean $\delta^{15}N$ of 10.6 ± 1.1‰.

7.3.2 Comparison Site Introduction

This section first introduces the contemporary sites, then begins the actual comparisons to Sanisera and Mérida.

7.3.2.1 Balearic Islands

There are three contemporary sites in the Balearic Islands, Can Reinés (Garcia *et al.* 2004), S'Hort des Llimoners, and Es Soto (both from Fuller *et al.* 2010, Nehlich *et al*. 2012) that have used isotope analysis for palaeodietary reconstruction. Can Reinés, part of the Roman city of Pollentia on Mallorca and it's individuals have been dated to the 7th century AD (Garcia *et al.* 2004). Unfortunately, the data was not presented in an easily comparable form (only the mean for humans). S'Hort des Llimoners and Es Soto are located on the island of Ibiza just outside the city wall of the city Eivissa. The individuals studied from the site of S'Hort des Llimoners date from the 4th-6th centuries AD, while the individuals analyzed from Es Soto date from the 10th-13th centuries AD.

7.3.2.2 Mainland Spain

Comparable studies are relatively limited in mainland Spain, and the majority of studies conducted in the region focus on the Islamic and Medieval time periods rather than the Roman or Late Antique periods. The contemporary individuals included in this comparison from mainland Spain are taken from Mundee's 2010 Thesis and the respective article (Alexander *et al.* 2015). They are from the cities of Albarracín, in east-central Spain; Valencia, on the eastern coast of Spain and Zaragoza in north-eastern Spain. Only individuals dating from the Islamic Period were included in this comparison.

7.3.2.3 Other Sites

As Italy was the center of the Roman Empire and culture, it is understandable why so many contemporary studies use Italian sites for comparisons. Isola Sacra was the Portus of Roman and is one of the largest and most well known populations to have been analyzed using carbon and nitrogen isotope analysis (Prowse 2001,

Prowse *et al.* 2004, 2005; Crowe *et al.* 2010). As one of the major hubs of trade and travel in the Late Antique world, it is important to compare individuals from Isola Sacra to those from Sanisera and Mérida to gain a better view of how these two sites correlate.

Another important location in the Late Antique world is that of North Africa, as many of the goods that were traded across the Empire were sourced there. The island of Menorca is on a trade route between Europe and Africa, and the island has been under the control of Romans and Byzantines (originating from the northern coast of Africa). In addition to the historical evidence, an African-style amphora has been associated with an amphora burial in Zone 1 of Necropolis 6. The abundance of African goods found at Sanisera and in Mérida could indicate the presence of individuals from the continent as well. It is, therefore, imperative to explore the possibility that individuals from Sanisera or Mérida could be from the Northern coast of Africa. The town of Leptiminus is on the Mediterranean coast of Tunisia, dates to the 2nd to 5th century AD (Keenleyside *et al.* 2009) and makes a good starting point for comparing North African populations to those from Spain.

The comparisons that follow will start with faunal samples from these sites, and then go on to explore the relation between the humans. These will be simplistic comparisons done with the aim of laying the groundwork for the analysis of the Meta-data.

7.3.3 Contemporary Comparison Analysis

7.3.3.1 Faunal

Human data and faunal data are shown in Figure 7.8. The precise manner in which human and faunal data should be used in developing theories about a

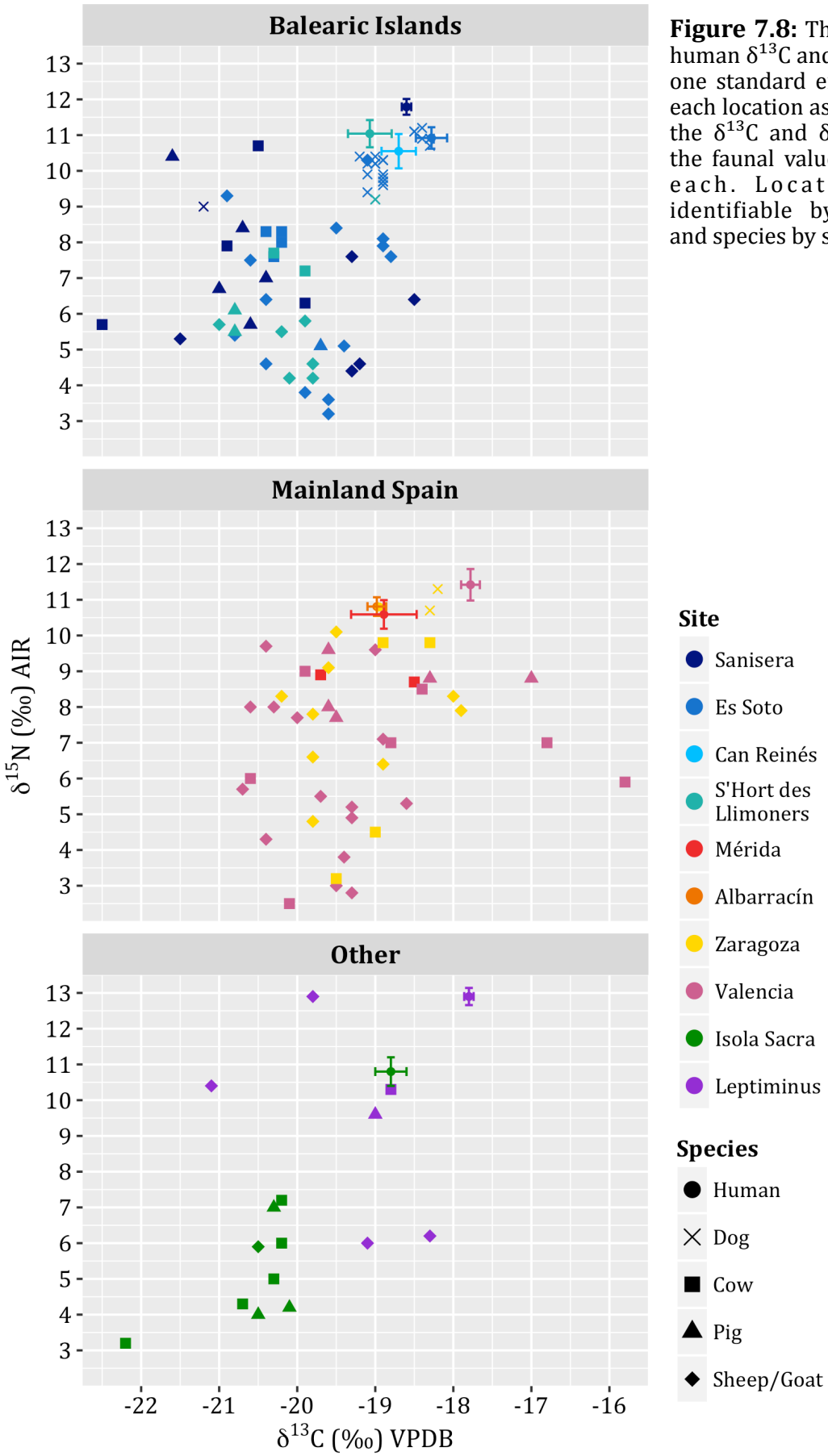


Figure 7.8: The mean human $\delta^{13}C$ and $\delta^{15}N$ ± one standard error for each location as well as the $\delta^{13}C$ and $\delta^{15}N$ for the faunal values from each. Location is identifiable by color and species by shape.

palaeodiet is discussed more in depth later in the chapter. However, based on Figure 7.8 it is clear that interpretations based solely on human data, can be misleading. The high isotope values of the faunal from Leptiminus being a prime example. Based on human data alone, it could be assumed that marine resources were commonly consumed by humans; however, the same cannot be said for cows and sheep of Leptiminus. This leads to the rejection of the marine hypothesis to explain the isotope values in favor of higher than expected values in other terrestrial food sources.

The faunal samples taken from the remaining sites also present another interesting interpretation. Overall, the faunal from the Balearic Islands has slightly lower $\delta^{13}C$ and $\delta^{15}N$ values than the fauna from mainland Spain. There are some stand out samples from both locations. The higher $\delta^{13}C$ values of some of the fauna from mainland Spain is most likely an indication of C_4 grains in their diet. However, the important point to take away is that the difference between the human means and the consumable fauna (the cows, pigs and sheep/goats) is surprisingly small for the mainland Spanish sites, especially when compared to those from the Balearic Islands, Italy and Tunisia.

Isola Sacra has the most terrestrial C_3-based fauna and one of the largest gaps between its human mean and its faunal data. This would indicate that there was more consumption of marine resources than at the other sites. The Leptiminus data is more difficult to interpret as there are only six faunal samples, and they are spaced rather far apart. Two thirds of the samples (4 out of 6) have $\delta^{15}N$ values above 9‰ which is well above the faunal means for any of the other sites (excluding the dogs).

Almost of third of the fauna from Sanisera (4 out of 15) has a $\delta^{13}C$ lower than -21‰. Also of note, these samples are all different species (a cow, a pig, a sheep/ goat and a dog). While they are not more than two standard deviations away from the mean of each species, they do stand out, as there are no other samples from the Balearic Islands or mainland Spain with such low $\delta^{13}C$ values. There is a cow from Isola Sacra in Italy and a sheep/goat from Leptiminus with $\delta^{13}C$ lower than -21‰, but they too seem to be anomalies. Another point of interest, is that the dogs from most sites cluster near the human values, except for the dog from Sanisera, which groups with the other faunal species from the site. This suggests it was not eating similar food to the humans (likely table scraps), like the dogs from the other Spanish sites. The Sanisera pigs' isotope values suggest a more omnivorous diet than those of the pigs from the other two sites. As for the cows, the elevated $\delta^{15}N$ at Es Soto and S'Hort des Llimoners was attributed to the animals being kept in pens and, therefore, consuming fertilized plants, while the other animals were allowed to roam (Fuller *et al.* 2010; 515). This may have been the case for one of the cows at Sanisera as well as for the cows from Mérida and some of the fauna from other sites in mainland Spain. The similar values for the sheep/goat, suggests that the majority of their diet was local, though the high $\delta^{15}N$ values for some of the sheep/goats from Es Soto could be an indication that some of them were penned as well, or possibly fed fertilized crops.

The inclusion of the faunal data as a factor makes the interpretation of the human data more complex, as there was clearly a wide variety of animal husbandry practices in Spain during the Late Antique and Islamic Periods. However, it is clear that the lack of faunal data in paleaodietary reconstruction would lead to less accurate interpretation of the data, since faunal levels are a reference for

understanding the human levels. With this in mind, the next chapter will analyze and discuss the methods by which variables outside the human $\delta^{13}C$ and $\delta^{15}N$ values can lead to variations in interpretation, and how best to account for these effects.

7.3.3.2 Human

When comparing sample populations it is important to compare the composition of those sample populations in order to make sure that any and all comparisons avoid undue influence from sample differences that could affect the over all analysis. One such variable in palaeodietary reconstruction is age. While some studies overlooked the effect of age on isotope values (Garcia e*t al.* 2004) or found little in the way of significant difference (Mundee 2010), this was not the case at S'Hort des Llimoners. The younger individuals from S'Hort des Llimoners (age groups 5-10, 10-15, and 15-20) were found to have had lower average $\delta^{15}N$ values, though not significantly so (Fuller *et al.* 2010; 518). This was interpreted as an indication that they consumed less animal protein than the adults from the site, as part of a more 'frugal' diet (Tuross & Fogel 1994, Bradley 1998, Richards *et al.* 2002, Fuller *et al.* 2006). The Italian site of Isola Sacra, is another site where similar age-related variations were present, with subadults <5 years in age having a more prominently terrestrially based diet (Prowse *et al.* 2005). The study on Leptiminus by Keenleyside *et al.* in 2009, found similar age-related variations in the sample population from Leptiminus with subadults under the age of 6 having significantly higher $\delta^{15}N$ values than the adult females sampled (Keenelyside 2009; 58). The inclusion of infants in the Isola Sacra and Leptiminus studies, means the higher $\delta^{15}N$ values for the youngest age group comes as no surprise since breastfeeding and weaning are known to lead to elevated $\delta^{15}N$ values (Schurr 1998). The samples from

Sanisera and Mérida did not include infants in the hopes of avoiding that exact effect, which is why only adults are included in any further inter-site comparisons.

Individuals outside two standard deviations of the population means were removed from this analysis, so as to void the influence of outliers. The mean $\delta^{13}C$ and $\delta^{15}N$ of the humans from each site are shown in Figure 7.9.

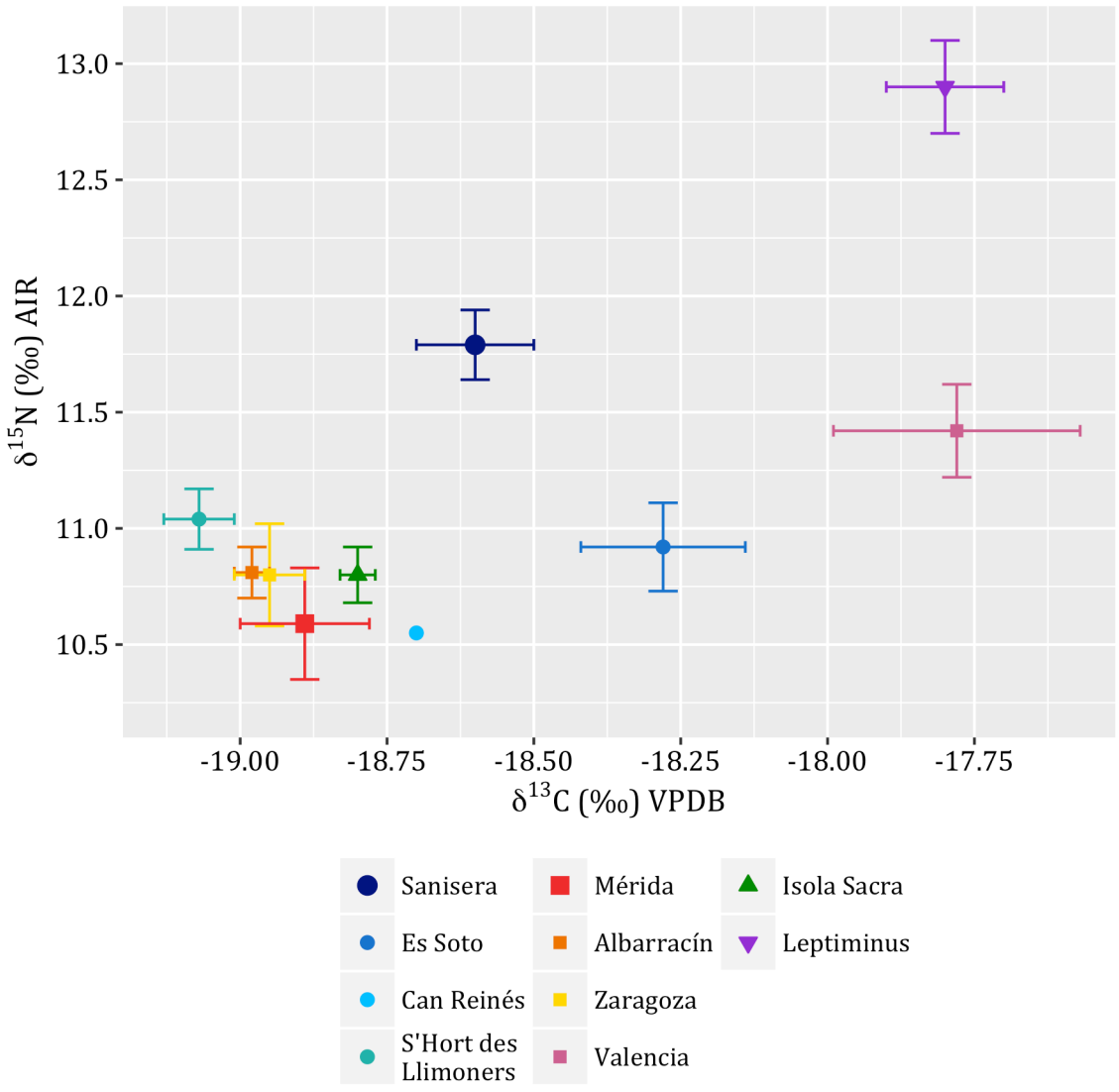


Figure 7.9: The mean $\delta^{13}C$ and $\delta^{15}N$ ± one standard error, of each location. The shape of the points is determined by the general area of each location: the Balearic Islands (circle), Mainland Spain (square), Italy (triangle), North Africa (inverted triangle).

The initial impression this figure gives is that many locations have very similar carbon and nitrogen isotope values. The interpretations of each of the populations in this comparison is that their diets consisted mainly of C_3-terrestrial resources, with varying inclusions of marine resources and C_4 grains. Most of the sites from mainland Spain group very closely together, with the exception of Valencia. Its higher $\delta^{13}C$ is most likely due to the presence of C_4 grains in the diet of its population, which would be reasonable, since it dates to the Islamic Period, when the consumption of C_4 grains such as sorghum and millet became more prevalent (Buxó 1992, Marnival 1992). This could also explain the increased $\delta^{13}C$ of Es Soto, compared to the other Balearic sites, as it too dates to the Islamic Period, though its $\delta^{13}C$ would suggest the inclusion of C_4 was relatively minimal.

The population from Isola Sacra has surprisingly little marine influence in their diet for individuals living on the coast. Along with S'Hort des Llimoners and Can Reinés, it would appear that seafood was not a main staple in these locations, despite its availability. Sanisera, has slightly higher $\delta^{13}C$ and $\delta^{15}N$ values, but its isotope values would still suggest that these individuals did not commonly consume marine foods. Leptiminus, on the other hand, stands out as the population with the most elevation in both $\delta^{13}C$ and $\delta^{15}N$ by far. Based on the human isotope values alone, it would be fair to conclude that the diet on the coast of Tunisa was heavily supplemented with seafood. Any recent migrants from Leptiminus would be immediately identifiable isotopically amongst the population included here.

The remaining three sites, Albarracín, Zaragoza and Mérida, are all inland and all have some of the lowest $\delta^{13}C$ and $\delta^{15}N$ values, implying that there was very little in the way of marine or freshwater influence in their diets. Their relative similarities to the values found for Isola Sacra, Can Reinés and S'Hort des Llimoners goes even

farther to suggest the lack of marine influence in the diets of theses coastal populations.

7.4: Meta-Analysis Discussion

The analysis of carbon and nitrogen isotopes in collagen is commonly used to paint a picture of long-term mean dietary intake. Variation in carbon and nitrogen isotope results between individuals and sites can be attributed to many factors, a point which emphasizes both the potential for advancing our understanding and the necessity for care in interpreting results. Fortunately, human isotopic data need not stand alone. Dietary reconstruction studies gain considerable interpretive power by including cultural, archaeological, and historical records. Information can be gleaned from sources such as contemporary writings mentioning diet, residue analysis on cook wear, artistic depictions, and faunal remains, to name a few. This information is then used to suggest a 'typical diet' for the region and period in question. Used concomitantly with background knowledge of isotopes, and contemporary isotope studies, a general interpretation of what the diet from this period and region will look like, isotopically, is formed.

This sounds challenging enough, but adding to the complexity is the manner in which natural factors such as climate and elevation can affect the isotope ratios. This indicates that inter-site variations may not be due solely to diet, but may be due, in part, to the fact that they are in different locations.

Having previously established that inter-site variations in carbon and nitrogen isotope values are not solely due to differences in diet, the next step is to look for these other factors, which are outside the realm of dietary variation. Geographically similar sites have been found to have isotopically similar data. While there are many ways to define and analyze the physical aspects of a location, which might impact isotopic values, this chapter reviews the geographic and climatological

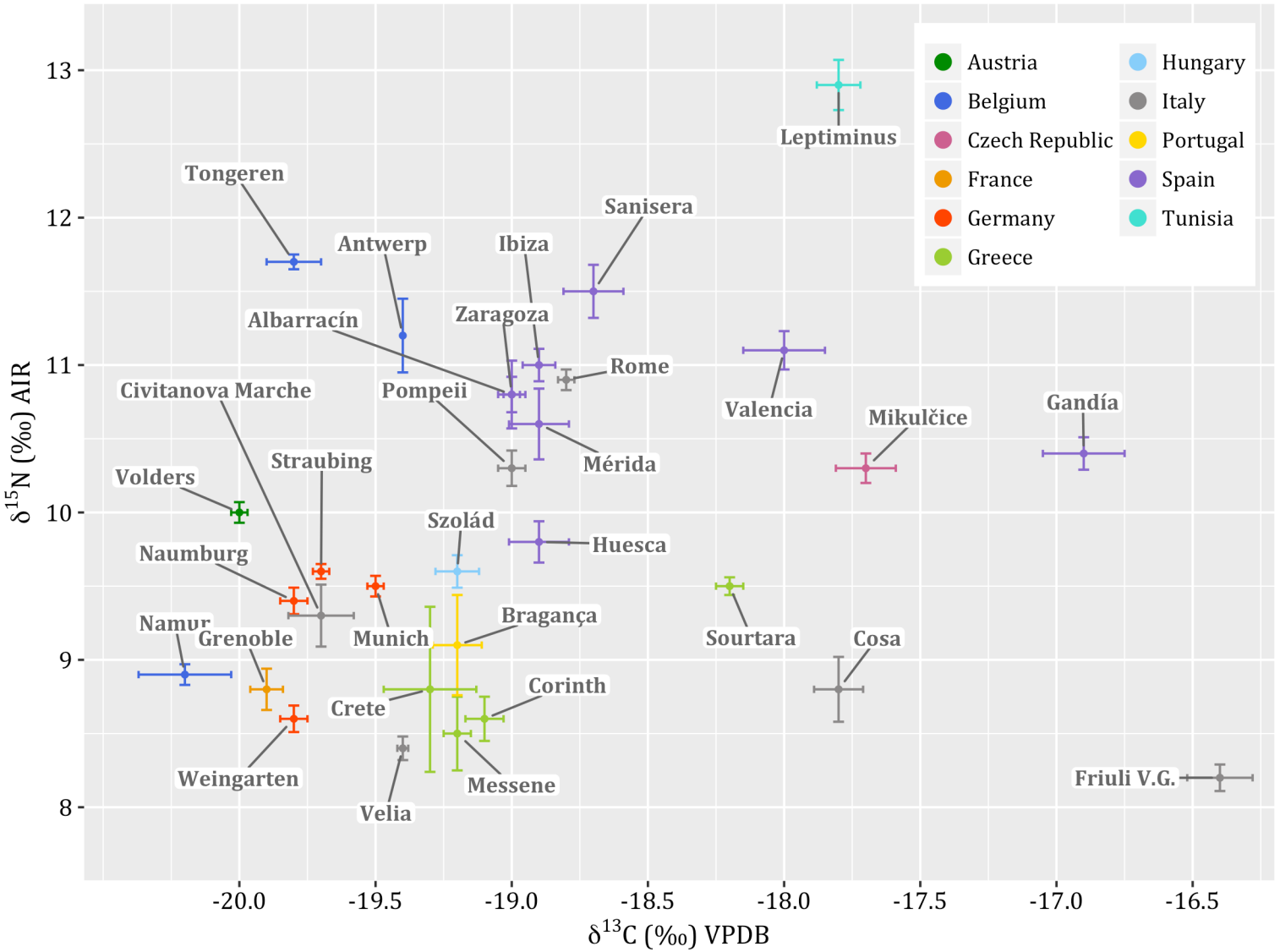


Figure 7.10: The mean $\delta^{13}C$ and $\delta^{15}N$ ± one standard error, for each location in the Meta-Data set. The points are colored by country as indicated in the legend.

parameters from the literature (reported in Chapter 6), and their relation to carbon and nitrogen values of the human individuals in the Meta-Data set. These include differences due to coastal versus inland location, the effect of latitude and longitude, and the role of local climate variation including variations in both temperature and precipitation.

Following the description of possible causes of variation, this chapter discusses control procedures, which allow for these effects to be teased apart. Then an alternative model for inter-site comparison is introduced based on the use of faunal isotopic data as a control for the effects of environmental factors on human isotopic values. This allows for a more comprehensive interpretation of diet data between sites.

7.4.1 Direct Comparisons

The Meta-Data set consists of 1,381 adult human individuals from 31 separate locations in Central Europe and North Africa, as well as 2,183 faunal samples from 95 different species in 26 different terrestrial locations, and 23 marine locations surrounding Europe (see Figure 7.10). A data set of such a large size (the $\delta^{13}C$ and $\delta^{15}N$ of over 3,000 individuals, also with the species, date, seven location variables and 49 climate variables), can seem unruly; however, it is the size of the data set that makes the interpretations derived from it so valuable. As with the previous results section, this discussion initially examines the human and faunal results separately with comparison between the two in subsequent sections.

7.4.1.1 Faunal Comparisons

7.4.1.1.1 Time Period

There was very little in the way of $\delta^{13}C$ and $\delta^{15}N$ variation when grouped by time period for the three domestic species being analyzed (see Figure 7.11 and Table 6.19 in the previous chapter). The largest change was the shift to higher mean $\delta^{13}C$ values in the Early Medieval cattle, pig and sheep/goats as compared their Late

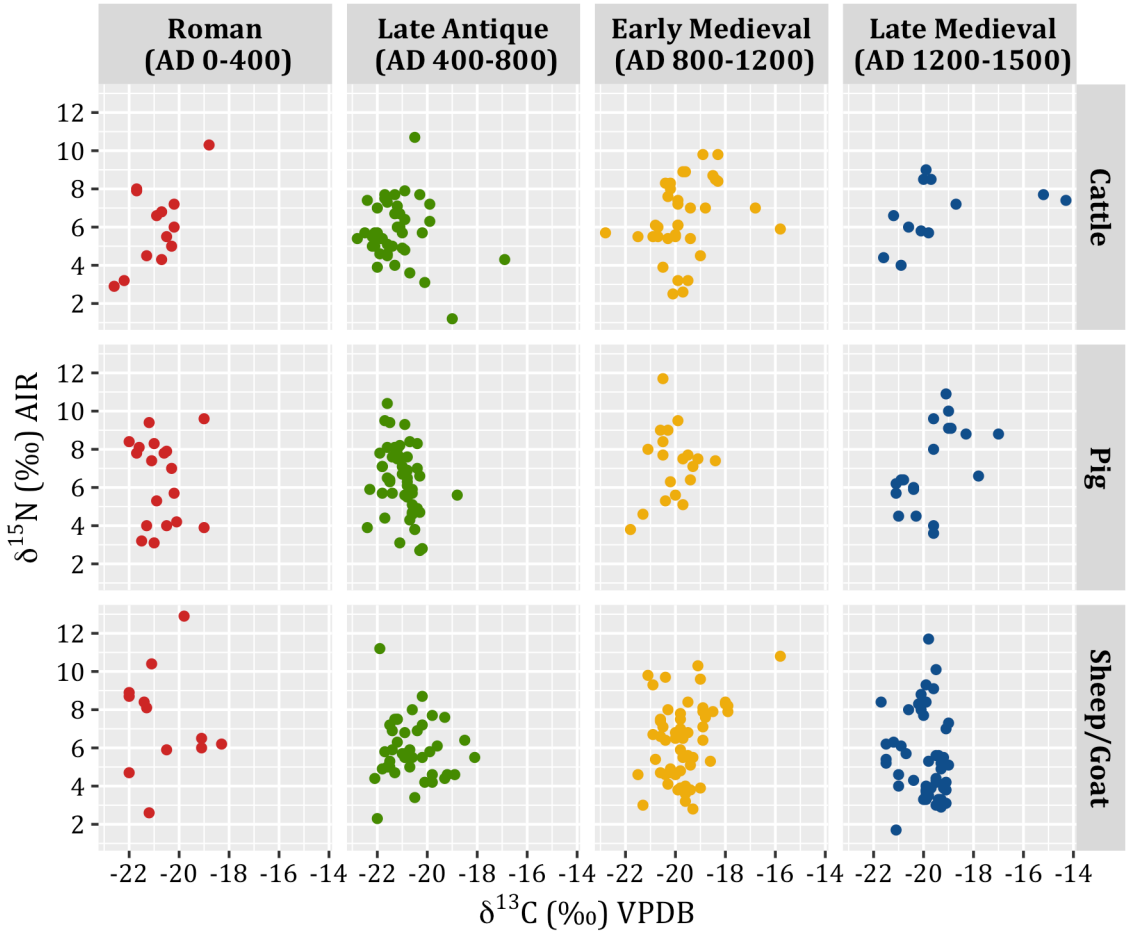


Figure 7.11: The $\delta^{13}C$ and $\delta^{15}N$, of the cattle, pigs, and sheep/goats in the Meta-Data set, faceted by time period and species.

Antique counterparts immediately predating them (Dunn's test p=0.00 for all three species). There was an increase of approximately 1.54‰ for cattle, 0.80‰ for the pigs, and 0.90‰ for the sheep/goats between these two periods. This implies that the introduction of C_4 grains to the human diet during this time period was mirrored in the diet of the domestic fauna. For the cattle, there was a also a significant difference in the $\delta^{15}N$ between the Late Antique and Early Medieval periods (Dunn's

test p=0.01). This could be due to changes in animal husbandry practices such as an increase in the number of cattle being fed fertilized crops or kept in pens (Bogaard *et al.* 2007, Fuller *et al.* 2010). Overall, the faunal data did not seem to have a substantial correlation to the established climatic trends occurring over this span of time.

7.4.1.1.2 Geography

7.4.1.1.2.1 Coastal versus Inland

The difference between coastal and inland fauna was similar to that found in the human samples. While there were significant statistical differences to be found between the coastal and inland fauna, there was a considerable amount of overlap between the two sets of samples. The higher $\delta^{13}C$ and $\delta^{15}N$ values reported for the coastal cattle suggests an increase in the likelihood of the practice of feeding these animals fertilized crops (Bogaard *et al.* 2007); however, this all but disappears when the data were divided by time period with five cattle from the Late Antique period having significantly higher $\delta^{15}N$ values (Mann-Whitney U p=0.01) than the 36 inland cattle of the same time period.

Overall, there was no significant difference between the coastal and inland pigs in either $\delta^{13}C$ or $\delta^{15}N$ (Mann-Whitney U p=0.05 and p=0.48, respectively). However, when the comparison was made within each time period, a significant difference between the coastal and inland pig $\delta^{15}N$ values appears both during the Roman and Late Antique periods. The differences between the coastal and inland pigs, however, were in the opposite direction, with the coastal Roman period pigs having lower $\delta^{15}N$ values than their inland counterparts and the reverse being found with the Late Antique pigs.

The coastal and inland sheep/goats data were only significantly different in terms of their $\delta^{13}C$ values (Mann-Whitney U p=0.00). In the absence of a accompanying increase in $\delta^{15}N$ values, the higher $\delta^{13}C$ values of the coastal sheep/goats were most likely due to an increased C_4 component in their diet, rather than the consumption of fertilized crops as with the cattle. This conclusion assumes that

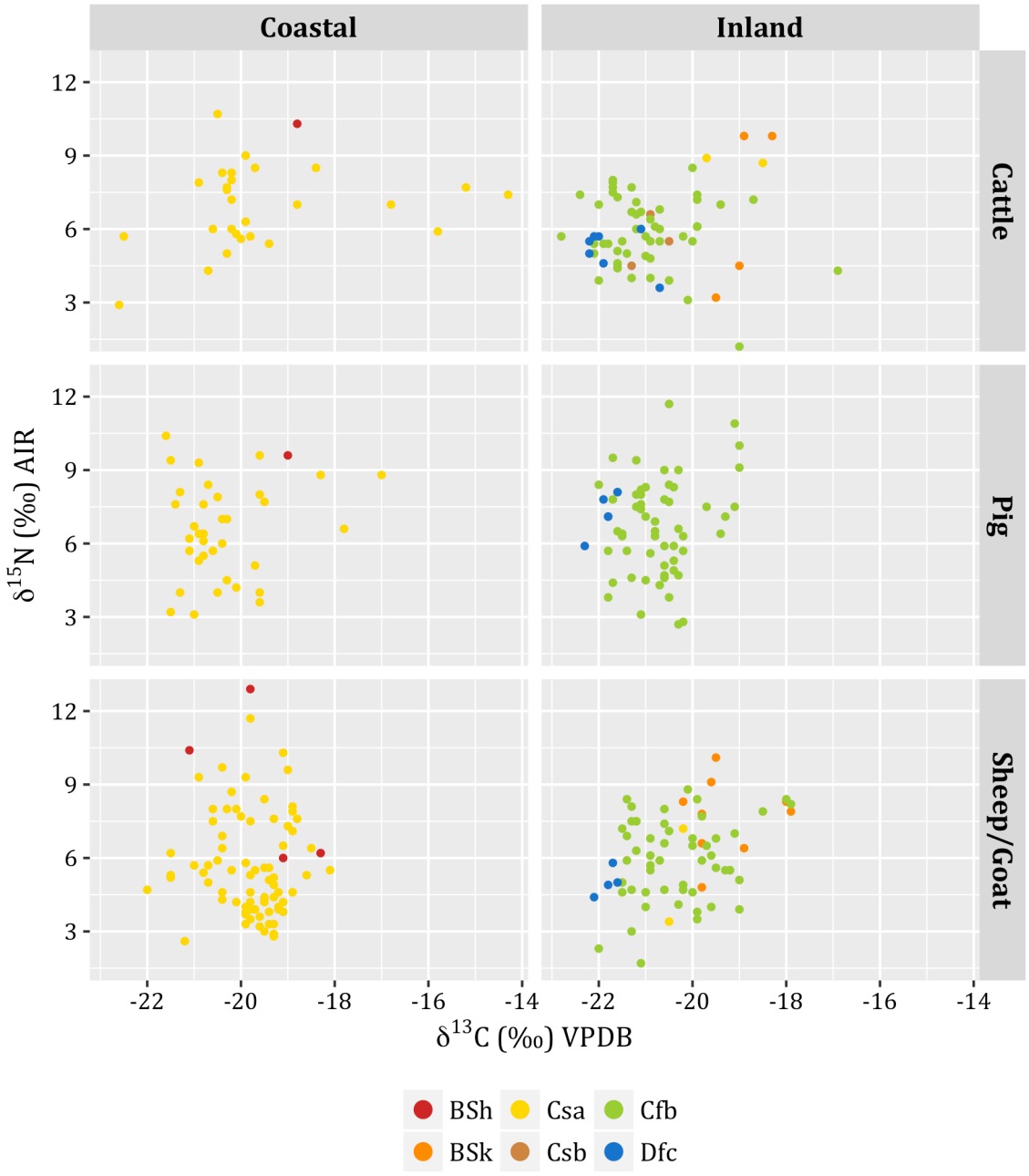


Figure 7.12: The $\delta^{13}C$ and $\delta^{15}N$ of each of the three principal species in the Meta-Data set, divided by whether they were from coastal or inland locations (coastal means less than 10km from the coast and inland means more than 10km) and colored by Köppen-Geiger Climate Classification.

sheep/goats were more likely to be kept in pastures, whereas cattle might be raised in pens. When these data were broken down by time periods, the significant difference between coastal and inland data was seen to be isolated to only the Late Antique samples.

Overall, no consistent relationship is seen between coastal and inland faunal isotopic data. This is most likely due to the lack of a presence of fish in the diets of any of these animals. As a result, any variation in the faunal data found between inland and coastal sites is likely due the fact that in the current data set, the coastal sites tend to also have warmer climates than the inland sites. This can be seen in Figure 7.12.

7.4.1.1.3 Climate

When the faunal samples were grouped by their Köppen-Geiger Climate Classification, it became clear that, as with the human data, the samples from hotter, more arid climates such as BSh and BSk, have higher $\delta^{13}C$ and $\delta^{15}N$ values, particularly when compared to the samples from the colder climates such as Dfc. Evidence of this trend can be seen in Figure 7.13. The fact that the same pattern was also present in the human data suggests that the origin of this variation was based on the effects on isotopic values that climate had on plant life. This effect was then being passed up the food chain to the fauna and then the humans. This brings into question the manner in which climate might be affecting these data. If variations between sites can be due to variations in climate, then this relationship needs to be more thoroughly examined.

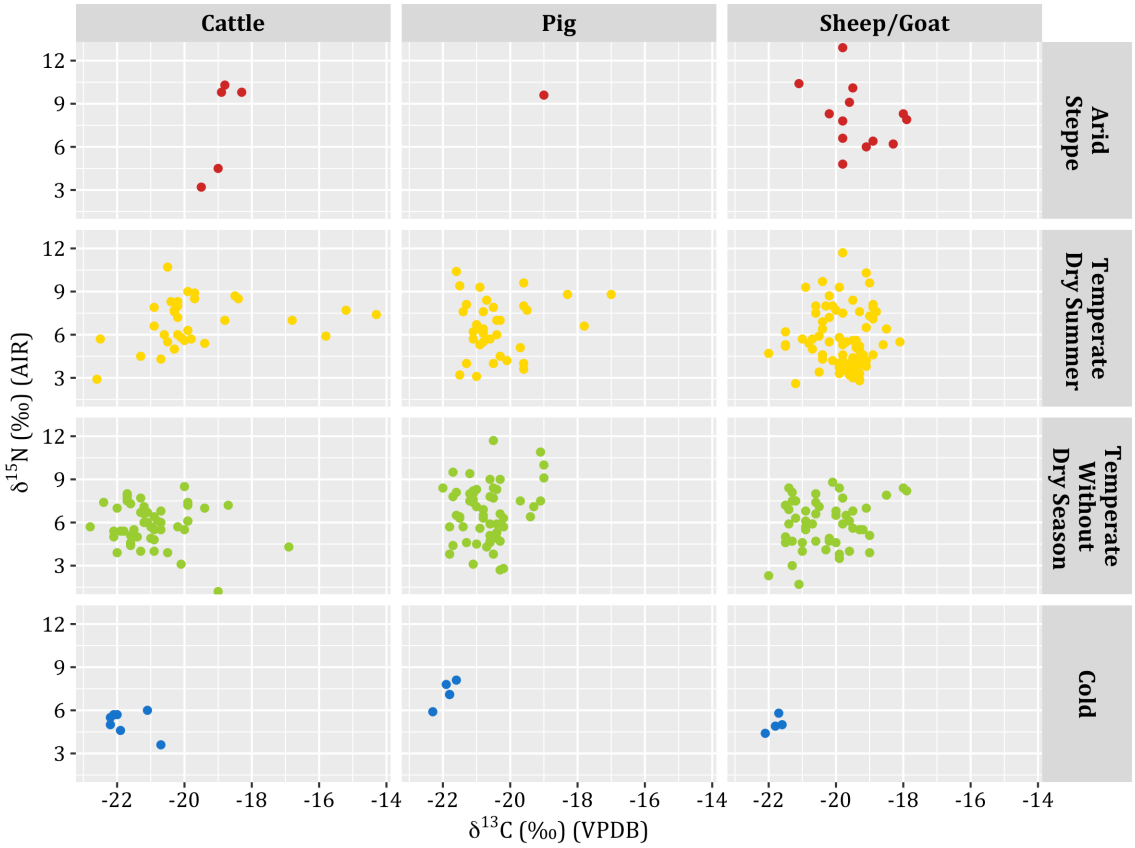


Figure 7.13: The $\delta^{13}C$ and $\delta^{15}N$ of the cattle, pigs and sheep/goats in the Meta-Data set, faceted by base climate classification and species.

7.4.1.2 Human Comparisons

Once the outliers were removed from the human data set, the mean $\delta^{13}C$ and $\delta^{15}N$ values were found to be -18.8 ± 1.1‰ and 10.0 ± 1.4‰, respectively. This implies that the data set as a whole consists of mostly individuals with a terrestrial C_3 based diet, supplemented by the occasional marine resource.

There were a few sites where it is evident that there was a substantial contribution of C_4 grains to the mean individual's diet. The most prominent of these is Fruili V.G., which lies over two standard deviations from the overall mean with a mean $\delta^{13}C$ of -16.4‰. Other sites with significant C_4 dietary input are Gandía ($\delta^{13}C$ of -16.9‰), Milkulčice-Kastelisko ($\delta^{13}C$ of -17.7‰), and Cosa ($\delta^{13}C$ of -17.8‰).

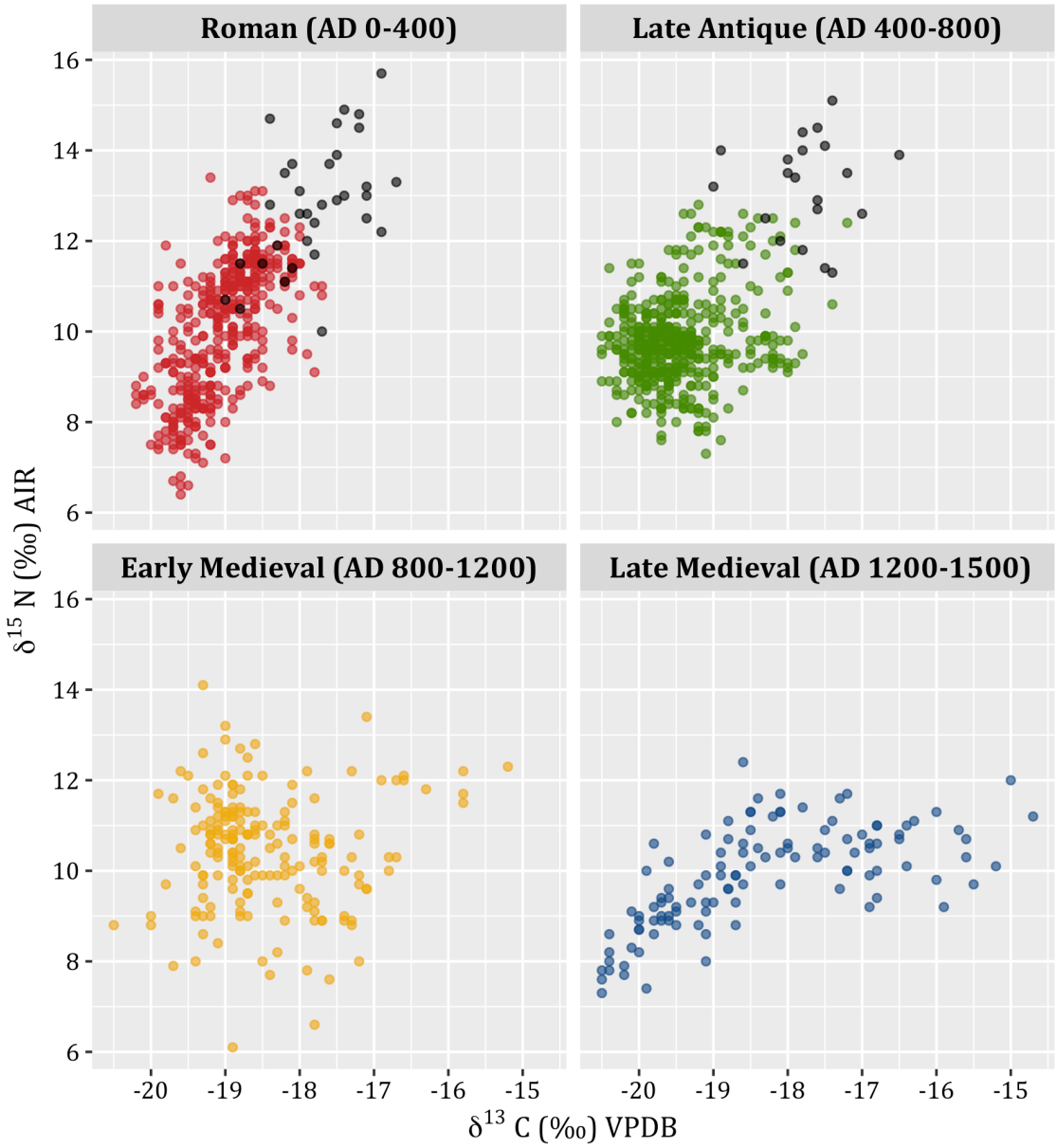


Figure 7.14: The $\delta^{13}C$ and $\delta^{15}N$ of the individuals from the Meta-Data set divided by time period, with the individuals from Leptiminus plotted in black.

When it comes to $\delta^{15}N$ values, the only site to stand out is Leptiminus, with a mean $\delta^{15}N$ of 12.9‰. Coupled with its high mean $\delta^{13}C$ of -17.8‰, Keenleyside *et al*. 2009, interpreted the general diet of the individuals tested to contain considerably more marine foods than the comparable populations in Europe. While its high $\delta^{13}C$ value would normally suggest C_4 input to the diet, when it is coupled with such high $\delta^{15}N$ values it became more likely that the isotopic values indicate marine food rather than C_4 plant consumption.

7.4.1.2.1 Time Period

The increased range of $\delta^{13}C$ values became visible when the individuals were grouped by time period (see Figure 7.14). During the Roman period, (AD 0-400), the carbon data is spread over only 2.5‰, and by the Late Medieval Period, (AD 1200-1500), the variability of the data has more than doubled the $\delta^{13}C$ range, being dispersed over 5.8‰. This is not a uniform spreading of the data though, there is a spike between the Late Antique Period, (AD 400-800), and the Early Medieval Period, (AD 800-1200), with the range of $\delta^{13}C$ values jumping from 3.3‰ to 5.3‰. The increased range of $\delta^{13}C$ values after the Late Antique was most likely the result of the spread of C_4 plants, such as millet and sorghum, across Europe (Braudel 1995, Glick 1982), which occurred due to the influx of migrants following the collapse of the Roman Empire (Hakenbeck *et al.* 2010, Lightfoot *et al.* 2012, López-Costas & Müldner 2016). There also appears to be a decrease in $\delta^{15}N$ values as the time periods progress; this can be attributed to the site of Leptiminus, only having individuals dating to the first two periods, both of which had extremely high $\delta^{15}N$ values as compared to the individuals from the rest of sites (see the black points in Figure 7.14).

7.4.1.2.2 Geography

The data in Figure 7.10 make it clear that individuals group strongly based on their location. This suggests influence which correlates with geography. The variables of longitude, latitude and altitude were analyzed to explore this feature of the data.

7.4.1.2.2.1 Longitude, Latitude and Altitude

When longitude, latitude and altitude were regressed (using a linear regression) against $\delta^{13}C$ and $\delta^{15}N$ values of the human individuals from the Meta-

Data set, the sheer size of the data set made any correlations between these variables statistically significant (p=0.00). However, the squared correlation coefficient (R^2), the proportion of variance accounted for by a factor, made the magnitude of relation between these geographic variables and the $\delta^{13}C$ and $\delta^{15}N$ values clearer. Latitude had the largest R^2 values for both $\delta^{13}C$ and $\delta^{15}N$, 0.27 and 0.10, respectively. Taking the slope into account, these regressions would suggest that the farther South an individual was found, the more enriched both their $\delta^{13}C$ and $\delta^{15}N$ values were likely to be. This is not the first time this has been noticed (van

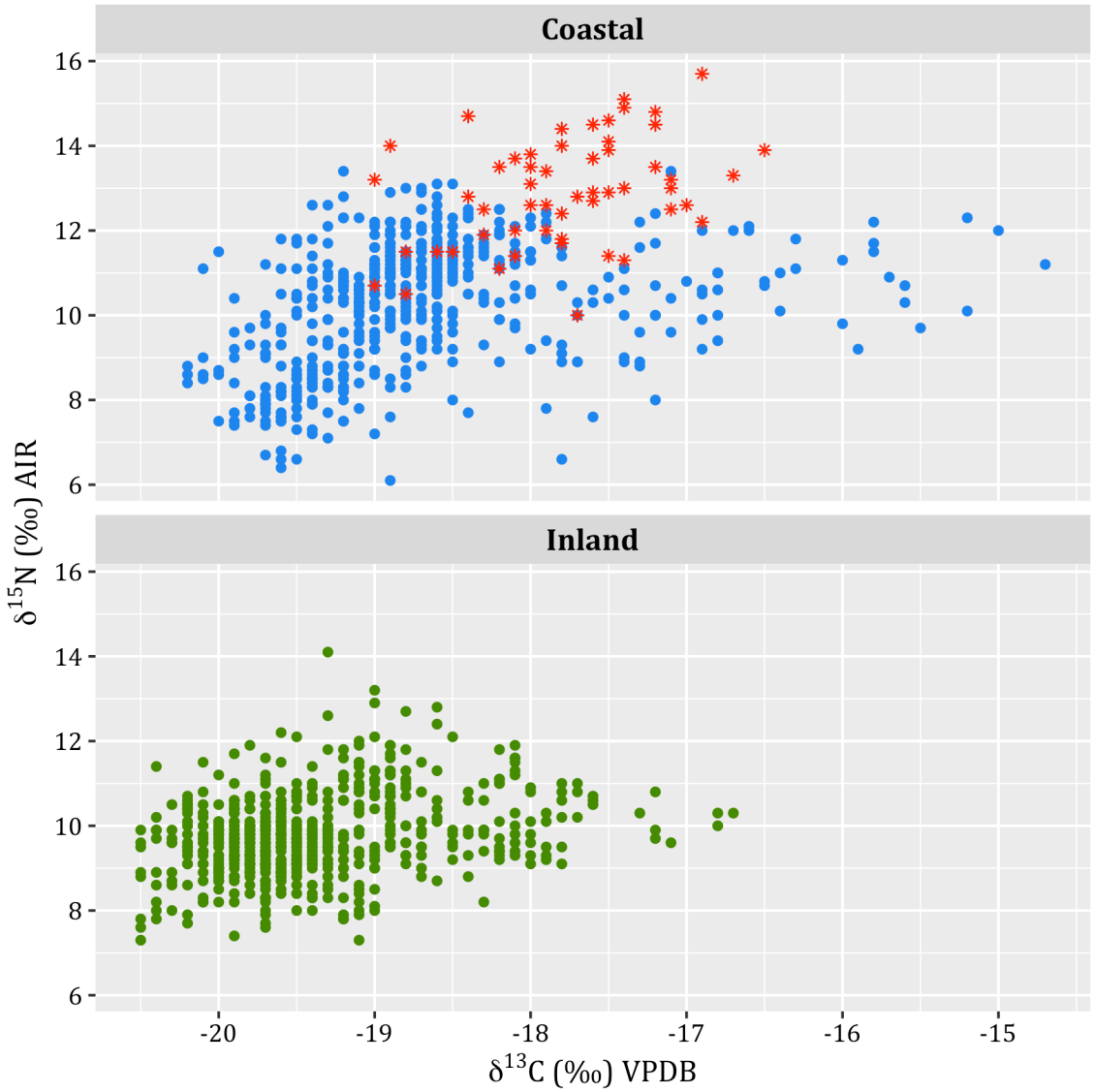


Figure 7.15: The $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived from the coast. Within 10 kilometers of the coast (Coastal) versus farther inland (Inland). Individual from the site of Leptiminus are plotted in red.

Klinken *et al*. 1994, 2002). However, latitude itself has no direct effect on isotope values. Rather, it is important to consider that for this particular set of data most of the southern-most individuals originate from coastal sites, where they would have had access to resources that would greatly effect carbon and nitrogen isotope ratios. At most then, latitude could be used only as a proxy to give a general sense how individuals from different sites could relate to one another.

7.4.1.2.2.2 Coastal versus Inland

Coastal sites were defined as sites that were less than ten kilometers from the coast, while sites greater than ten kilometers from the coast were categorized as inland (See Figure 7.15). The difference between $\delta^{13}C$ and $\delta^{15}N$ values between individuals from coastal and inland sites was done individually by regressing both, $\delta^{13}C$ and $\delta^{15}N$ on a binary indicator variable for coastal and inland locations. This analysis found that there was a significant difference between the two types of location both in terms of $\delta^{13}C$ ($p<0.00$) and $\delta^{15}N$ ($p<0.00$) values. However, the R^2 values indicate that the variation between coastal and inland locations only accounted for 0.17 of the variation in carbon isotope values and only 0.06 of variation in nitrogen isotope values. This small effect size indicates that while coastal individuals may have consumed more marine foods (leading to higher $\delta^{13}C$ and $\delta^{15}N$ values), the majority of their diet resembled that of individuals from the inland sites. It is important to consider the unusually high $\delta^{13}C$ and $\delta^{15}N$ values of

Table 7.9: The results of regressing $\delta^{13}C$ and $\delta^{15}N$ values, individually on the binary indicator variable for coastal and inland locations, excluding the site of Leptiminus.

Isotope	p-value	R^2	coefficient
$\delta^{13}C$	<0.00	0.147	-0.654
$\delta^{15}N$	<0.00	0.032	-0.448

the individuals from Leptiminus separately. Leptiminus is a coastal site, whose $\delta^{13}C$ and $\delta^{15}N$ values were sufficiently higher than the rest of coastal values to have a substantial influence on the mean coastal $\delta^{13}C$ and $\delta^{15}N$ values. This is clear in Figure 7.15, where the individuals from Leptiminus were plotted in red. As can be seen in Table 7.9, without the individuals from Leptiminus, the correlation between $\delta^{13}C$ and $\delta^{15}N$ values and coastal versus inland locations was not as strong, particularly in terms of $\delta^{15}N$.

7.4.1.2.3 Climate

7.4.1.2.3.1 Individual Variables

Individual climate variables were linearly regressed against both $\delta^{13}C$ and $\delta^{15}N$ values. The climate variables were divided into two groups, temperature and precipitation. The temperature group included monthly, seasonal, and annual means as well as monthly and annual standard deviations (all in degrees Celsius). The precipitation group included monthly, seasonal, and annual totals as well as standard deviations from the annual total (in millimeters). In total, this came to 96 different regressions (60 for temperature and 36 for precipitation); the results of which can be seen in Chapter 6, Figure 6.30.

Of the 30 regressions run between $\delta^{13}C$ and temperature variables, only two had a p-value over 0.05 indicating that they were not statistically significant (standard deviation of temperature Annually and in March). However, with such a large data set the p-values can often be misleading as to the significance of a variable. The slope coefficients for mean temperature variables were all positive; indicating that, overall, the higher the temperature, the higher the $\delta^{13}C$ value, a mean increase of 0.12‰ per degree.

The strongest correlation was found between $\delta^{13}C$ and the mean temperature in September; a relationship which accounted for 37% of the variance in $\delta^{13}C$ (or R^2=0.37). The other mean temperature correlations were between 36% and 27% of the variance in $\delta^{13}C$; while the standard deviations only accounted for between 0% and 19% of the variance in $\delta^{13}C$. Of special note is the mean temperature in July, which van Klinken *et al.* 1994 found to have the strongest correlation to $\delta^{13}C$ values. While the mean temperature in July was one of the stronger correlations (R^2=0.34), it was surpassed by the mean temperatures of both September and April as well as the annual mean. This was due to differences between the data sets, but it is worrying that the van Klinken *et al.* 1994 results were not replicated when new data was introduced.

As with $\delta^{13}C$, two of the thirty regressions run between the temperature variables and the $\delta^{15}N$ values were found to be not statistically significant; the standard deviation of August temperatures (p=0.09) and the standard deviation of October temperatures (p=0.97). The rest have p-values suggesting statistical significance, though as before, the size of the data set makes the importance of the statistical significance subject to doubt. Overall, the correlations between the temperature variables and the $\delta^{15}N$ values were less strong than those found with the $\delta^{13}C$ values. They too have positive slopes, indicating that the higher the temperature, the higher the $\delta^{15}N$ value (at 0.13‰ per degree).

The percent of variance accounted for by each temperature variable ranged between 18% (mean temperature in April) and 0% (standard deviation of temperature in October). Overall, the mean temperature in April had the highest correlation to both $\delta^{13}C$ and $\delta^{15}N$ values as it had the highest R^2 for $\delta^{15}N$ (0.18) and the second highest R^2 for $\delta^{13}C$ (0.36).

Of the 36 regressions run on the precipitation variables only four were found to have p-values over 0.05, suggesting they were not statistically significant. All four were related to $\delta^{13}C$, specifically the regressions between $\delta^{13}C$ and total precipitation in May (p=0.16), September (p=0.22), the Spring (p=0.05) and the Fall (p=0.28).

Precipitation also correlated more strongly with $\delta^{13}C$ than $\delta^{15}N$, with the mean $\delta^{13}C$ R^2 values being almost twice that of the $\delta^{15}N$. The strongest correlation between $\delta^{13}C$ and a precipitation variable was for total precipitation in August (R^2=0.31) while the strongest correlation for $\delta^{15}N$ was found with the total precipitation in December (R^2=0.17).

While there is clearly a relationship between $\delta^{13}C$ and $\delta^{15}N$ and some of the temperature and precipitation variables, none of them had a significantly large R^2 value to place it as a serious candidate for a variable which was a primary driver of isotopic value.

7.4.1.2.3.2 Climate Classification

There was clear relation between the climate classifications and carbon and nitrogen isotope values. The seven Köppen-Geiger Climate Classifications were compared using Dunn's Test for Stochastic Dominance (Dunn 1964), resulting in 42 total comparisons (21 for $\delta^{13}C$ and 21 for $\delta^{15}N$). Seventeen of the comparisons were found to be statistically different (p<0.05) both in terms of $\delta^{13}C$ and $\delta^{15}N$, three were found to be different only in terms of $\delta^{15}N$, two were only significantly different in terms of $\delta^{13}C$, and only one comparison found none in either isotope.

When the data were divided by time period, the analysis became more difficult as not every time period contained data from every climate classification. Overall, the trend of decreasing $\delta^{13}C$ values accompanying decreasing temperatures

Table 7.10 Description and defining criteria of the Köppen-Geiger Climate Classification that apply to this study. Taken from Peel *et al.* 2007 Table 1.

1st	2nd	Description	Criteria*
B		**Arid**	MAP < 10 x $P_{threshold}$
	S	- Steppe	MAP > 5 x $P_{threshold}$
C		**Temperate**	T_{hot} > 10 & 0 < T_{cold} < 18
	s	- Dry Summer	P_{sdry} < 40 & P_{sdry} < P_{wwet}/3
	f	- Without dry season	Not (Cs) or (Cw)
D		**Cold**	T_{hot} > 10 & T_{cold} < 0
	f	- Without dry season	Not (Ds) or (Dw)

*MAP = mean annual precipitation, MAT = mean annual temperature, T_{hot} = temperature of the hottest month, T_{cold} = temperature of the coldest month, T_{mon10} = number of months where the temperature is above 10, P_{sdry} = precipitation of the driest month in summer, P_{wwet} = precipitation of the wettest month in winter, $P_{threshold}$ = varies according to the following rules (if 70% of MAP occurs in winter then $P_{threshold}$ = 2 x MAT, if 70% of MAP occurs in summer then $P_{threshold}$ = 2 x MAT + 28, otherwise $P_{threshold}$ = 2 x MAT + 14).

remains the same, although it became less prominent in the Early Medieval and Late Medieval Periods. The wide introduction of C_4 grains during this time is the most likely explanation, as it would best explain the higher $\delta^{13}C$ values.

The climate classifications, defined by a combination of temperature, precipitation and vegetation, when considered together, strongly correlate to carbon and nitrogen isotope values in humans. The most striking conclusion that can be reached from this analysis is that individuals from arid environments (BSh and BSk)

Table 7.11: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) from the Meta-Data set divided by the base two variables of the Köppen-Geiger Climate Classifications.

Climate Classification	Abreviation	n	$\delta^{13}C$ ± σ (‰)	$\delta^{15}N$ ± σ (‰)
Arid Steppe	BS	94	-18.28 ± 0.77	12.05 ± 1.69
Temperate Dry Summer	Cs	628	-18.71 ± 0.84	10.23 ± 1.43
Temperate without Dry Season	Cf	465	-18.90 ± 1.33	9.34 ± 0.94
Cold	Df	81	-19.99 ± 0.30	9.97 ± 0.60

particularly those from the hot arid environment (BSh), had higher $\delta^{13}C$ and $\delta^{15}N$ values than individuals from the cold and temperate environments. When the climate classifications were defined by only their first two variables (see Table 7.10 for definitions), the difference between climates was more defined. The mean and standard deviation for each of these four climate classifications can be seen in Table 7.11, while the individuals from each can be seen plotted in Figure 7.16.

In terms of $\delta^{13}C$, all for four classifications were statistically different (see Table 7.12), and, for the most part, the groups were statistically distinct from each other in terms $\delta^{15}N$, with the exception of the Temperate without Dry Season group from the Cold group and the Arid group (p=0.14 and p=0.13, respectively).

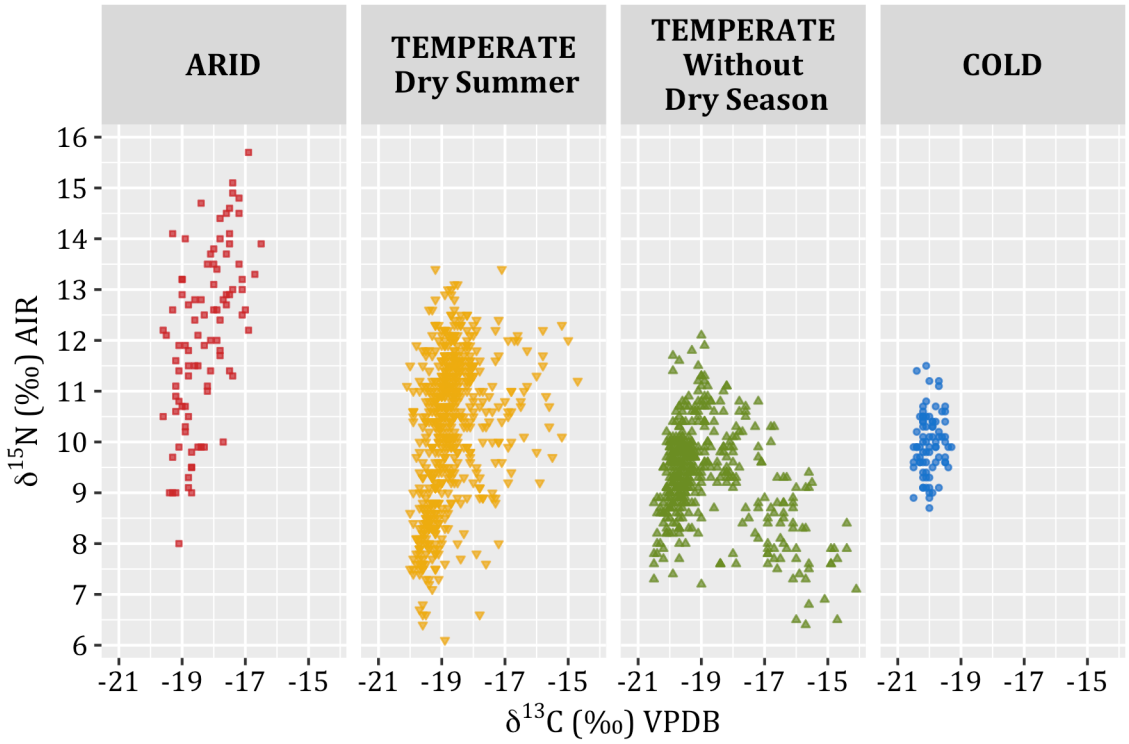


Figure 7.16: The $\delta^{13}C$ and $\delta^{15}N$ of the human samples divided by the first two variables of the Köppen-Geiger Climate Classifications. It should be noted that the individuals who make up the cold group were sourced from one site, and those in the arid group were from two. See Table 5.8 for further details.

Table 7.12: The p-values for the Dunn's test on the difference between Köppen-Geiger Climate Classifications of the $\delta^{13}C$ and $\delta^{15}N$ values. Values indicating statistically

		BS	Cs	Cf
Df	$\delta^{13}C$	0.00	0.00	0.00
	$\delta^{15}N$	0.01	0.00	0.14*
Cf	$\delta^{13}C$	0.00	0.00	
	$\delta^{15}N$	0.13*	0.00	
Cs	$\delta^{13}C$	0.00		
	$\delta^{15}N$	0.00		

What is clear is that the variations between climate classifications should be taken into account when comparing the carbon and nitrogen isotope values of populations, particularly in terms of dietary comparisons. To exclude such considerations would certainly lead to skewed interpretations.

7.4.3 Importance of Climate

The importance of climate in determining carbon and nitrogen isotope values is been generally accepted. As a practical consequence, isotope results for populations from drastically different climate classifications are generally not compared. This cautious approach is supported by the data shown previously in Section 6.4.2.3. In turn, this limits palaeodietary reconstruction's ability to combine results from different studies, making results difficult to interpret and less productive than might otherwise be the case. This problem has been recognized and a solution offered.

7.4.3.1 Correcting for Climate: van Klinken *et al*.

In their 1994 study, van Klinken *et al*. compared the $\delta^{13}C$ values of 4620 samples[1] (20% bone, 55% charcoal and 26% wood) dating throughout the Holocene and from across Europe and the Middle East, to the local climate data for each sample and found a relationship between climactic variation and carbon ratios. Using this correlation, a formula was developed to normalize the effect of climate on carbon isotope values (van Klinken *et al*. 2002). With this formula correcting for climate, it was hoped that more accurate comparisons could be made with carbon isotope data from sites having different climates. In the current study, the correction method used was taken from van Klinken *et al.* 2002. For this analysis, the equation below was used to correct the $\delta^{13}C$ values for climate and used the corrected values for inter-site comparisons.

$$Y= -30.202 + .0214x$$

In the equation, x is the mean temperature (in degrees Celsius) at the site in July and Y is the expected $\delta^{13}C$ value. van Klinken *et al*. 2002 found that the temperature in July at the site had the strongest correlation to carbon ratios. To correct the $\delta^{13}C$ values, the difference between the expected $\delta^{13}C$ value (Y) and an arbitrary value of -26‰ for wood (van Klinken *et al.* 2002) is added to the $\delta^{13}C$ of the human samples, which results in a climate corrected value $\delta^{13}Cc$. The application of the equation to the human $\delta^{13}C$ data in the Meta-Data set can be seen in Table 7.13 and Figure 7.17.

[1] Samples were sourced from the Groningen and Oxford ^{14}C databases as well as taken from the Heidelberg lab. There was also an inclusion of "some Swedish material" (van Klinken *et al*. 1994; 445).

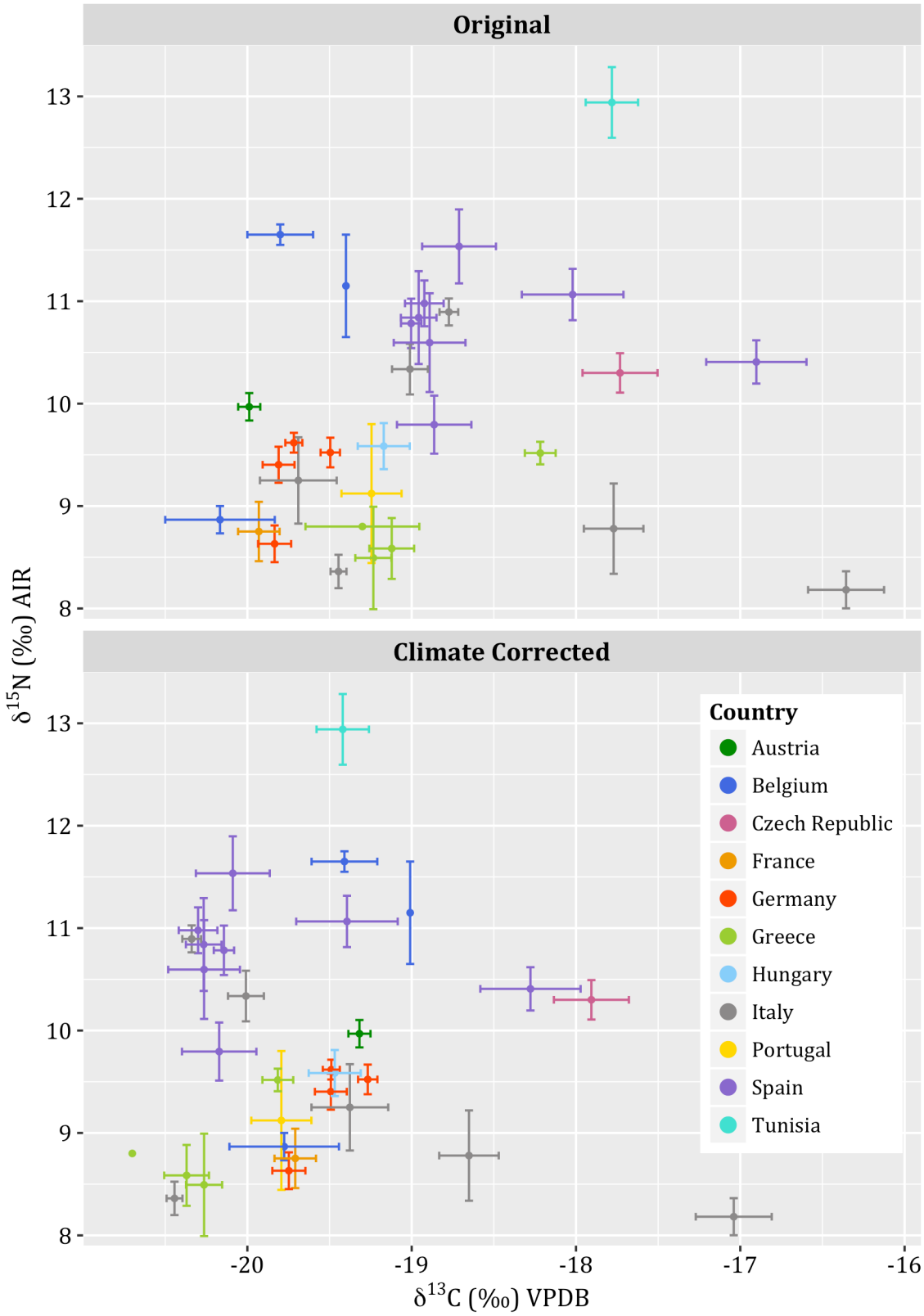


Figure 7.17: The original and climate corrected mean $\delta^{13}C$ and $\delta^{15}N$ values (± two standard errors) for each location in the meta-analysis. The points are colored by country.

Table 7.13: The original $\delta^{13}C$ and climate corrected $\delta^{13}C_c$ means, of each location in the Meta-Data set, well as the difference between the two.

Country	Location	n	$\delta^{13}C$	$\delta^{13}C_c$	Difference
Austria	Volders	81	-19.99	-19.32	0.67
Belgium	Antwerp	2	-19.40	-19.01	0.39
	Namur	3	-20.17	-19.78	0.39
	Tongeren	2	-19.80	-19.41	0.39
Czech Republic	Mikulčice	25	-17.73	-17.91	-0.17
France	Grenoble	33	-19.93	-19.71	0.22
Germany	Munich	66	-19.50	-19.27	0.23
	Naumburg	30	-19.81	-19.49	0.32
	Straubing	87	-19.72	-19.49	0.23
	Weingarten	32	-19.83	-19.75	0.09
Greece	Corinth	14	-19.12	-20.37	-1.25
	Crete	3	-19.30	-20.70	-1.40
	Messene	15	-19.23	-20.26	-1.03
	Sourtara	23	-18.22	-19.81	-1.60
Hungary	Szolád	20	-19.17	-19.47	-0.30
Italy	Civitanova Marche	20	-19.69	-19.38	0.31
	Cosa	24	-17.77	-18.65	-0.88
	Friuli V.G.	73	-16.36	-17.04	-0.68
	Pompeii	19	-19.01	-20.01	-1.00
	Rome	236	-18.77	-20.34	-1.57
	Velia	108	-19.45	-20.44	-1.00
Portugal	Bragança	9	-19.24	-19.79	-0.55
Spain	Albarracín	30	-19.00	-20.14	-1.14
	Gandía	43	-16.90	-18.28	-1.37
	Jaca	19	-18.86	-20.17	-1.31
	Ibiza	52	-18.92	-20.30	-1.38
	Sanisera	34	-18.71	-20.09	-1.38
	Mérida	22	-18.89	-20.26	-1.37
	Valencia	49	-18.02	-19.39	-1.37
	Zaragoza	40	-18.96	-20.27	-1.31
Tunisia	Leptiminus	54	-17.78	-19.42	-1.64

The first change one notices in the corrected Meta-Data set is that $\delta^{13}C$ values are less variable. The initial difference between the highest mean $\delta^{13}C$ value for a site population and the lowest was 3.81‰; after the $\delta^{13}C$ values have been corrected, the range of site means was reduced to 3.66‰. Taken individually, the mean shift in $\delta^{13}C$ was -0.66 ± 0.77‰, with the largest shift being at Leptiminus (-1.64‰) and the smallest shift being at Weingarten in Germany (0.09‰)(see Figure 7.18).

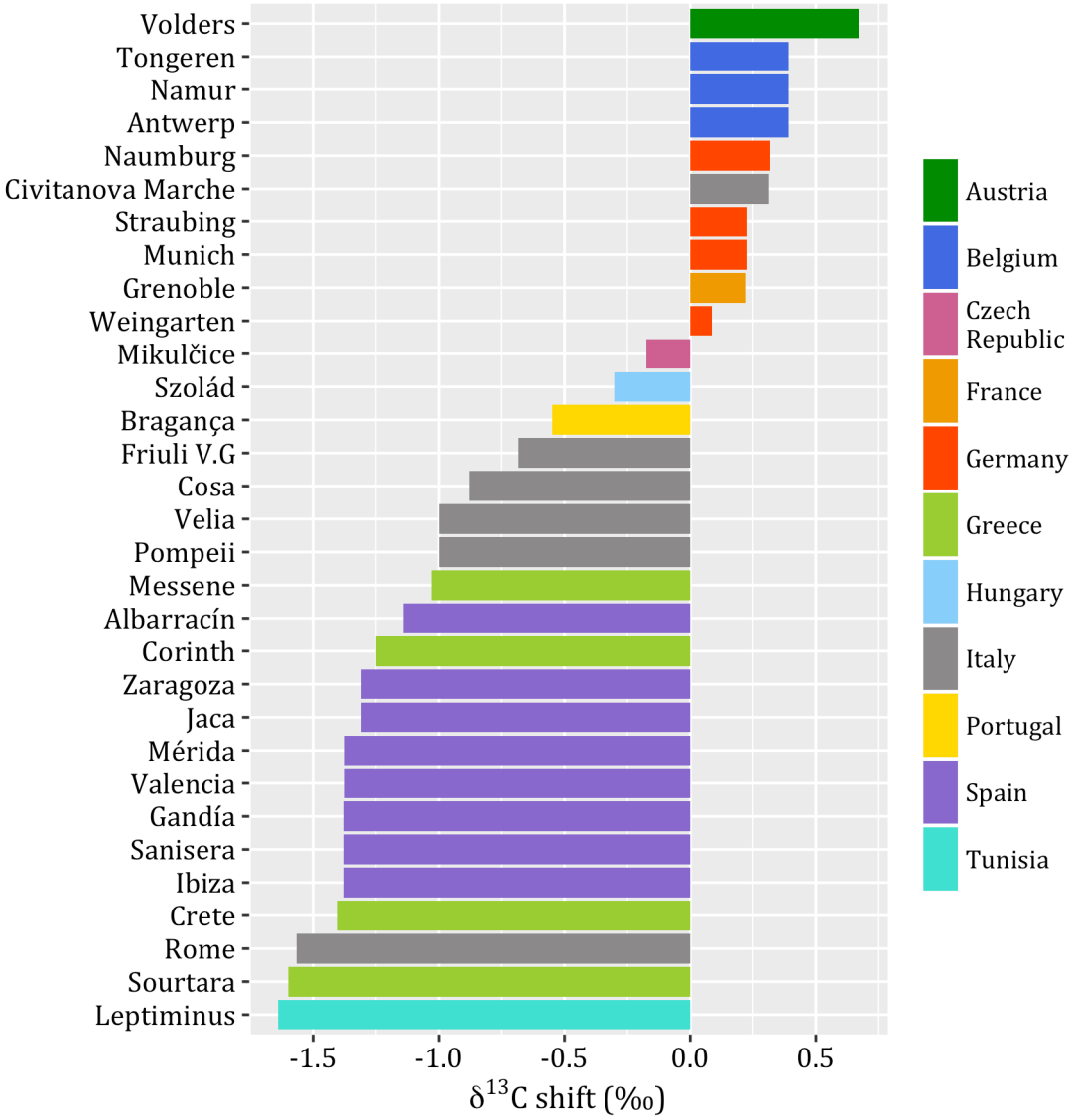


Figure 7.18: The difference between the original and climate corrected mean $\delta^{13}C$ for each location in the Meta-analysis. The points are colored by country

Based on the formula, the direction and magnitude of the shift depends on the mean temperature in July. The critical number for this formula is 19.64°C; at that temperature, there is no shift in $\delta^{13}C$. If the mean temperature in July is above 19.64°C, the correction factor will cause the $\delta^{13}C$ value to decrease. A mean temperature below this value will cause the $\delta^{13}C$ value to increase. This led to a general trend for the $\delta^{13}C$ values from Mediterranean sites to decrease and appearing to be influenced less by C_4 than might have been originally thought. With the $\delta^{15}N$ values not being corrected by this method, the interpretation of elevated $\delta^{13}C$ values means towards these locations having more marine resources in their diet, as that would account for the elevated nitrogen.

7.4.3.2 Discussion of the van Klinken Model

The van Klinken model makes a number of assumptions. The first and biggest assumption is that temperature plays the largest role in how carbon isotopes are affected by climate and location. The only input to the formula is the location's mean July temperature. Thus, the formula only indirectly incorporates other factors such as precipitation, distance from the ocean, and elevation, which might also be expected to play a role. While the van Klinken model is a good start at correcting carbon values for environmental variables, which might impact how human diets are reflected in the collagen of bone and dentine; it only uses one variable, mean July temperature. It seems likely that this effort is only the first step towards a more complete understanding of the impact of environment on isotopic values. As a next step, it seems logical to use a more complete characterization of the climatic data to bolster the picture of how climatic and locational variables effect isotopic ratios. The

goal is to insure that inter-site comparisons are actually about variations in dietary practices rather than a reflection of their varied location and climate.

Another shortcoming of the model proposed by van Klinken *et al.* 2002 is that it fails to address effects on $\delta^{15}N$. In palaeodietary reconstruction, both carbon and nitrogen are used in concert to create a description of the likely diet. As demonstrated in the previous chapter, climate also has an effect on $\delta^{15}N$ values. While it might not be as well understood as the effect that it plays on $\delta^{13}C$ values (van Klinken *et al.* 2002), simply excluding $\delta^{15}N$ is not a solution.

7.4.4 Human/Faunal Comparison

The relationship between human and faunal remains has long been a study at archaeological sites. Faunal remains were often extensively catalogued and studied with the aim of better understanding animal husbandry practices. While faunal remains were understood to be important in isotopic-based palaeodietary reconstruction, often analyses were qualitative rather than quantitative. This leads to faunal remains often being left out or misused when it comes to inter-site comparisons. By analyzing the quantitative relationship between a site's human and faunal remains, not only can these relationships be compared between sites, but also there is a quantifiable means by which to do so.

This section will first cover the relationship between the human and faunal remains at the site level with a discussion of the sites of Sanisera and Mérida. Then continue on to discuss how the comparison between human and faunal remains can be used to alleviate some of the concerns surrounding inter-site comparisons.

7.4.4.1 Sanisera Comparison

The relationship between the carbon and nitrogen isotope values of the fauna of Sanisera and its human population were compared by examining the difference between the human means, the individual species means and the pooled mean for the domestic fauna (*Bos taurus, Sus domestics and Ovis/Caprid*) (see Table 7.14, Figure 7.19 A and B).

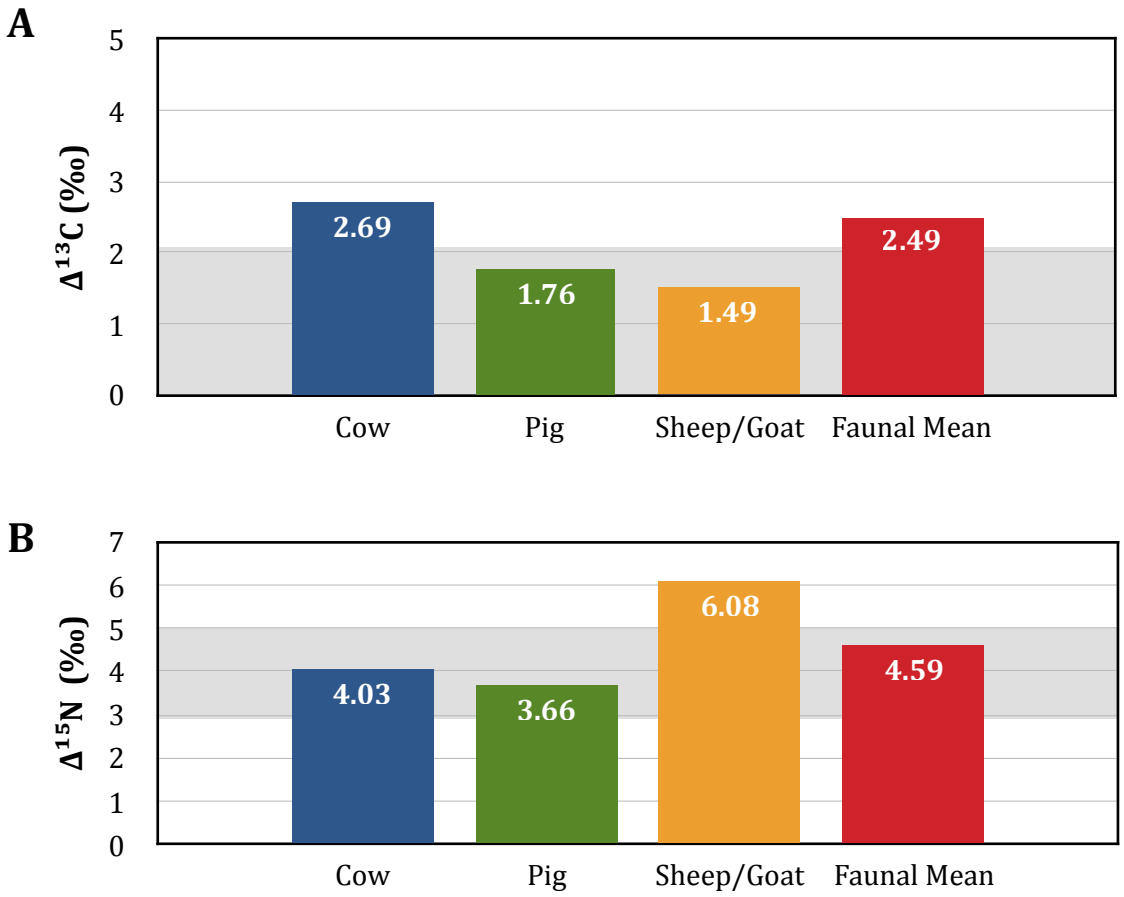


Figure 7.19: The difference between the mean $\delta^{13}C$ of a given species and a population, $\Delta^{13}C$ (human-faunal) (A) and the mean $\delta^{15}N$ of a given species and a population, $\Delta^{15}N$ (human-faunal) (B). The shaded area is the expected shift in values of a single trophic level; 0-2‰ for $\delta^{13}C$ and 3-5‰ for $\delta^{15}N$ (Brocherens & Drucker 2003, Brocherens *et al.* 1994, DeNiro & Epstein 1981, Hare *et al.* 1991, Vogel *et al.* 1990)

Table 7.14: The mean faunal $\delta^{13}C$ and $\delta^{15}N$ (± σ) from Sanisera, divided by species. The means consist of bone collagen, except for the *Bos taurus* mean, which was derived from two bone samples and two dentine samples. Also included are the Domestic Faunal Mean and outlier free mean of the human samples from Sanisera.

Species	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
Bos taurus (cow)	4	-20.95 ± 1.11	7.65 ± 2.24
Sus domesticus (pig)	10	-21.02 ± 0.41	8.02 ± 1.41
Ovicaprid (sheep/goat)	8	-19.75 ± 1.03	5.60 ± 1.21
Domestic Faunal Mean	22	-20.57 ± 0.73	7.09 ± 1.30
Human Mean	34	-18.71 ± 0.65	11.54 ± 1.05

If the individuals from Sanisera were solely consuming the fauna sampled, the expected difference between their data would be 0-2‰ for carbon ($\Delta^{13}C$) (Bocherens & Drucker 2003) and between 3-5‰ for nitrogen ($\Delta^{15}N$) (Bocherens *et al*. 1994, Vogel *et al.* 1990, DeNiro & Epstein 1981, Hare *et al.* 1991). For $\Delta^{13}C$, both the pig and sheep/goat means fell within the expected offset between putative diet and expected consumer values. The cattle mean, however, was greater than the expected offset, leading to the Faunal mean also being greater than the expected offset. This was due to one of the four cattle samples having a $\delta^{13}C$ value of -22.46‰. While not sufficiently anomalous to count as an outlier, this high value had a disproportionate effect on the mean. For $\Delta^{15}N$, only the sheep/goat had a larger offset than expected. This suggests the possibility that crops consumed by the cattle, pigs, and humans had been fertilized (leading to higher $\delta^{15}N$ values), while the sheep/goats were left to roam on uncultivated land, and consumed unfertilized crops.

These results imply, as would be expected, that diets of individuals from Sanisera did not consist solely of animal meat and byproducts (such as milk and cheese). Rather, their diet would have mainly consisted of grains (Rickman 1980,

Garnsey 1983, White 1988, Killgrove 2010). For the typical C_3 grain consumer, the expected $\delta^{13}C$ is -21.5‰ (Chisholm 1989) and a $\delta^{15}N$ is 6-9‰ (Coltrain *et al.* 2004). This means that domestic fauna alone cannot account for the human isotope values from Sanisera; therefore, the individuals sampled were likely to have been consuming fish as well.

7.4.4.2 Mérida Comparison

There were only three *Bos taurus* samples from Mérida, and two belong to the same individual. This reduced confidence in the analysis comparing the human and faunal samples from the city. The difference between the mean human value and the mean value of the two cow samples was 0.21‰ for $\Delta^{13}C$ and 1.80‰ for $\Delta^{15}N$. While

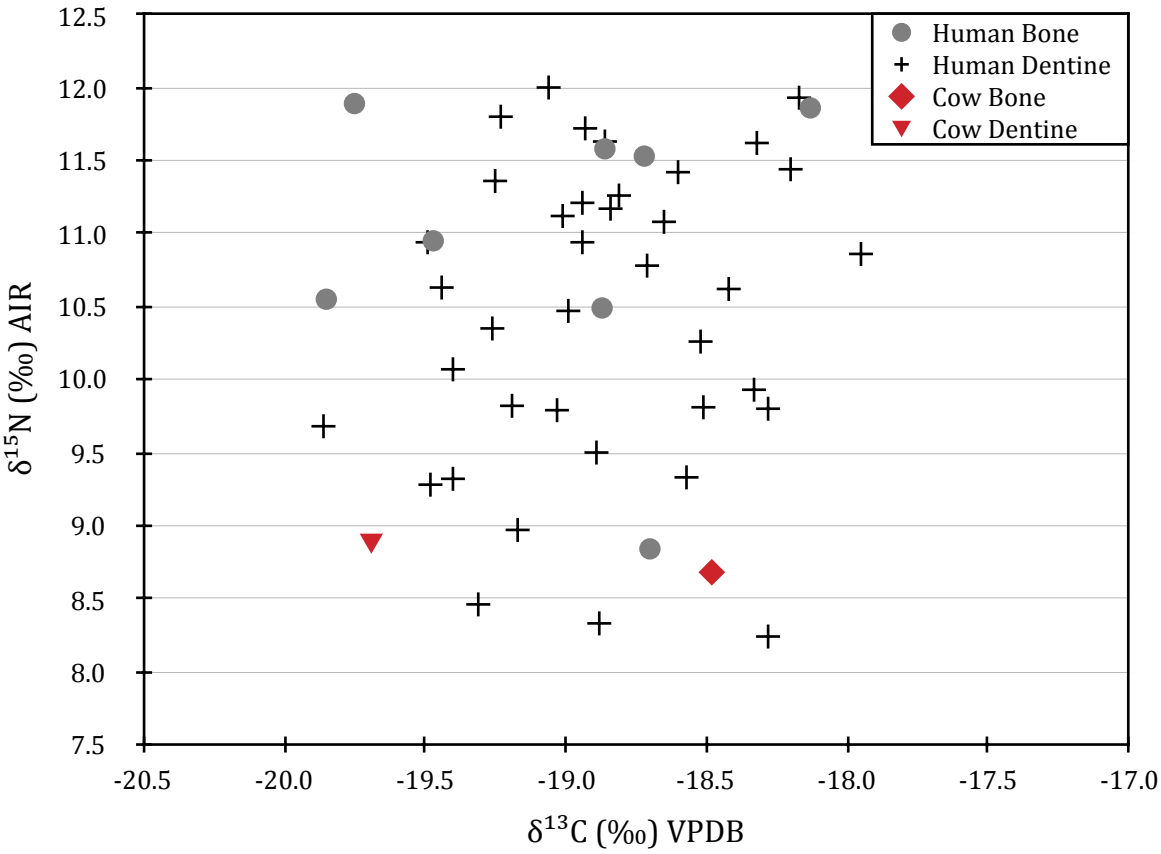


Figure 7.20: The human $\delta^{13}C$ and $\delta^{15}N$ results from Mérida without outliers (defined as >2σ from the population mean) as well as the results from the two cattle tested (in red).

these fall within the established expected offset for each isotope (Bocherens *et al.* 1994, Bocherens & Drucker 2003, Vogel *et al.* 1990, DeNiro & Epstein 1981, Hare *et al.* 1991), they differ considerably from the variation found at Sanisera in terms of $\Delta^{13}C$. As Figure 7.20 shows, there was relatively little variation in $\delta^{13}C$, and, in the case of some individual faunal samples, even have higher $\delta^{15}N$.

From the data available, there are three reasonable interpretations. The first is that cattle products (meat, milk or cheese) contributed little to the diet of the individuals from Mérida as compared to Sanisera, and the human and fauna sampled subsisted on similar diets. The second is that the inclusion of marine fish in the diet of individuals from Sanisera is only truly reflected in the $\Delta^{13}C$ of the site. The third and final interpretation is that the $\delta^{13}C$ of these two sites is more reflective of the grains consumed, while the $\delta^{15}N$ is more a product of the protein consumed. With this in mind, it is possible that the fauna from Mérida was consuming small amounts of C_4 grains, while the humans did not and that the consumption of animal protein by the humans produced the increase in $\delta^{13}C$ that matched the values found in the fauna.

7.4.4.3 Meta-Data Comparison

7.4.4.3.1 Data Set and Sources

Similar to the Meta-Analysis in Chapter 6, the fauna included in this comparison are only the three most common domestic faunal species included in isotopic studies: *Bos taurus*, *Sus domestics*, and Ovicaprids, (hereafter referred to as their common names cattle, pig and sheep/goat, respectively) and only locations that had humans as well as at least one of the aforementioned faunal species. This narrowed the data set down to twenty-two locations, spread across ten countries

from Central Europe down through North Africa listed by study in Table 5.5. As before, outliers defined as a sample falling outside 1.5 times the interquartile range (1.5 × IQR) of a location and species, were removed from the data set. This left 1065 humans, 84 cattle, 76 pigs and 121 sheep/goats. Table 7.15 shows the mean and standard deviations for each species of the data set, while Figure 7.21 shows the samples included in this analysis divided by species.

Table 7.15: The mean $\delta^{13}C$ and $\delta^{15}N$ (± σ) for each species.

Species	n	$\delta^{13}C \pm \sigma$ (‰)	$\delta^{15}N \pm \sigma$ (‰)
Human	1065	-18.71 ± 1.11	10.14 ± 1.50
Cattle	84	-20.36 ± 1.56	6.29 ± 1.77
Pig	76	-20.66 ± 0.95	6.94 ± 2.05
Sheep/Goat	121	-19.95 ± 0.94	6.01 ± 1.98

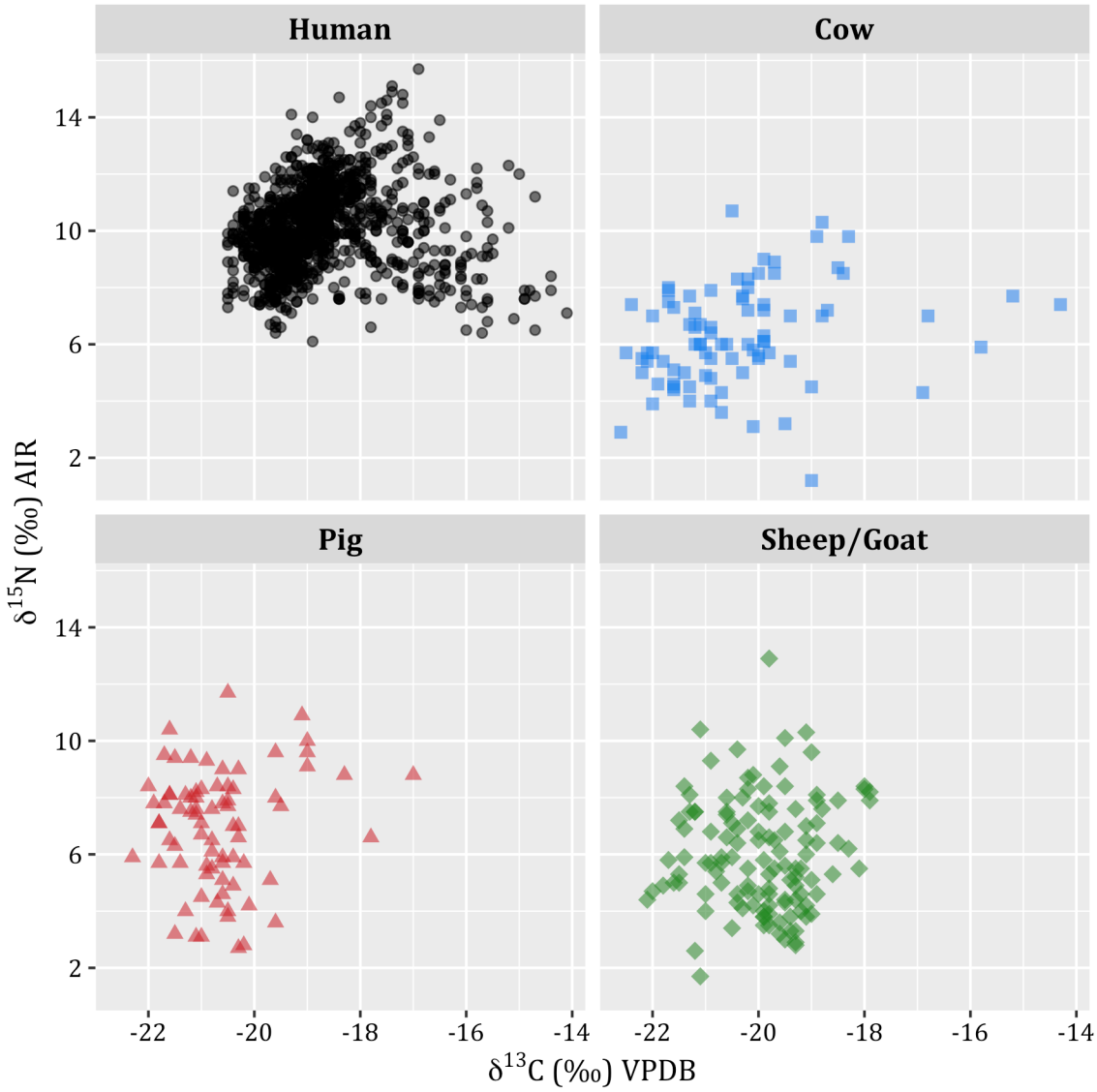


Figure 7.21: The $\delta^{13}C$ and $\delta^{15}N$ of the samples from the restricted Meta-Data set divided by species. Points are plotted at 75% opacity, to compensate for overlapping samples.

7.4.4.3.2 Human/Faunal Differences

Comparing human samples directly to fauna from a given area is one way to work around the effects that varying climates have on isotope values without having to include any new measurements and variables beyond the isotope values of the immediate study. This avoids some of the difficulties that a climate-based comparison, such as that found in van Klinken *et al.* 2002, encounters. For example, even present day climate data for remote areas can be difficult to procure and may be limited to the nearest weather station. This can create the situation in which one

weather station must be used for multiple sites in a given area, reducing both the sensitivity and utility of the adjusted results. The van Klinken *et al.* 2002 model relies entirely on a correlation between modern mean temperatures in July and isotopic values that strongly predate them. In this, it lacks means for replication, since it is completely dependent on the climatological data available at a given point in time and for a given site. If the latest available climate data is included, it will present an ever-changing data set as time progresses. In stark contrast, the methodology behind carbon and nitrogen isotope data in palaeodietary studies is held to strict standards, which require replication, and measures of precision and accuracy, features which climatological data do not possess.

A preferable basis to correct for environmentally-induced inter-site variability in palaeodietary reconstruction would be a variable which has a logical place in the path of causation producing the human isotopic values in question. Contemporary faunal isotopic values provide just such a data source. More importantly, comparing diets of past populations based on their contemporary faunal data can be applied to both carbon and nitrogen isotope values. Such a model provides the additional advantage of being based on data from a source, the consumption of which is also the ultimate goal of the analysis.

7.4.5 Faunal Correction Model

7.4.5.1 Model Application

The results of the application of this model to the human-faunal variation in the Meta-Data set discussed above is presented in the right panel of Figure 7.22 with the original data shown in the left panel. Initially, there would appear to be a reduction in the overall variability of the Faunal Corrected data set. The mean

isotope values for the original data set are $\delta^{13}C$: -18.7 ± 1.1‰ and $\delta^{15}N$: 10.1 ± 1.5‰ and the mean values for the corrected data set are $\delta^{13}C$: -18.5 ± 1.0‰ and $\delta^{15}N$: 10.4 ± 1.3‰. Not surprisingly, the two data sets are significantly different both

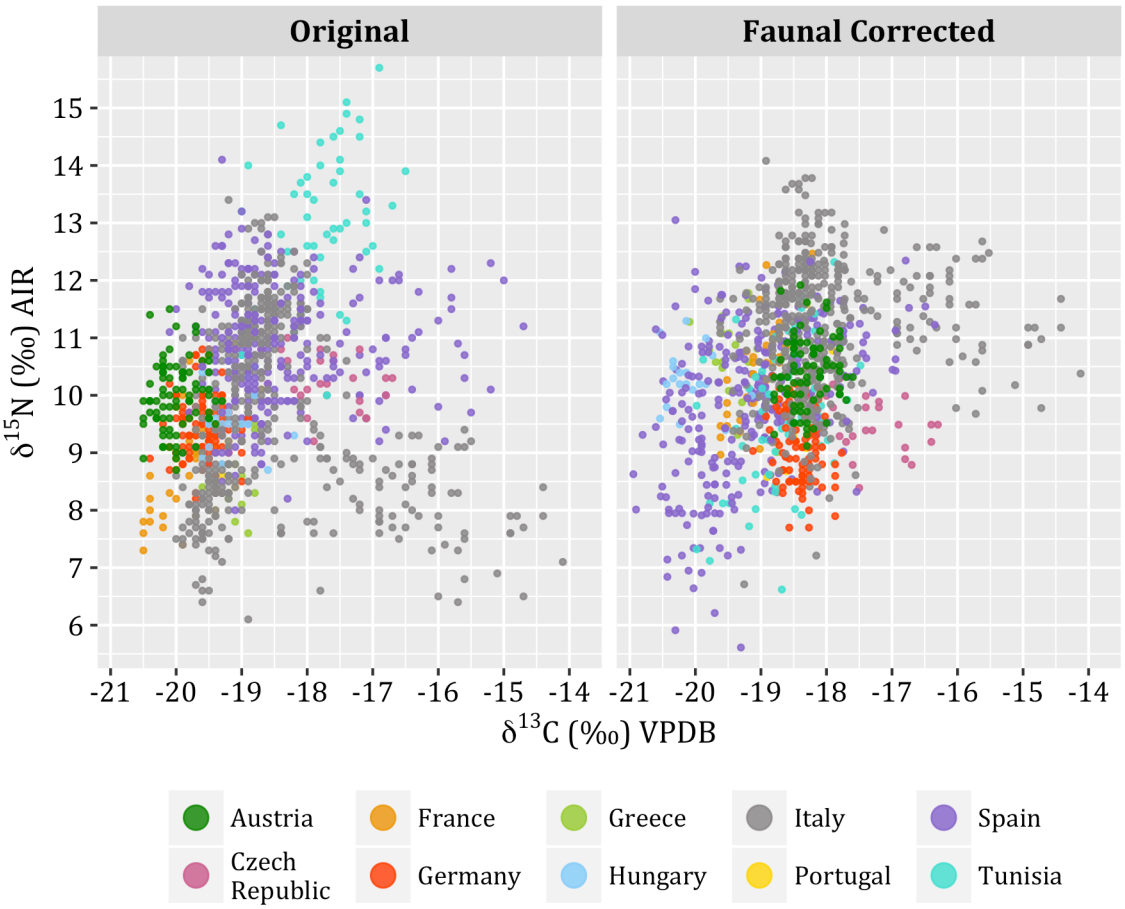


Figure 7.22: The Original and Faunal Corrected $\delta^{13}C$ and $\delta^{15}N$ values of the human samples from the Meta-Data set. The points are colored by country.

in terms of $\delta^{13}C$ and $\delta^{15}N$ (Mann-Whitney U test, p=0.00 for both). Upon closer inspection, it is clear that while the means may not be drastically different, the corrected data set lacks the high $\delta^{15}N$ values seen in the original data set, and has slightly more positive $\delta^{13}C$ values. Also of interest, is that the individuals with C_4 dietary influences, are no longer in the lower half of the overall $\delta^{15}N$ values in the corrected data. This would indicate that C_4 grains such as millet and sorghum were

consumed as part of a diet that also contained relatively high amounts of animal protein, which is not in keeping with the notion that C_4 grains were only consumed during times of famine or as a food of the poor.

7.4.5.1.1 Results by Climate Classification

A simple way to determine if the faunal correction model successfully minimizes variation due to climatological differences, is to plot the individuals by their Köppen-Geiger Climate Classification, using both their original values and their Faunal Corrected values as can be seen in the left and right panels of Figure 7.23.

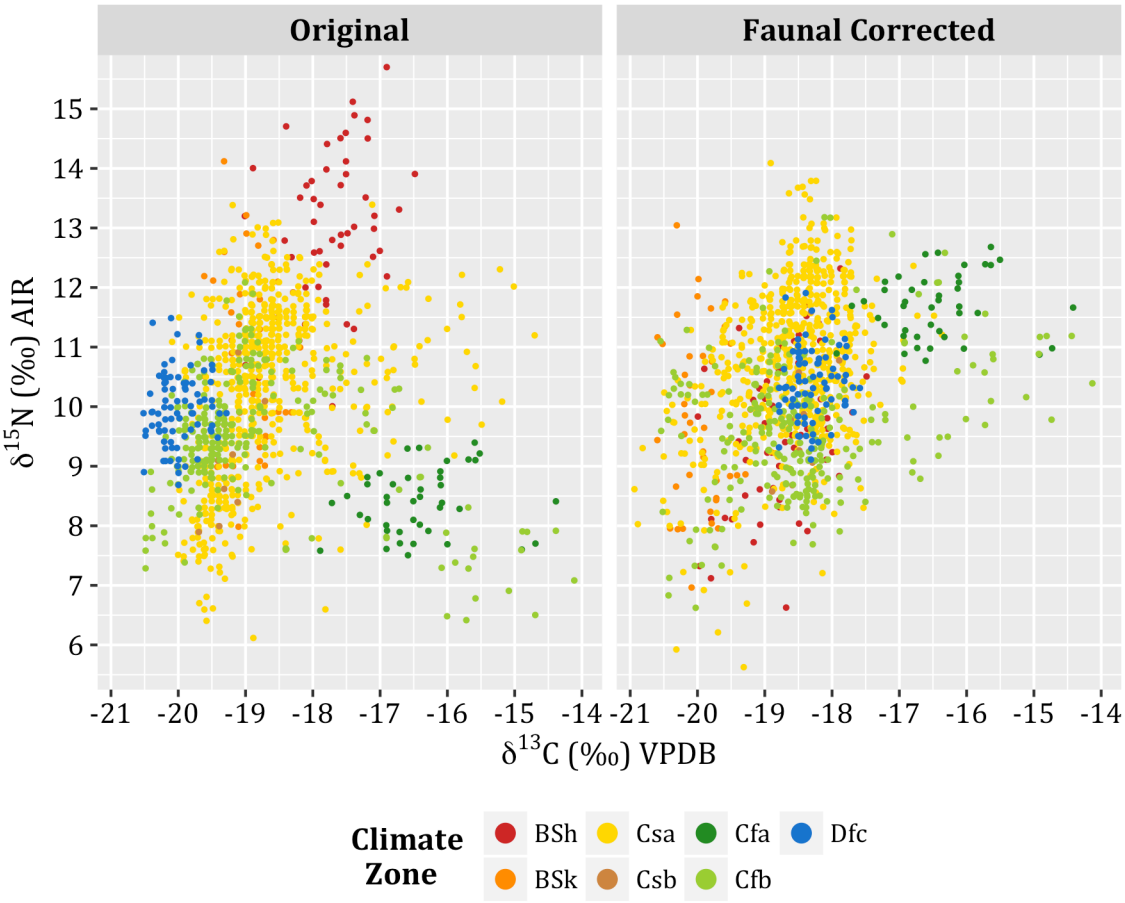


Figure 7.23: Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ divided by Köppen-Geiger Climate Classification.

When the faunal corrected data is plotted by climate classification, there are no longer the clear distinctions between the climate classifications, which are so obvious in the original data. This indicates that the correction does indeed help to

negate the effects of climate on stable carbon and nitrogen isotope ratios. The result is that variations seen between individuals and sample groups from different locations are more representative of dietary variation than they were prior to the correction. Thus, the isotopic effect differences in diet are no longer mixed with and masked by the effects of climate.

7.4.5.1.2 Results by Coastal versus Inland

Another comparison which can help assess the effectiveness of the Faunal Correction Model is a comparison of individuals located in coastal versus inland sites. The original and Faunal Corrected data can be seen in the top and bottom panels of Figure 7.24. Again, the Faunal Corrected data are less variable, but overall there is a similar division in the Faunal Corrected data as with the original data; with coastal populations having higher $\delta^{13}C$ and $\delta^{15}N$. An interesting consideration is that the inland sites have greater C_4 influences. Even excluding individuals from these sites, there is still a substantial amount of overlap between those living by the coast and those living farther inland. This is be expected, because while coastal versus inland is a binary variable, the diets of those falling into these categories would not have been. A coastal individual would likely not have subsisted on solely marine foods, and those living inland may have had access to fish from lakes and rivers. The majority of the dietary input at any coastal site was clearly terrestrial. While this was statistically the case with the original data (the coastal and inland groups were not statistically different), it is clearly the case with the Faunal Corrected data. The access to marine resources means that there is a greater possibility of higher $\delta^{13}C$ and $\delta^{15}N$ values, though as a group, the coastal population is more similar to the inland population than it is different.

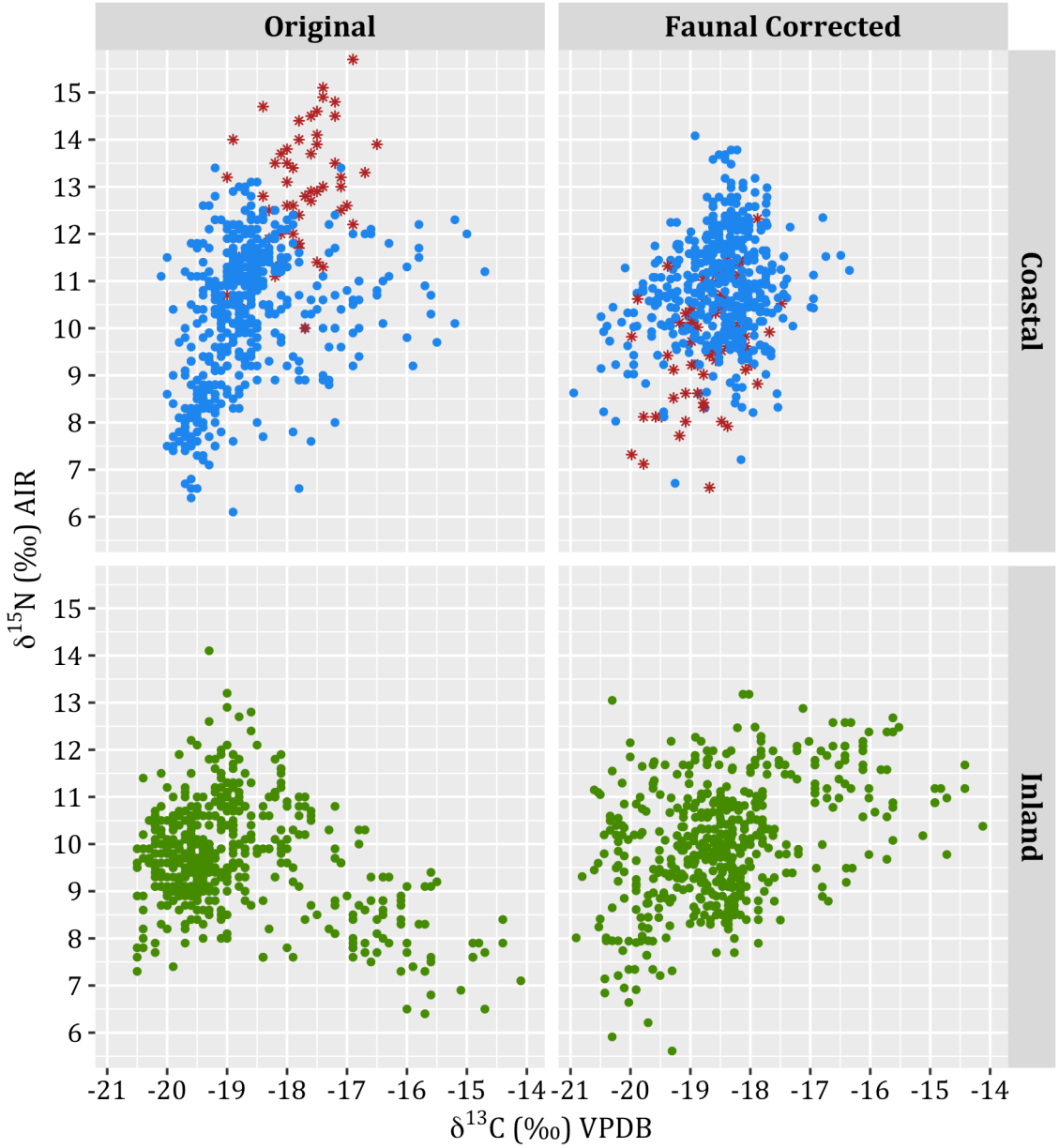


Figure 7.24: Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ divided by the distance an individual lived to the coast by within ten kilometers of the coast (Coastal) versus farther inland (Inland). The red points indicate individuals from the site of Leptiminus.

7.4.5.1.3 Results by Time Period

The Faunal Corrected data plotted next to the original data and grouped by time period can be seen in Figure 7.25. The figure shows that the Faunal Corrected results, when divided by time period, paints the same picture as the original data. There is also a clear indication that C_4 grains were introduced as a dietary staple, for

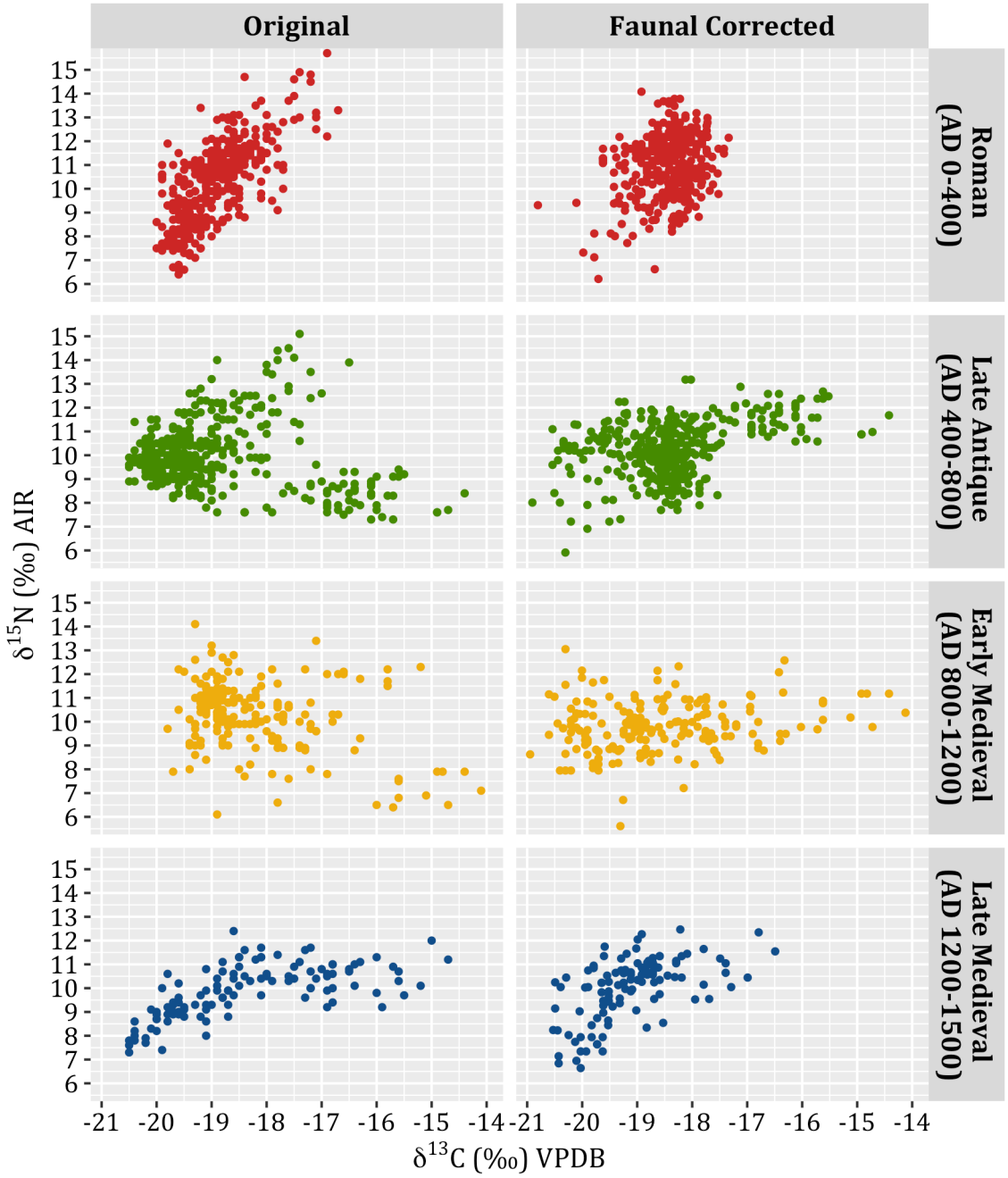


Figure 7.25: Original and Faunal Corrected plots of $\delta^{13}C$ and $\delta^{15}N$ faceted by Time Period.

some populations during the Late Antique Period, and that this practice became more common in the Early Medieval period. Also, the high carbon, low nitrogen values seen in the uncorrected data for these same two periods were adjusted in the corrected data to reflect a C_4 diet with high N values suggestive of a higher proportion of meat as well.

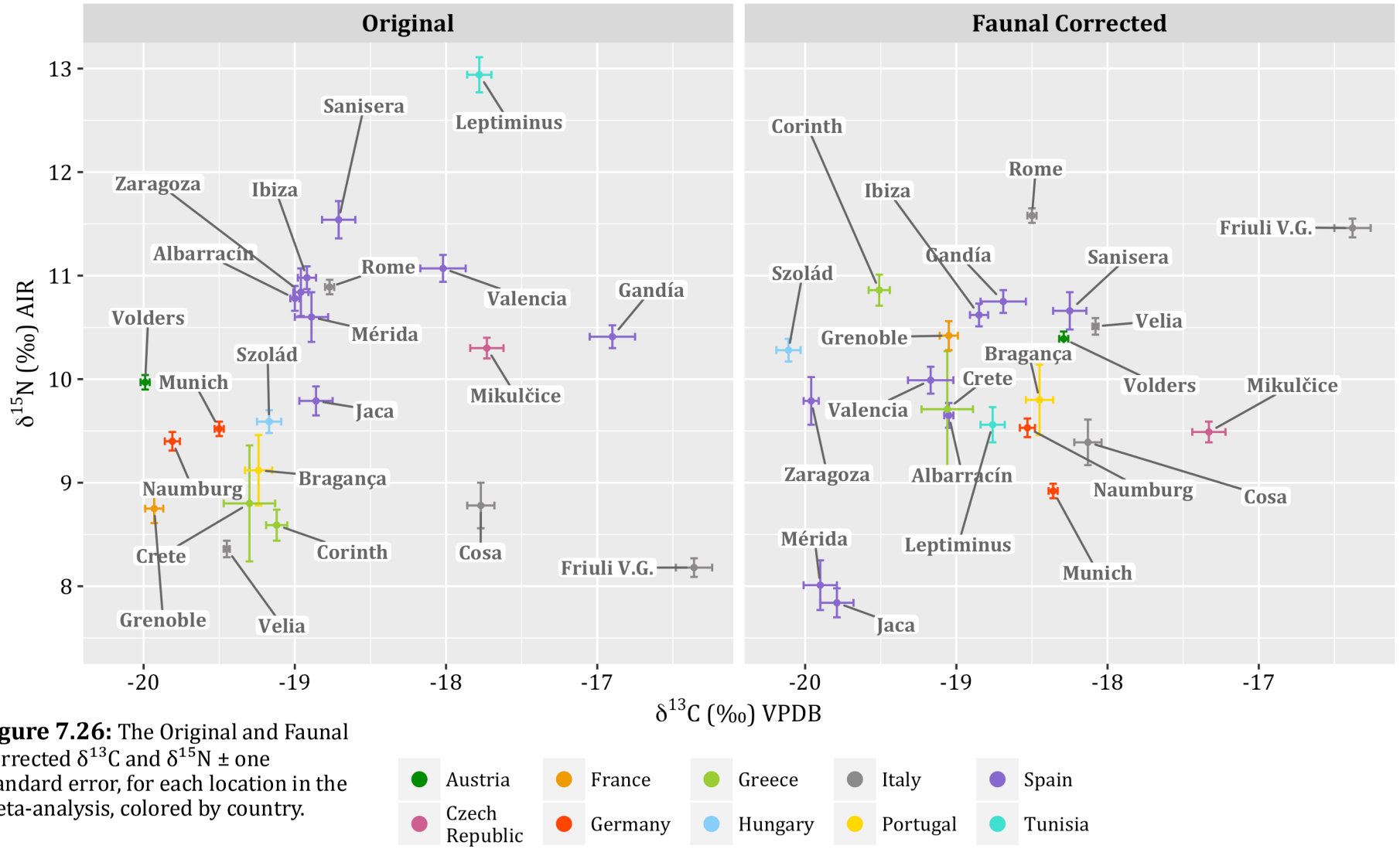


Figure 7.26: The Original and Faunal Corrected $\delta^{13}C$ and $\delta^{15}N$ ± one standard error, for each location in the meta-analysis, colored by country.

7.4.5.1.4 Results by Location

When the Faunal Corrected sites were plotted along side their original values (see Figure 7.26), it became clear how the Faunal Correction model leads to a drastically different interpretation of the inter-site comparisons. The sites with considerable C_4 contributions (Friuli V.G. and Mikulčice) are still apparent with their elevated $\delta^{13}C$ values, while the site of Leptiminus, that was once thought to have had considerable marine consumption, now has relatively average $\delta^{13}C$ and $\delta^{15}N$ values. Individuals from Rome (the capital of the Empire for much of this time period) have the highest mean $\delta^{15}N$ (11.58 ± 1.01‰) and a $\delta^{13}C$ of (-18.50 ± 0.44‰), an indication that there was a significant contribution of marine resources to their diets, but also that it was mainly a diet based on terrestrial C_3 grains and meats. This is the case for the majority of the sites included in this analysis; however, the higher mean $\delta^{13}C$ and $\delta^{15}N$ values for Rome indicates that those individuals consumed more fish and animal protein than individuals from other locations.

The Balearic locations (Sanisera and Ibiza) along with the Spanish location of Gandía and the Italian location of Velia also had relatively high mean $\delta^{13}C$ and $\delta^{15}N$ values. As these are all coastal locations, these results are most likely due to the contribution of more marine resources in their diet. The locations of Volders and Grenoble (in Austria and France, respectively) have similarly high mean $\delta^{15}N$ values, though their inland location means that their isotope values were more likely due to freshwater fish consumption, or an elevated consumption of animal protein.

At the other end of the spectrum, the sites of Mérida and Jaca have the lowest mean $\delta^{13}C$ and $\delta^{15}N$ values, Mérida with a $\delta^{13}C$ of -19.90 ± 0.51 and a $\delta^{15}N$ of 8.01 ± 1.13 and Jaca with a $\delta^{13}C$ of -19.79 ± 0.49 and a $\delta^{15}N$ of 7.84 ± 0.62. Neither of these values are that low overall, and both indicate a terrestrial C_3-based diet of grains and

meats. However, when compared to the other sites in this analysis, it is clear that they were not consuming as much of the fauna (that was sampled) as individuals from other sites. For Mérida, this may be corrected when more faunal samples become available to be included in the study. Particularly, if those faunal samples are from sites more centrally located in the city. The same may be said for Jaca, as the faunal samples from this location are not from the same site as the human remains.

Overall, this new model of correcting isotopic data, using faunal samples from similar locations, has provided a new method of conducting inter-site comparisons. The Faunal Correction Model has been shown to help eliminate the effect of climate on both $\delta^{13}C$ and $\delta^{15}N$ values, making analysis of these values more revealing with regard to variations diet. It has also made it clear the extent to which uncorrected data can be determined by location and climate. The advantage of the Faunal Correction Model is not based in its mathematical sophistication, rather in its logical correspondence to the causative events of interest to palaeodietary reconstruction. As such, it should lead to more productive questions and hypotheses about the relationship between past human diets in the future.

Chapter 8: Conclusion

Analyses of stable carbon and nitrogen isotopes of bone and tooth collagen has played an increasing role in archeological studies. Isotopic data, while subject to an objective analysis in the measurement of the isotope levels in samples is, nevertheless, subject to considerable interpretation due to a variety of factors which are likely to face any archeological study. Starting with the results of an isotopic analysis of samples from two Late Antique sites in Spain (Sanisera in Menorca and Mérida in central Spain) an investigation was conducted to reconstruct the likely diet and to integrate these results with other isotopic studies in the European and North African regions.

The isotopic data from sites such as Sanisera and Mérida are likely to cover a considerable span of time which can include substantial economic, political, and social change. In addition, depending on the precise tissue sampled, the isotope will reflect the diet during a specific portion of that individual's life. Finally, changes in the isotopic data may also be subject to multiple interpretations due to environmental factors influencing the preservation of the samples at the site, the influence of climate on the presence of isotopes in the environment, as well as the impact of the dietary changes which are the goal of the study.

Previous studies have used isotopic data in addition to other information made available by an anatomical examination of the remains (e.g., sex, age, evidence of disease, and cause of death) and other archeological evidence (e.g., grave goods, method of interment, and historical records) to develop a theory as to the diet, status, and community in which the individual may have lived. However, these analyses are generally confined to intra-site comparisons due to the lack of an

accepted means of controlling for the effects of factors that may vary between sites, including variations in methodology, samples selected for collection, and any number of other choices made by different archeologists. The drawback of this single site analysis methodology is that as the limited number of samples at any single site are successively divided by factors such as time of death, age at death, sex, and isotopic values, to name just a few; the number of samples in each category diminishes to such a point that only the most tentative conclusions can be drawn. Being able to draw samples from a considerably larger pool is, therefore, advantageous to drawing conclusions.

8.1 Sanisera and Mérida

Human and faunal samples from Sanisera and Mérida provided the primary data for this study. Both are Late Antique sites, Sanisera is located on the island of Menorca and Mérida, an inland site, located in central Spain. The isotopic results from these sites suggested a diet dominated by terrestrial C_3-based grains that was occasionally supplemented with marine and animal resources. These data are typical for both the region and time periods.

Comparisons with other sites are subject to qualifications which make the integration of these results into a greater archeological picture difficult. Even comparisons between the two sites in this single study are subject to many of these limitations. In spite of this, it is possible to draw conclusions about the two sites. In addition, a comparison of the Sanisera and Mérida data to that from nearby, contemporary sites highlights both the implications of inter-site differences, and strengthens conclusions supported by inter-site similarities. These inter-site comparisons allow consideration of cultural influences, in particular, with other

contemporary Roman and African sites. In general, the carbon and nitrogen isotope values suggest that the individuals consumed a terrestrially-based C_3 diet supplemented with animal and marine protein. There was only occasional evidence of the consumption of C_4 grains in certain individuals.

8.2 Meta-Analysis

To place these results into a greater context, data from fifty-three other contemporary sites in the Mediterranean and continental Europe were assembled into a data set consisting of roughly one thousand individuals and three hundred fauna. With the greater number of locations came the ability to consider the effects of climate and geography on the isotopic data. Typical studies, which consider only the primary data at hand, cannot adequately consider the implications of these variables from their more limited data set. The accumulation of an increased number of isotopic studies, greatly increases the potential benefit of comparing the collected data to gain a more comprehensive picture of how ancient diets changed with time, location, and the development of human culture.

The purpose of this expanded data set was to allow an investigation into potential methods for integrating individual site data into a more comprehensive picture of diet taken over a broader geographic region and time period. As with Sanisera and Mérida and the nearby contemporary sites previously mentioned, the diet at the majority of locations consisted terrestrial C_3-based diets with variable amounts of meat, fish, and C_4 plants. Nevertheless, some sites stood out from the rest with regard to their isotopic data. In particular, Friuli Venezia Giulia in Italy with its exceptionally high $\delta^{13}C$ values and relatively low $\delta^{15}N$ was attributed to a C_4-

based diet (Iacumin et al. 2014), and Leptiminus, in Tunisia, with its high $\delta^{15}N$ values, has been suggested as indicative of increased marine diet.

Analysis of the Meta-Data set by time period, latitude, climate zone, and coastal versus inland location clearly demonstrated the influence of local environment on isotopic values and also suggested the presence of changes in human diet such as an increase in the contribution of C_4 plants to human diet in Early Medieval to Late Medieval periods as compared to the preceding Roman and Late Antique periods. The limited conclusions, which can be drawn from such a large data set, is somewhat disappointing as the number of significant covariates makes the conclusions either highly qualified or couched in a nest of qualifying statements. This dilemma is clearly the motivation for van Klinken et al.'s 2002 climate correction model for carbon isotopic values. However, being limited to carbon values and based on a correlation, the van Klinken model cannot be as productive as an alternative model more closely based on the causative chain which ultimately determines the observed isotopic data.

Fortunately, there are already data in the Meta-Data set and in the data collected by many isotopic studies which incorporates these features. At many sites, faunal remains were also found which were contemporary with the humans remains. The isotopic values in these faunal remains were subject to the same climate and environmental conditions which previously confounded efforts to make sense of the human data. In addition, because the faunal data was gathered and analyzed by the same procedures which were used with the human samples, they incorporate the same precision and biases which characterize a given study's human data collection methodology. Finally, unlike van Klinken et al.'s 2002 carbon only

correction model, the use of faunal isotopic data to control for environmental effects can be applied to both carbon and nitrogen.

The simplest implementation of this idea is to use the difference between the human and faunal data to make intra-site comparisons. This method, however, must be rejected since its output would no longer conform to the accepted range of isotopic values.

A slightly more complex method was proposed, the application of which preserves the accepted isotopic data ranges. Briefly, starting with the isotopic data from a single site, a site faunal mean for nitrogen and carbon was constructed. This value was subtracted from the corresponding nitrogen and carbon values for each human sample. Then, a Faunal Standard value was constructed from the collected sites' faunal means. Finally, the Faunal Standard value was added to the previously computed difference between each site's human data and each site's faunal mean. In effect, the faunal value of each site was replaced with the mean of all the sites' faunal means. This insured that the corrected data retained the expected isotopic ranges; an important feature for further comparisons.

What results should a correction such as this produce? First, since its purpose is to remove variability in inter-site comparisons, the variability of the resulting corrected inter-site data set should be reduced. This may be most powerfully evidenced by the movement of some otherwise outlying site data into a position more reflective of a typical site. Second, plots of the corrected data set should more closely conform to the expected dietary classes of herbivore, omnivore, and carnivore of the theoretical model shown in Figure 7.22. Finally, a comparative analysis of the uncorrected and the corrected data, in terms of climate, should show

that evidence of variation due to climate in the uncorrected data is minimized in the corrected data (See Figure 7.23 for an example).

The Faunal Correction Model has a final attribute which van Klinken's correlation model lacks. The faunal data, which is the basis of the correction, are part of the diet of the humans, and therefore, direct contributors to the human isotopic data; hypotheses about diet can be expressed as alternative constructions of the faunal correction applied to address specific questions. For example, if it is suspected that certain faunal species contributed more or less to the human diet, then computation of the site's faunal mean or even the Faunal Standard could be adjusted to allow observation of the impact of this change on the resulting corrected data.

A final step was to assess the impact of the Faunal Correction on the current Meta-Data set. While this analysis is presented in detail in Chapter 7, it is summarized here. Unless noted otherwise, comments refer to the relationship depicted in a plot of carbon and nitrogen isotope ratios. As a surrogate for geographic location, a site's modern national location provides a convenient basis for a geographic comparison. This analysis is shown in Figure 7.26. The corrected data is less variable and is more readily interpreted in terms of the standard theoretical model. The same result is evident in the comparison based on climate zone (see Figure 7.23). In this figure, the impact of climate zone is greatly reduced. Similar results are seen when the data are analyzed by coastal versus inland location, time period, and location. One feature, which is consistently preserved, is the individuals which appear to have a significant C_4 component to their diet, but appear to have a low trophic level in the uncorrected data. This would suggest a diet "synonymous with poverty and famine" (Adamson 2013; 8) in which the preferred

C_3 grains were unavailable. After the Faunal Correction is applied, these individuals have a significantly higher $\delta^{15}N$ values, which is evidence of the consumption of meat and a voluntary shift to C_4 grains rather than a shift due to necessity.

8.3 Future Research

The Faunal Correction Model is not without its faults though. This project is merely a starting point for furthering the understanding and interpretation of palaeodietary reconstruction using stable carbon and nitrogen isotope analysis. Where the model most noticeably falls short is in the interpretation of C_4 consumption, specifically when both human and faunal samples from a site are consuming C_4 grains. The enriched $\delta^{13}C$ values of both the human and fauna cancel each other out, leading to individuals having corrected values ($\delta^{13}C_F$) that reflect the faunal consumption rather than the grain consumption. Manners in which this problem could be addressed are the inclusion of wild fauna, the inclusion of grain samples, both C_3 and C_4, and the tempering of the weight given to domestic faunal samples in the formula.

With the majority of the Roman to Medieval diet consisting of grains (Rickman 1980, Garnsey 1983, White 1988, Killgrove 2010), the Faunal Correction Model likely places too much emphasis on the faunal samples of a site. Future development of this model will need to work at developing a better method for representing relative contribution to dietary input. This may be done by multiplying the Faunal Site Mean by the percentage of the diet that fauna have likely contributed to the diet, or by including grains in the calculation of the correction factor, or possibly both.

The Faunal Correction overcomes much of the complexity of interrupting isotopic data to assess the diet of Roman to Late Medieval period sites in Europe and the Mediterranean. Though dietary variations still exist in the locations and temporal periods considered, the overall data set is less variable and better conforms to the standard theoretical model which relates stable carbon and nitrogen isotope values to diet. Furthermore, it is a model which itself depends on isotopic data, that of local fauna and, as such, lends itself to the generation and testing of hypotheses concerning diet. While work is still needed to improve the model, it is clearly a tool that will aid the interpretation of inter-site comparisons and add to the usefulness of stable carbon and nitrogen isotope analysis as a means of palaeodietary reconstruction.

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Appendix A: Materials Catalogue

A.1: Sanisera Human

S-7

Zone: 2
Context Number: 2221
Tomb: 12
Sampled: Mandible and Lower Right Second Molar



S-9

Zone: 2
Context Number: 2221
Tomb: 12
Sampled: Mandible and Lower Right Second Molar



S-10

Zone: 2
Context Number: 2221
Tomb: 12
Sampled: Lower Right Second Molar



S-11

Zone: 2
Context Number: 2221
Tomb: 12
Sampled: Lower Right Second Molar



S-15

Zone: 2
Context Number: 2312
Tomb: 28
Sampled: Lower Left Second Molar



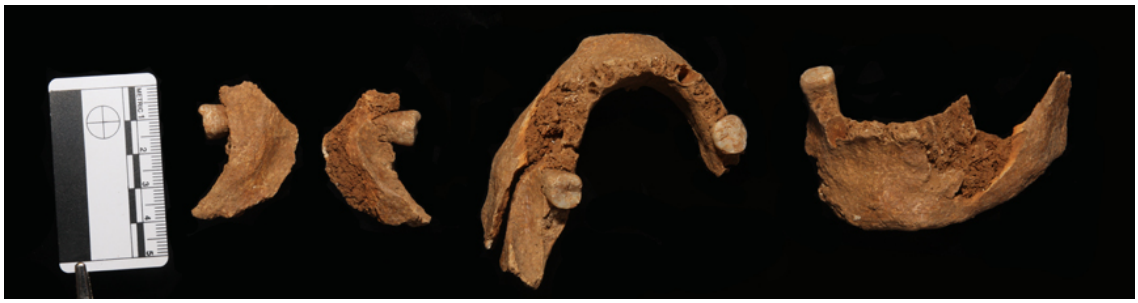
S-16

Zone: 2
Context Number: 2302
Tomb: 28
Sampled: Lower Left Second Molar



S-18

Zone: 2
Context Number: 2313
Tomb: 28
Sampled: Mandible and Lower Left Second Molar



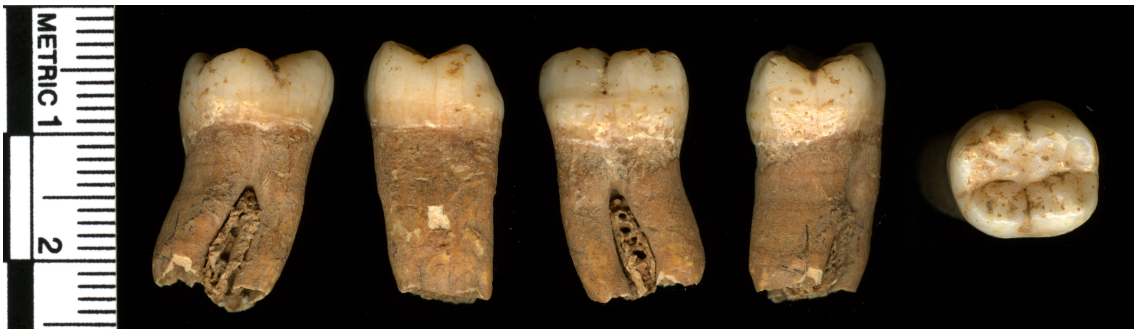
S-21 B

Zone: 2
Context Number: 2313
Tomb: 28
Sampled: Lower Left Second Molar



S-26

Zone: 2
Context Number: 2233
Tomb: 13
Sampled: Lower Left Second Molar



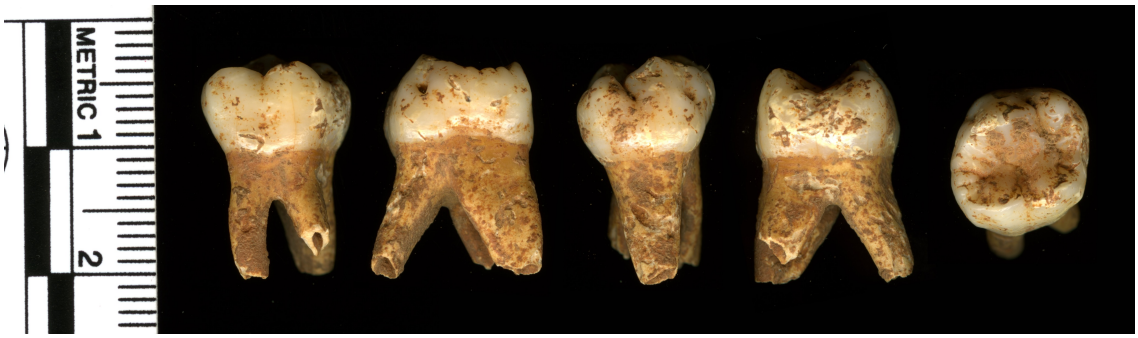
S-29

Zone: 1
Context Number: 2333
Tomb: 33
Sampled: Mandible and Lower Left Second Molar



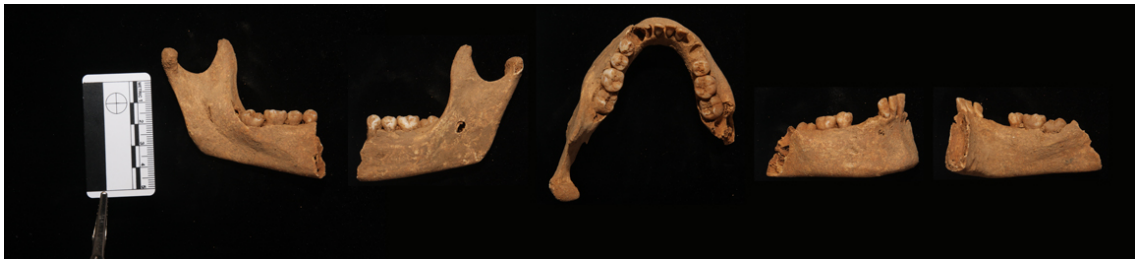
S-31

Zone: 2
Context Number: 2311
Tomb: 23
Sampled: Upper Right Second Molar



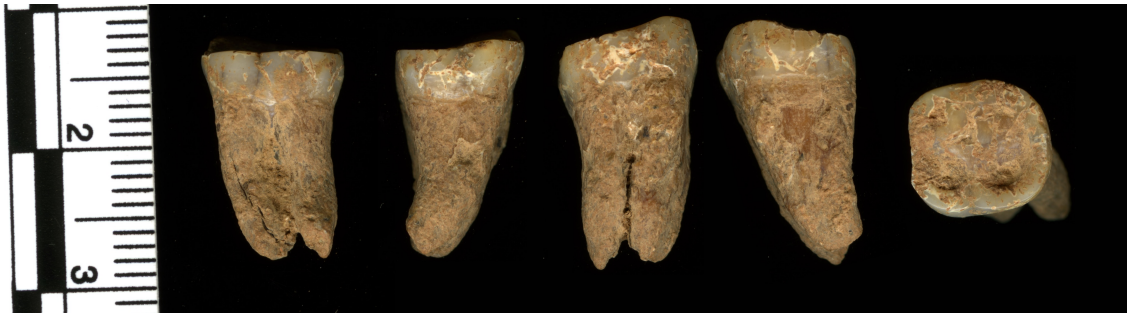
S-32

Zone: 2
Context Number: 2304
Tomb: 30
Sampled: Mandible and Lower Left Second Molar



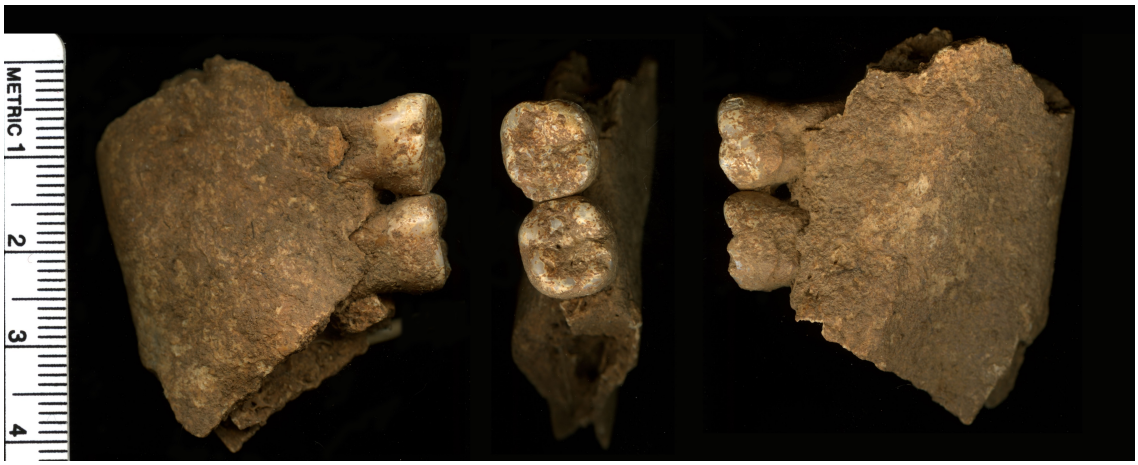
S-35

Zone: 1
Context Number: 2327
Tomb: 31
Sampled: Lower Left Second Molar



S-38

Zone: 1
Context Number: 2327
Tomb: 31
Sampled: Mandible and Lower Left Second Molar



S-40

Zone: 1
Context Number: 2336
Tomb: 26
Sampled: Maxilla and Upper Right Second Molar



S-43

Zone: 1
Context Number: 2347
Tomb: 26
Sampled: Maxilla and Upper Right Second Molar



S-52

Zone: 2
Context Number: 2252
Tomb: 16
Sampled: Lower Left Second Molar



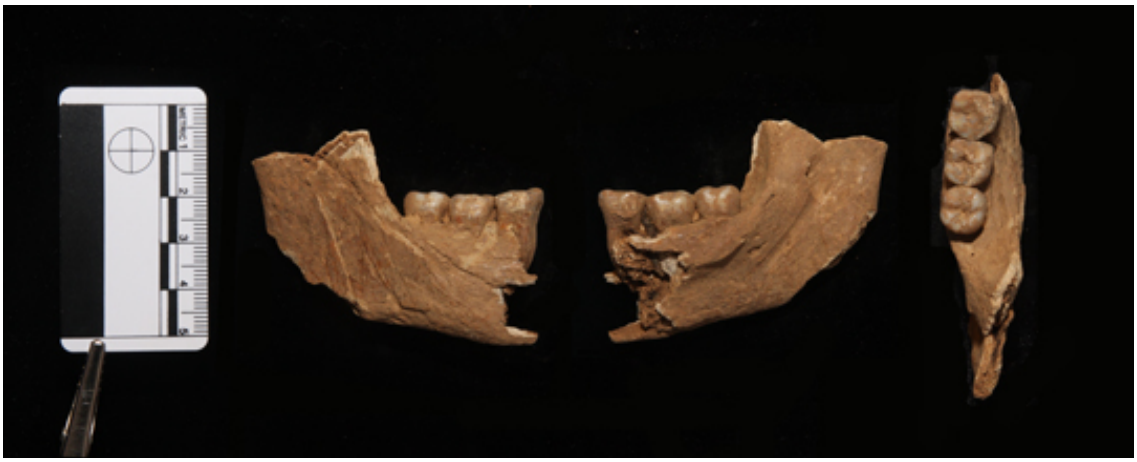
S-58

Zone: 2
Context Number: 2267
Tomb: 15
Sampled: Lower Right Second Molar



S-60

Zone: 2
Context Number: 2249
Tomb: 15
Sampled: Mandible and Lower Right Second Molar



S-61

Zone: 2
Context Number: 2268
Tomb: 15
Sampled: Mandible and Lower Right Second Molar



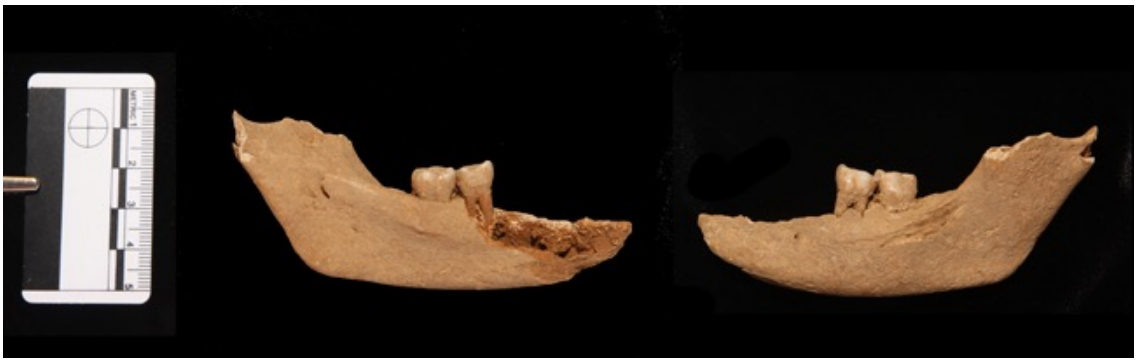
S-62

Zone: 2
Context Number: 2249
Tomb: 15
Sampled: Mandible and Lower Right Second Molar



S-63

Zone: 2
Context Number: 2240
Tomb: 17
Sampled: Mandible and Lower Right Second Molar



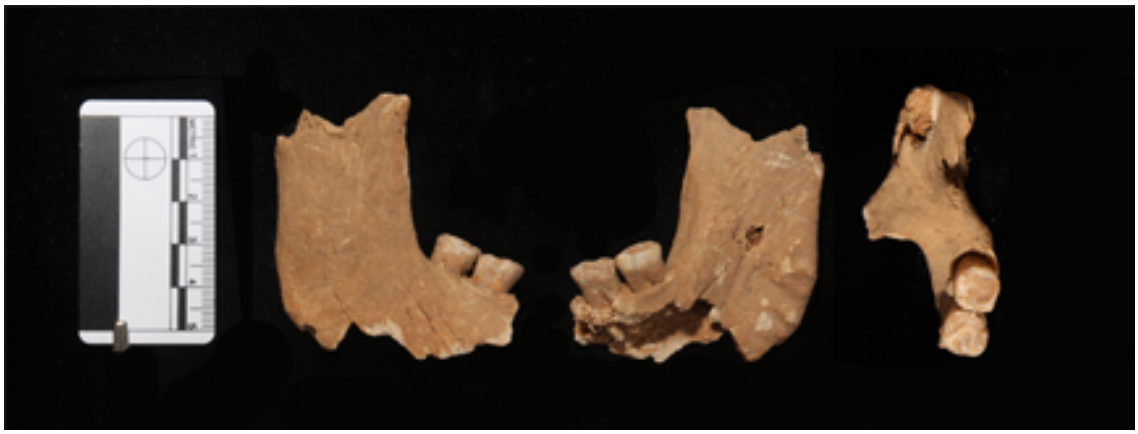
S-64

Zone: 2
Context Number: 2240
Tomb: 17
Sampled: Mandible and Lower Right Second Molar



S-70

Zone: 2
Context Number: 2210
Tomb: 10
Sampled: Mandible and Lower Right Second Molar



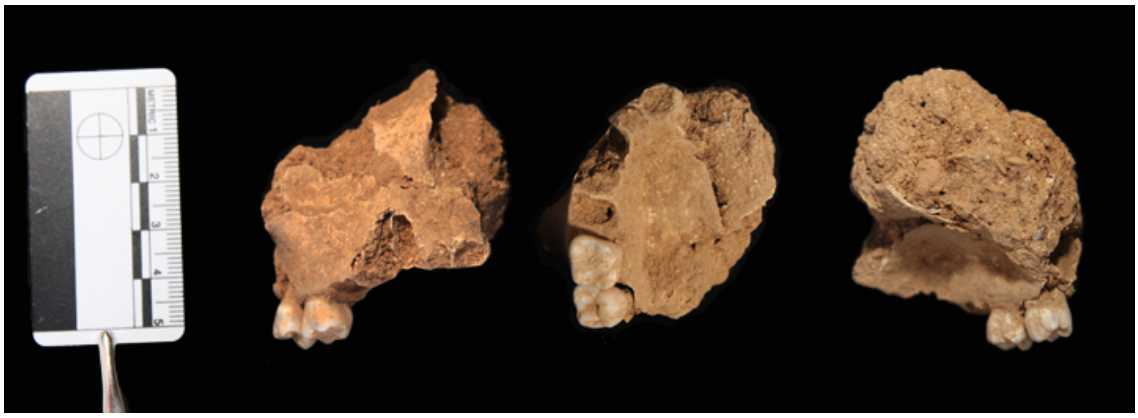
S-71

Zone: 2
Context Number: 2210
Tomb: 10
Sampled: Mandible and Lower Right Second Molar



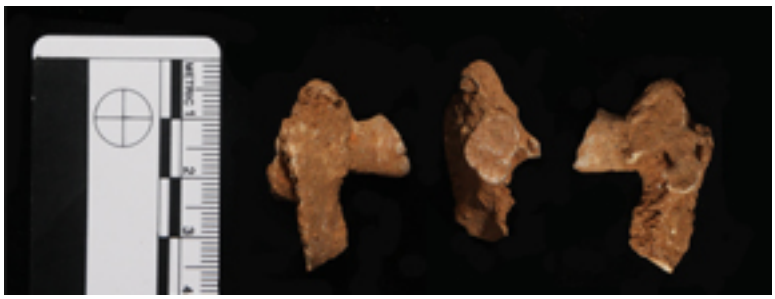
S-80

Zone: 2
Context Number: 2081
Tomb: 8
Sampled: Maxilla and Upper Left Third Molar



S-81

Zone: 2
Context Number: 2209
Tomb: 11
Sampled: Mandible and Lower Right Second Molar



S-86

Zone: 2
Context Number: 2070
Tomb: 9
Sampled: Mandible and Lower Right Second Molar



S-98

Zone: 1
Context Number: 2011
Tomb: 6
Sampled: Lower Right Second Molar



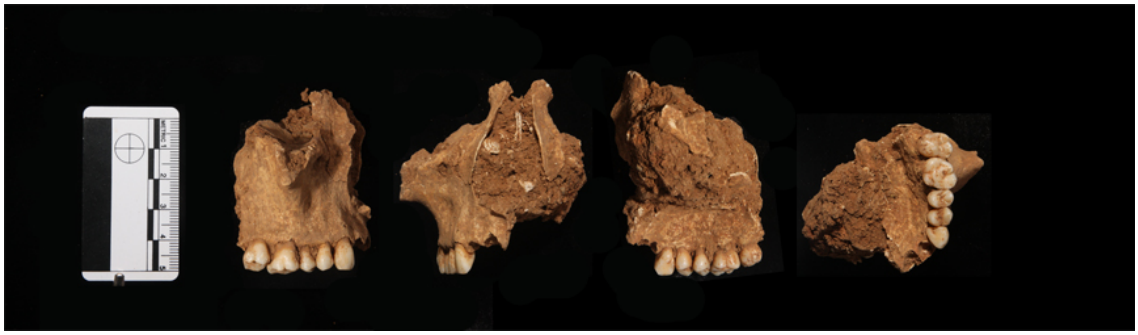
S-103

Zone: 1
Context Number: 2013
Tomb: 3
Sampled: Lower Right Third Molar



S-106

Zone: 1
Context Number: 2009
Tomb: 5
Sampled: Maxilla and Upper Right Second Molar



S-107

Zone: 1
Context Number: 2009
Tomb: 3
Sampled: Lower Right Third Molar



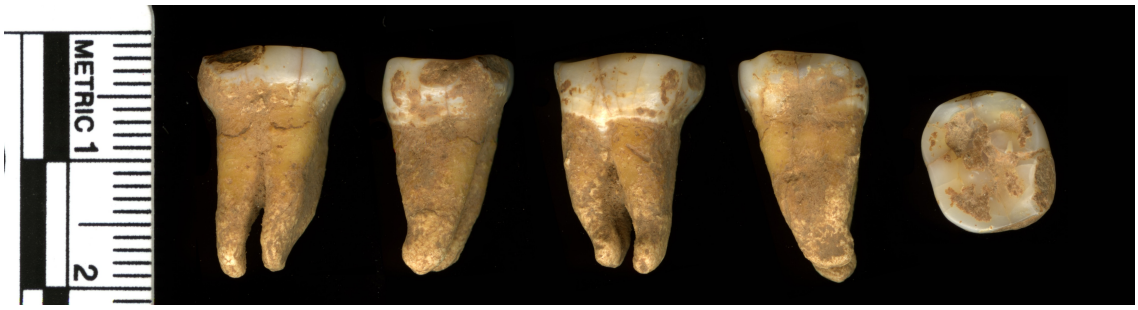
S-114A

Zone: 1
Context Number: 2010
Tomb: 1
Sampled: Lower Left Second Molar



S-114B

Zone: 1
Context Number: 2010
Tomb: 1
Sampled: Lower Left Second Molar



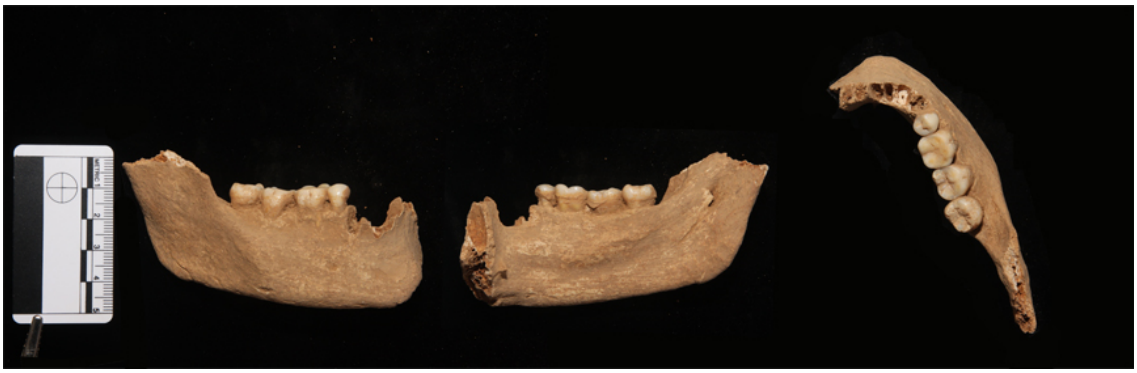
S-115

Zone: 1
Context Number: 2010
Tomb: 1
Sampled: Lower Left Second Molar



S-119

Zone: 1
Context Number: 2011
Tomb: 6
Sampled: Mandible and Lower Right Second Molar



A.2: Mérida Human

140

Site: Nova Romana (1021)
Tomb: 32

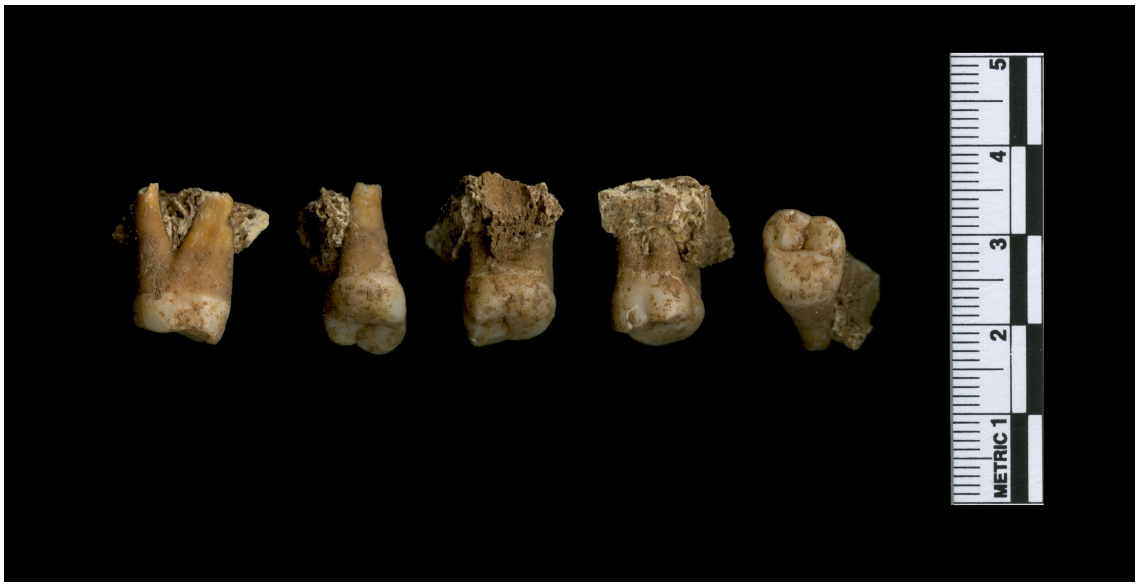
Sampled: Mandible, Lower Left First Molar, Lower Left Second Molar and Lower Left Third Molar



141

Site: Nova Romana (1021)
Tomb: 33

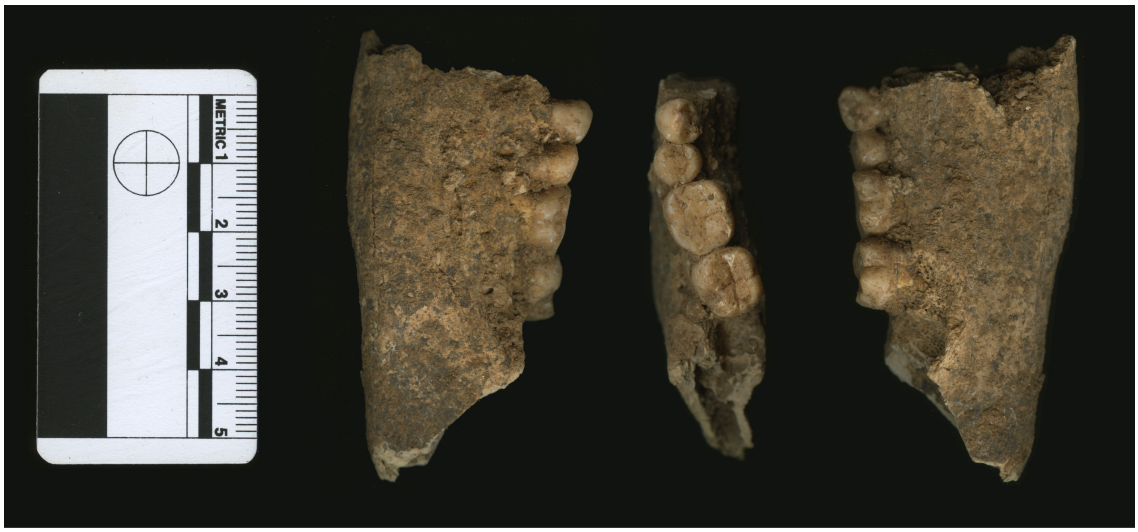
Sampled: Maxilla and Upper Left Second Molar



149

Site: Nova Romana (1021)
Tomb: 35

Sampled: Mandible, Lower Right First Molar and Lower Right Second Molar



16

Site: Nova Romana III (7017)
Tomb: 3

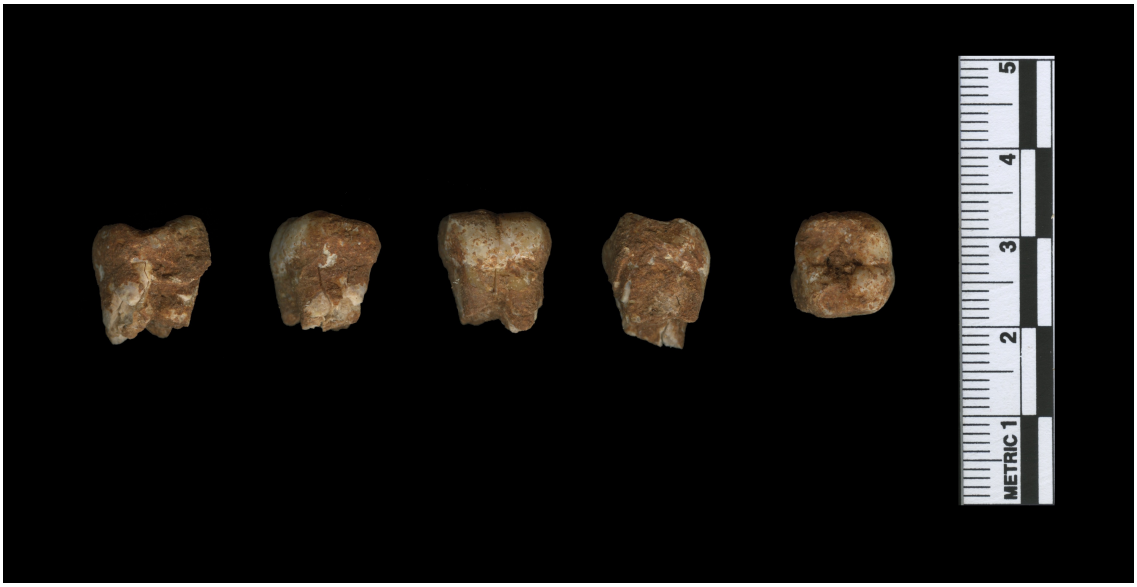
Sampled: Lower Right Third Molar



25

Site: Nova Romana III (7017)
Tomb: 6

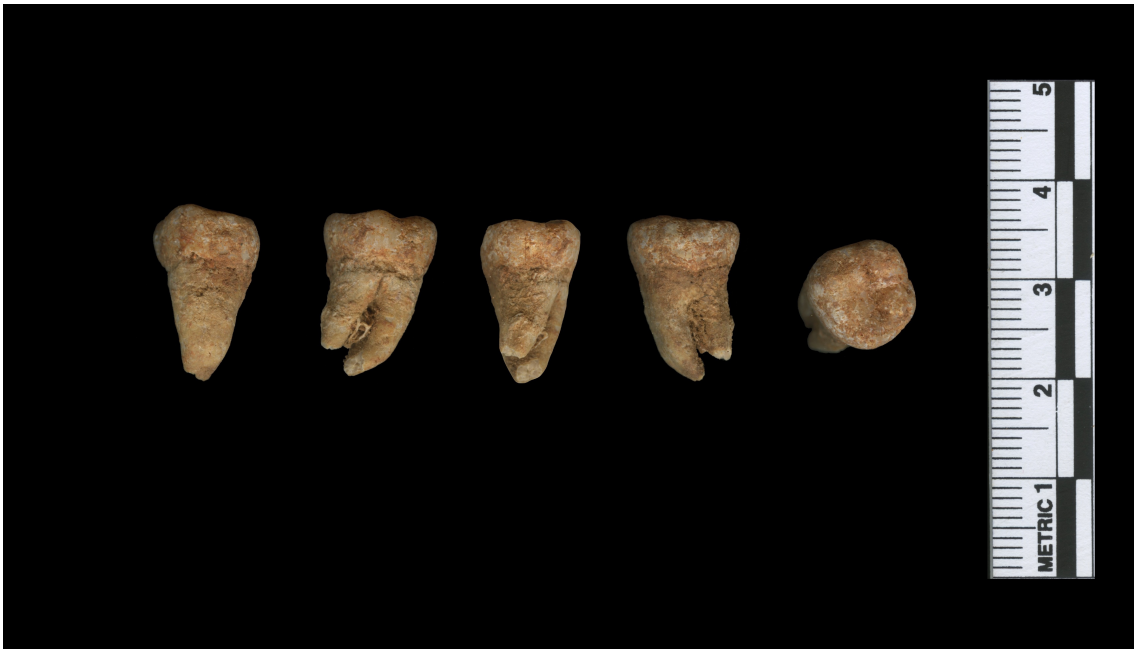
Sampled: Mandible and Lower Left Second Molar



69

Site: Nova Romana III (7017)
Tomb: 20

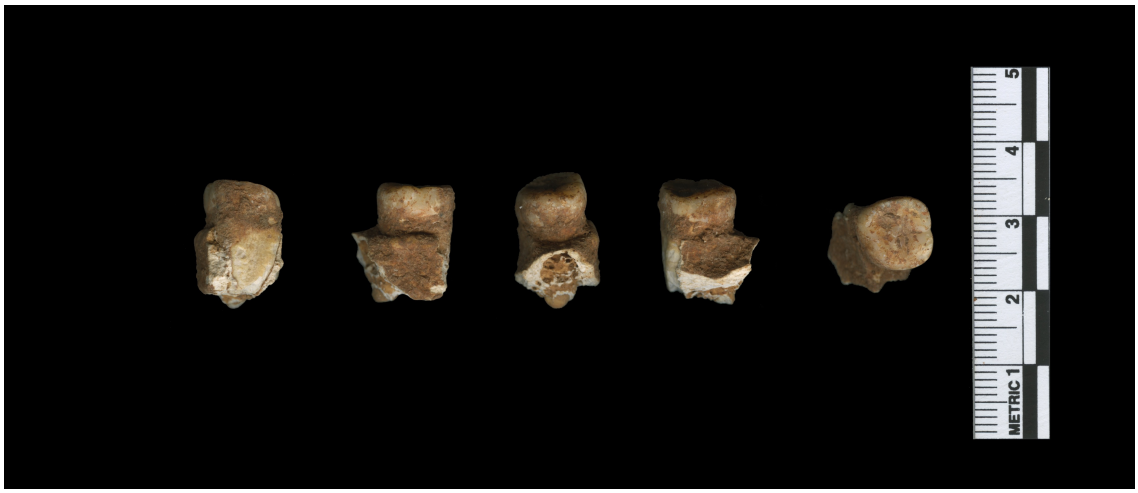
Sampled: Lower Right Second Molar



84

Site: Nova Romana III (7017)
Tomb: 58

Sampled: Mandible and Lower Left Third Molar



96

Site: Nova Romana III (7017)
Tomb: 28

Sampled: Lower Right First Molar (not pictured) and Lower Right Second Molar



103

Site: Nova Romana III (7017)
Tomb: 32

Sampled: Upper Left Second Molar



103

Site: Nova Romana III (7017)
Tomb: 32

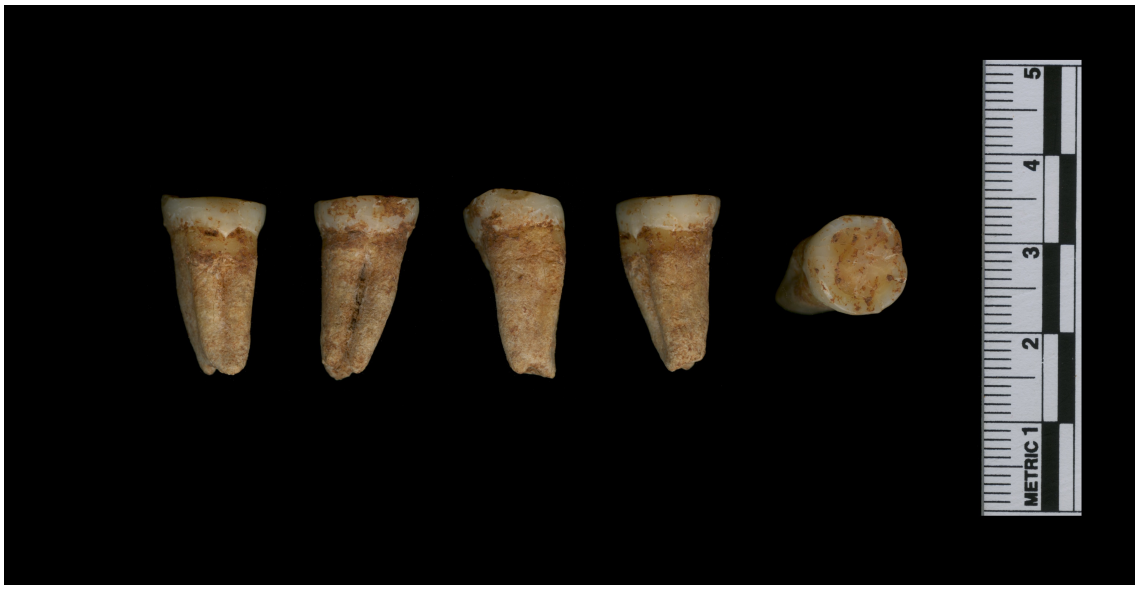
Sampled: Upper Left Second Molar



107

Site: Nova Romana III (7017)
Tomb: 32

Sampled: Lower Left Second Molar



140

Site: Nova Romana III (7017)
Tomb: 36

Sampled: Lower Right Third Molar



144

Site: Nova Romana III (7017)
Tomb: 37

Sampled: Lower Right Second Molar



150

Site: Nova Romana III (7017)
Tomb: 38

Sampled: Lower Right Second Molar



153

Site: Nova Romana III (7017)
Tomb: 39

Sampled: Mandible and Lower Left Second Molar



162

Site: Nova Romana III (7017)
Tomb: 42

Sampled: Lower Left Third Molar



174

Site: Nova Romana III (7017)
Tomb: 45

Sampled: Lower Left Second Molar



17

Site: Nuevo Mérida (7034)

Sampled: Mandible, Lower Left First Molar and Lower Left Second Molar



23

Site: Nuevo Mérida (7034)

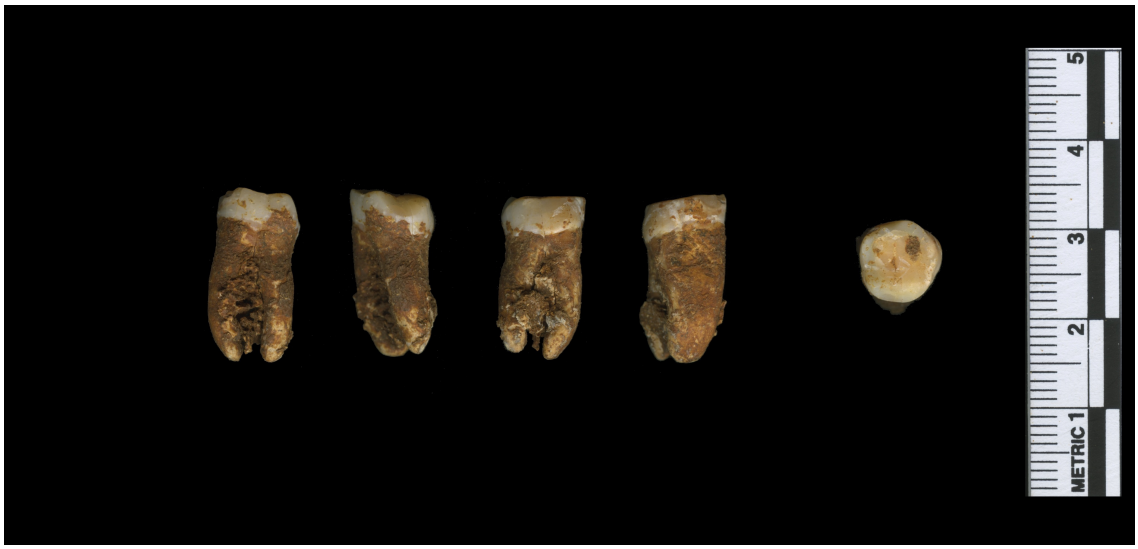
Sampled: Mandible, Lower Left First Molar and Lower Left Second Molar



26

Site: Nuevo Mérida (7034)

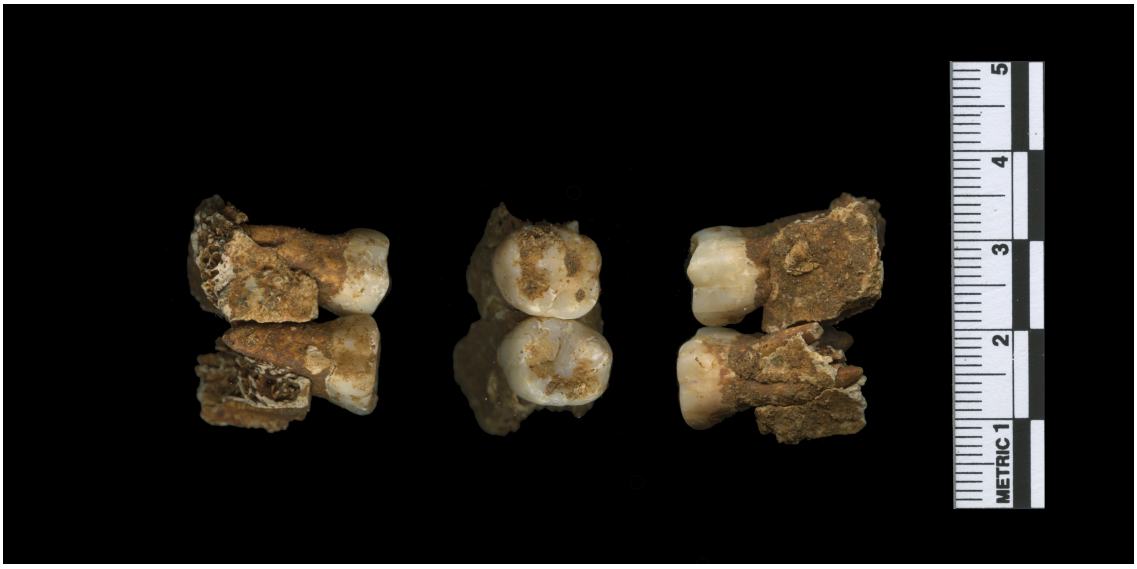
Sampled: Mandible and Lower Right Second Molar



67

Site: Nuevo Mérida (7034)

Sampled: Maxilla, Upper Left First Molar and Upper Left Second Molar



73

Site: Velada (8060)
Tomb: 4

Sampled: Mandible and Lower Right Second Molar



96

Site: Velada (8060)
Tomb: 17

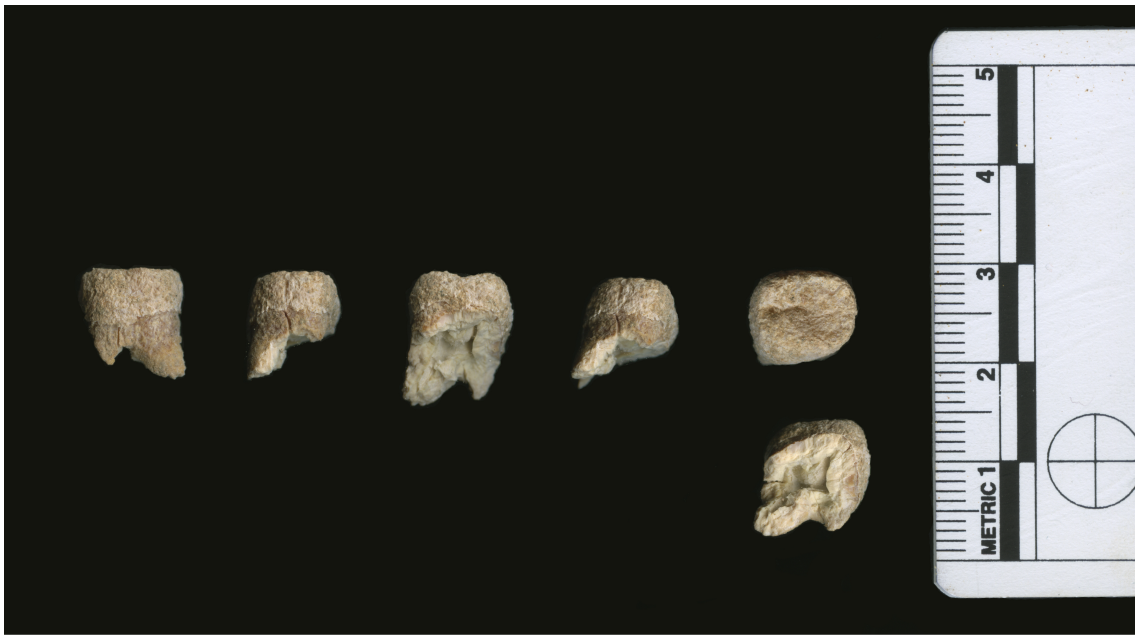
Sampled: Mandible, Lower Right First Molar, Lower Right Second Molar and Lower Right Third Molar



99

Site: Velada (8060)
Tomb: 21

Sampled: Mandible and Lower Left Third Molar



115

Site: Velada (8060)
Tomb: 28

Sampled: Mandible and Lower Left Second Molar



162

Site: Velada (8060)
Tomb: 47

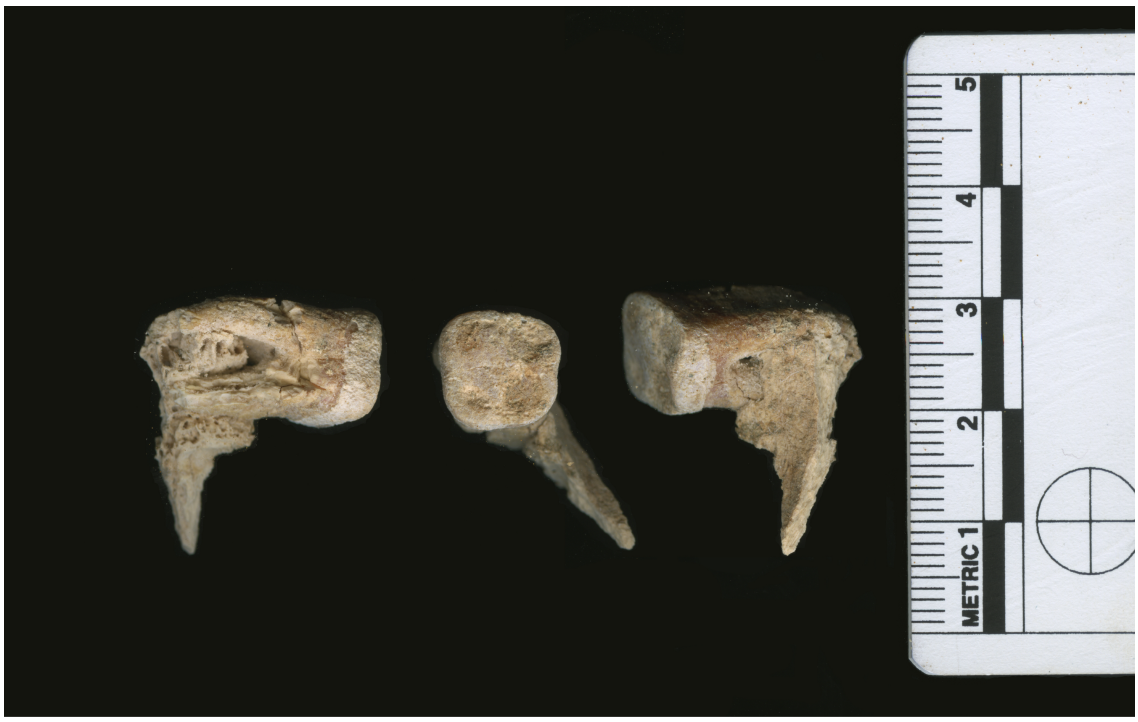
Sampled: Mandible and Lower Right Third Molar



207

Site: Velada (8060)
Tomb: 54

Sampled: Mandible and Lower Left Second Molar



208

Site: Velada (8060)
Tomb: 33

Sampled: Mandible and Lower Left Second Molar



216

Site: Velada (8060)
Tomb: 19

Sampled: Mandible, Lower Left First Molar, Lower Left Second Molar and Lower Left Third Molar



232

Site: Velada (8060)
Tomb: 13

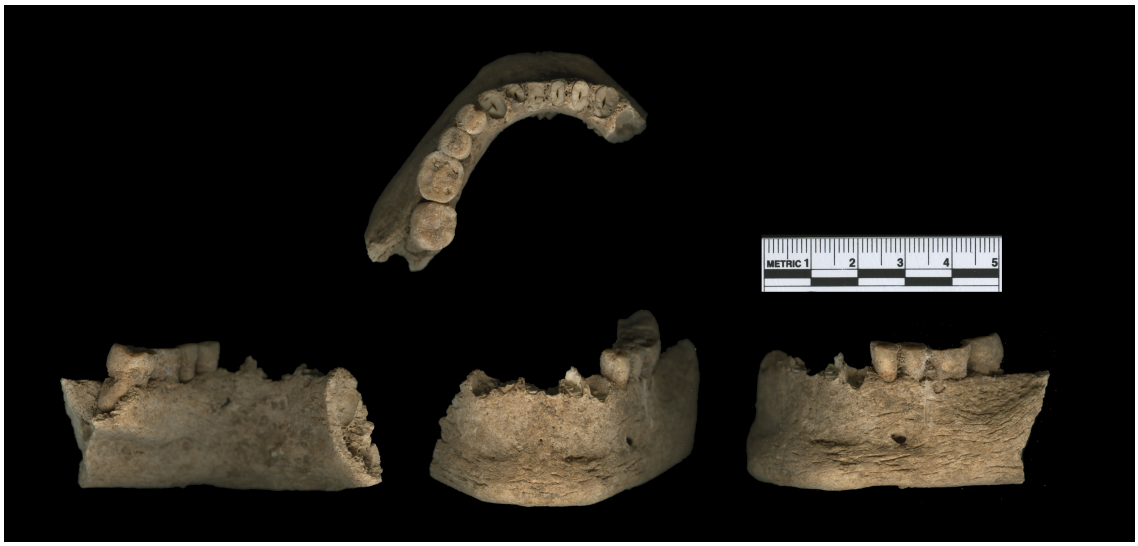
Sampled: Mandible, Lower Left First Molar and Lower Left Second Molar



248

Site: Velada (8060)
Tomb: 56

Sampled: Mandible, Lower Left First Molar and Lower Left Second Molar



nn

Site: Velada (8060)
Tomb:

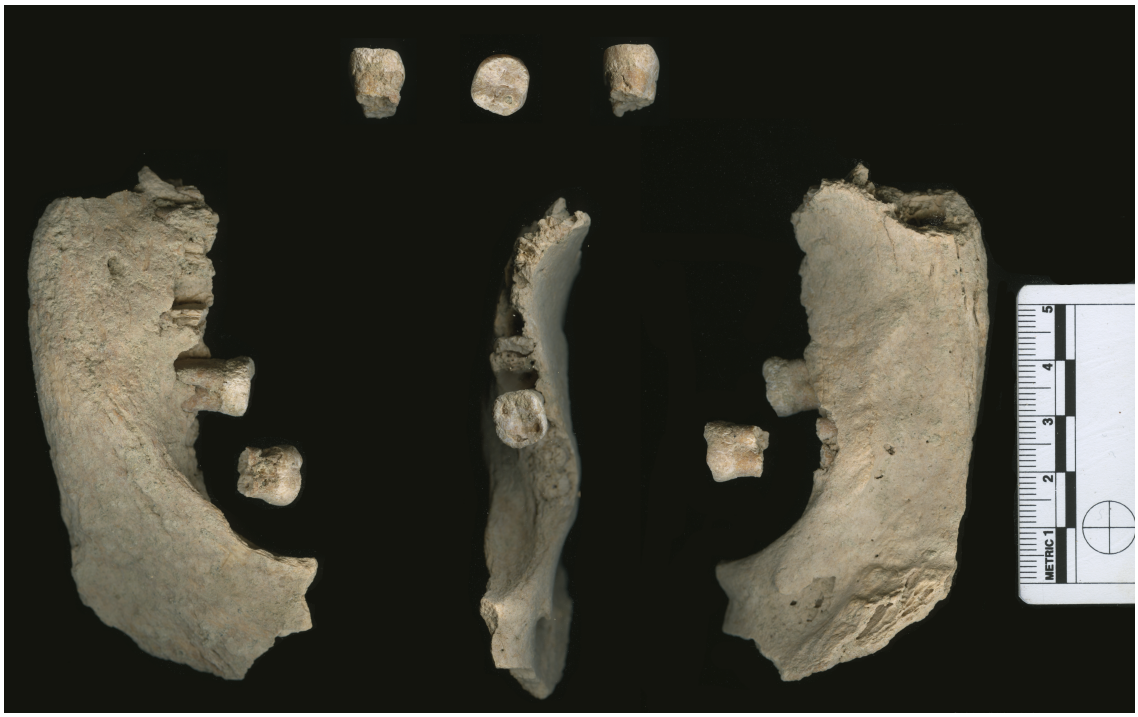
Sampled: Mandible, Lower Right Second Molar and Lower Right Third Molar



Tomb 17

Site: Velada (8060)
Tomb: 17

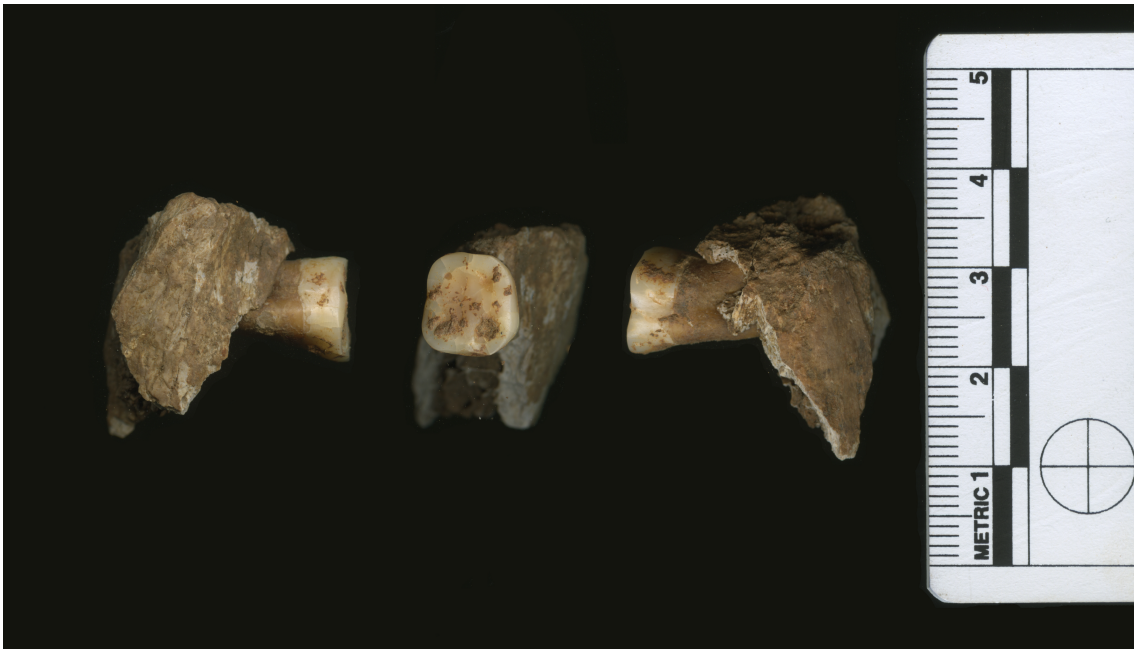
Sampled: Mandible, Lower Left Second Molar and Lower Left Third Molar



16

Site: YAC (83925)

Sampled: Mandible and Lower Left Second Molar



27

Site: YAC (83925)

Sampled: Mandible and Lower Left Third Molar



27

Site: YAC (83925)

Sampled: Skull



31

Site: YAC (83925)

Sampled: Mandible and Lower Right Third Molar



A.3: Sanisera Faunal

F-1

Species: *Bos taurus*
Context number: 1080
Sampled: Maxilla



F-2

Species: *Bos taurus*
Context number: 1080
Sampled: Maxilla and Second Molar



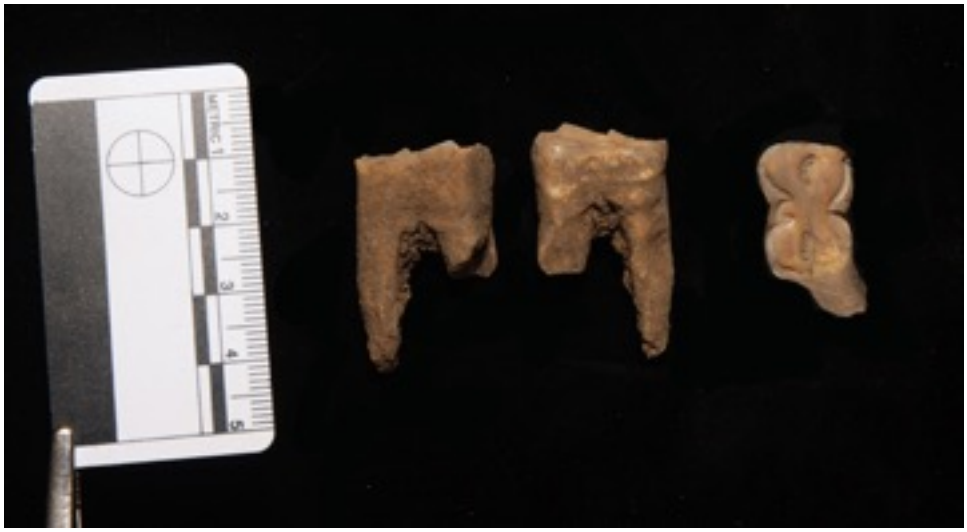
F-4

Species: *Bos taurus*
Context number: 1061
Sampled: Third Molar



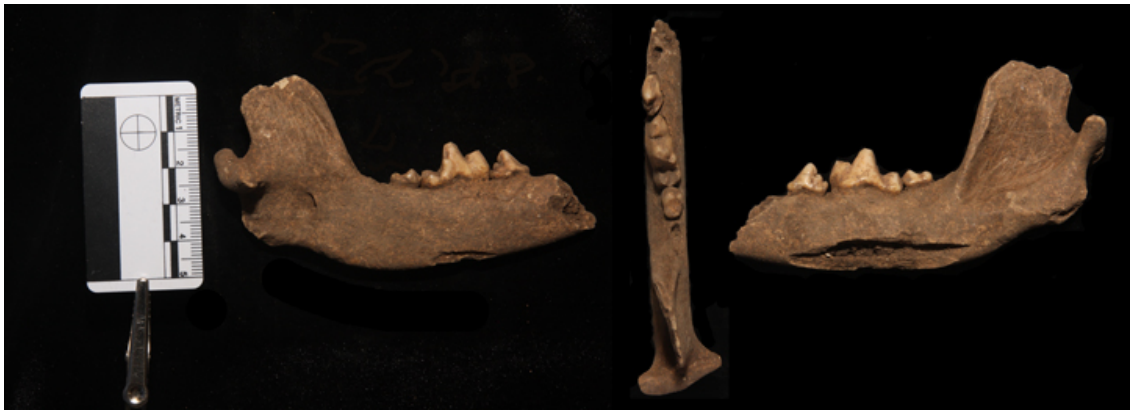
F-5

Species: *Bos taurus*
Context number: 1130
Sampled: Second Molar



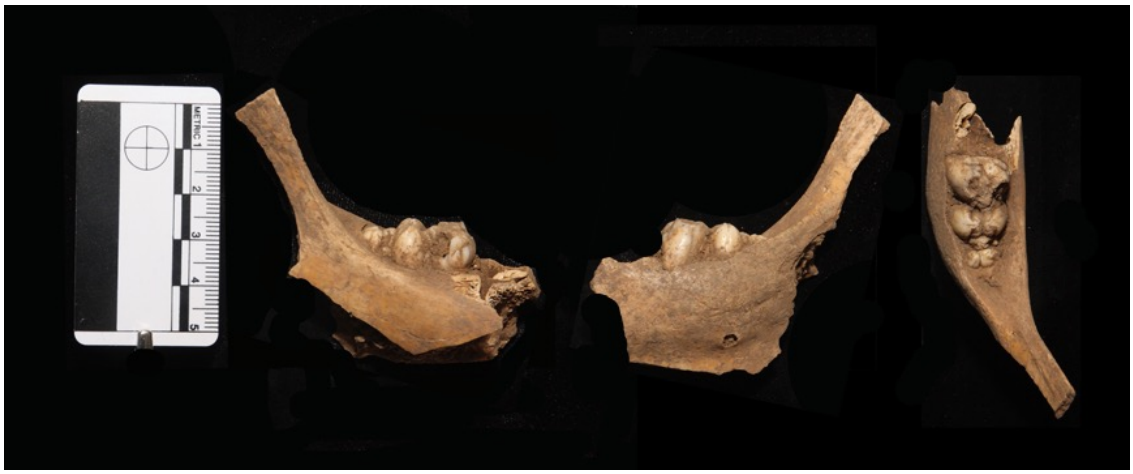
F-8

Species: *Canis familiaris*
Context number: 1131
Sampled: Mandible



F-9

Species: *Sus domesticus*
Context number: 1028a
Sampled: Mandible



F-10

Species: *Sus domesticus*
Context number: 1080
Sampled: Mandible



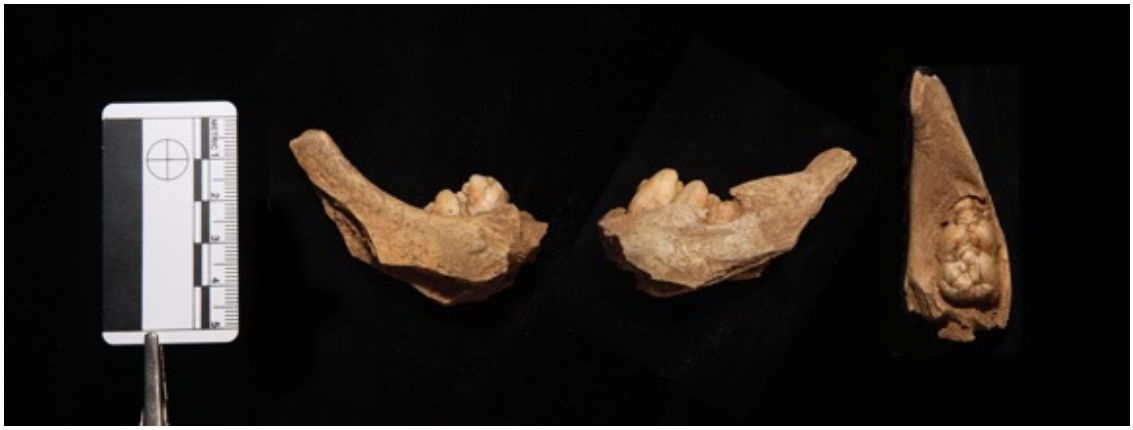
F-11

Species: *Sus domesticus*
Context number: 1130
Sampled: Mandible



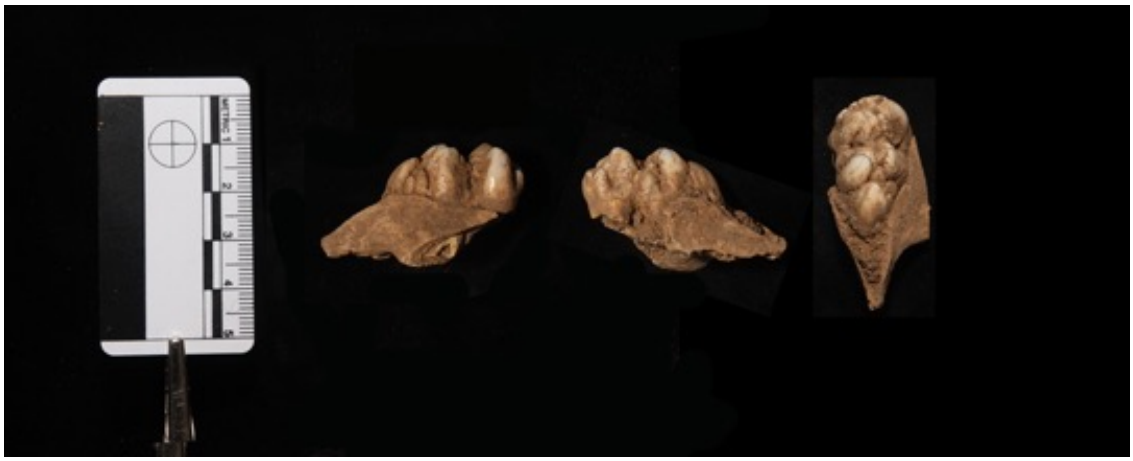
F-12

Species: *Sus domesticus*
Context number: 1061
Sampled: Mandible



F-13

Species: *Sus domesticus*
Context number: 1126
Sampled: Mandible



F-14

Species: *Sus domesticus*
Context number: 1050
Sampled: Maxilla



F-15

Species: *Sus domesticus*
Context number: 1028b
Sampled: Mandible



F-16

Species: *Sus domesticus*
Context number: 1051
Sampled: Mandible



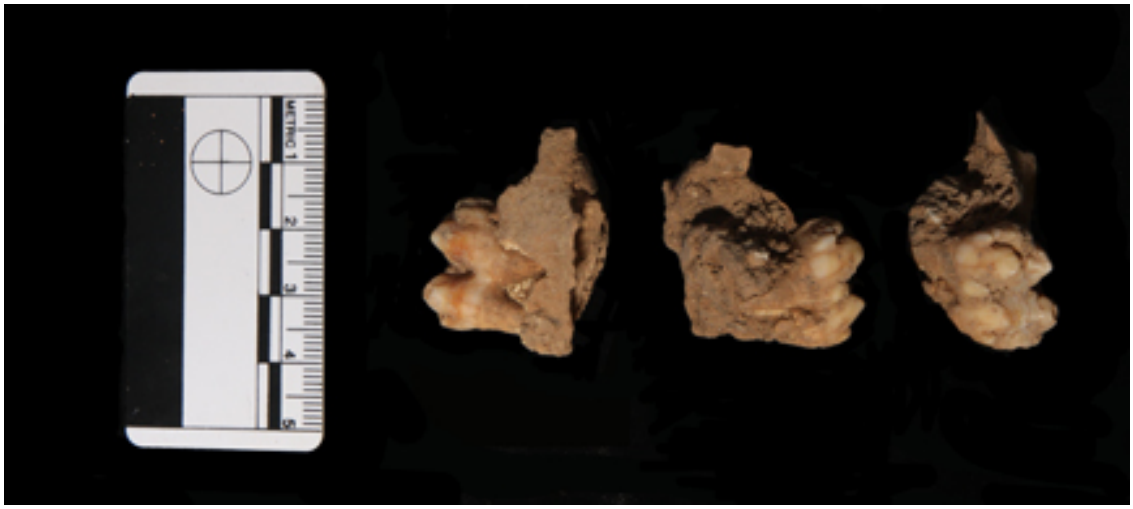
F-17

Species: *Sus domesticus*
Context number: 1093
Sampled: Mandible



F-18

Species: *Sus domesticus*
Context number: 1094
Sampled: Maxilla



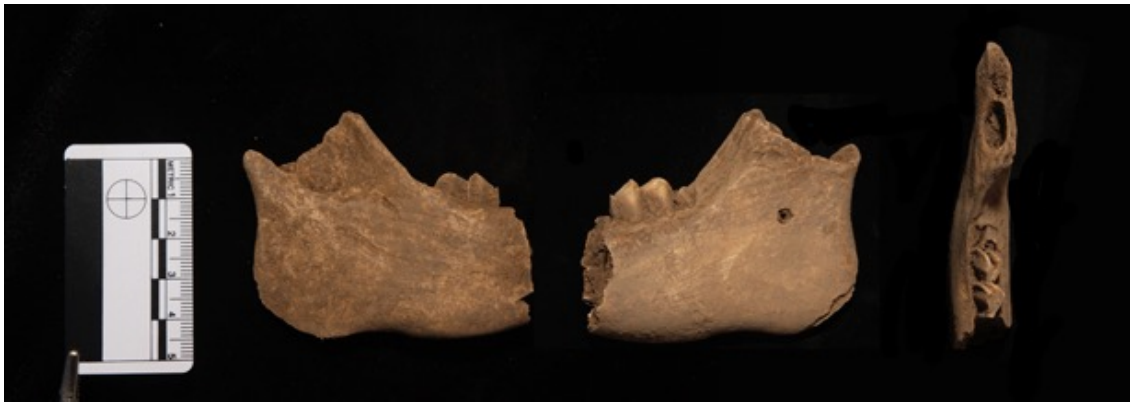
F-19

Species: Ovicaprid
Context number: 1051
Sampled: Mandible



F-20

Species: Ovicaprid
Context number: 1130 (sample A)
Sampled: Mandible



F-21

Species: Ovicaprid
Context number: 1130 (sample B)
Sampled: Mandible



F-22

Species: Ovicaprid
Context number: 1131 (sample A)
Sampled: Mandible



F-23

Species: Ovicaprid
Context number: 1018
Sampled: Maxilla



F-25

Species: Ovicaprid
Context number: 1143
Sampled: Mandible



F-26

Species: Ovicaprid
Context number: 1144
Sampled: Mandible



F-27

Species: Ovicaprid
Context number: 1130 (sample C)
Sampled: Mandible



F-28

Species: Ovicaprid
Context number: 1131 (sample B)
Sampled: Mandible



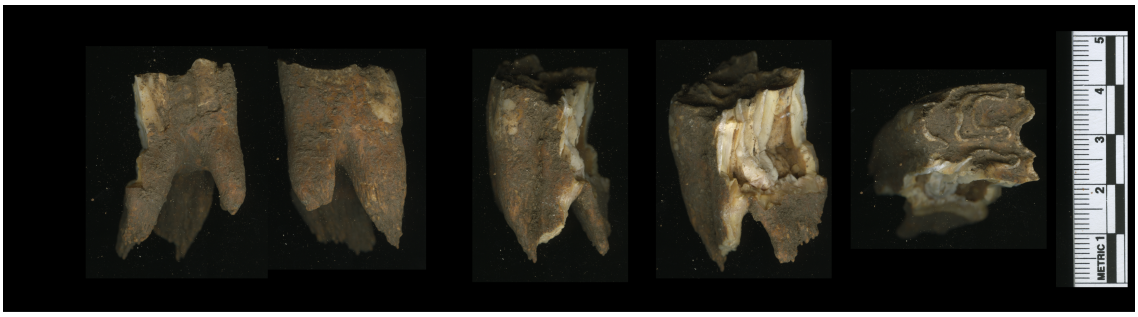
A.4: Mérida Faunal

A

Site: Casa Herrera (8265)

Species: *Bos taurus*

Sampled: Mandible and Lower Left Second Molar

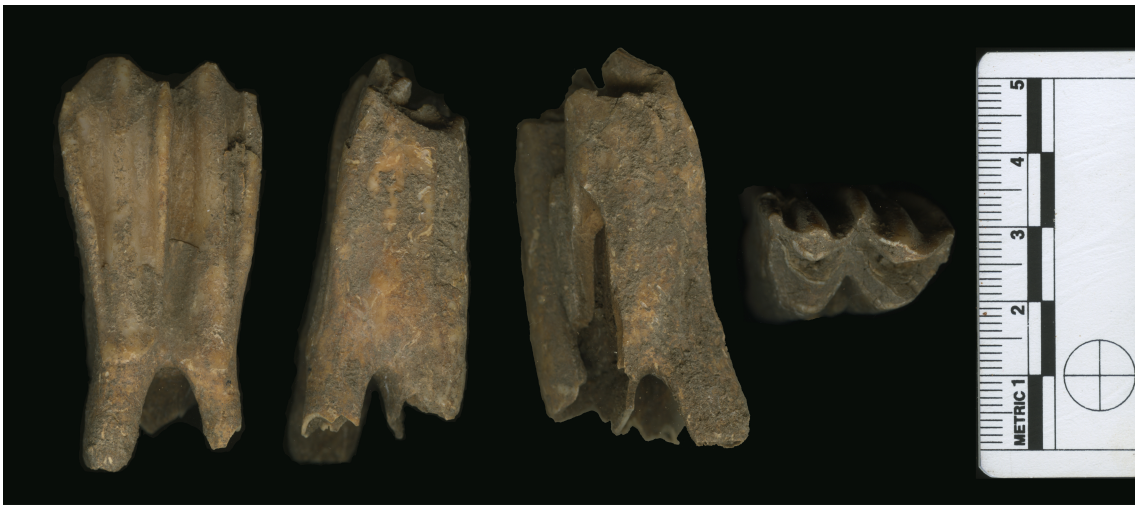


B

Site: Casa Herrera (8265)

Species: *Bos taurus*

Sampled: Mandible and Lower Left Second Molar



Appendix B: Dental Wear

B.1 Sanisera

Sample No.	Tooth	Wear Stage	Age at Death
1	URM2	2	<17
7	LLM1	3+	17-25
	LLM2	3-	
	LLM3	1	
	LRM2	2+	
	LRM2	1	
8	LLM2	2	17-25
9	LRM1	4	25-35
	LRM2	3+	
	LRM2	3	
10	LLM2	3-	17-25
11	LRM2	2+	17-25
12	LLM2	1	<17
15	LLM2	2+	17-25
16	LLM2	3	25-35
18	LLM1	3+	17-25
	LLM2	2+	
	LRM1	3	
	LRM2	2+	
19	LLM2	2	17-25
21a	LLM2	2	17-25
21b	LLM2	2+	17-25
22	LRM2	2	17-25
23	LRM2	2+	17-25
25	LRM2	3+	25-35
26	LLM2	1	<17
27	LLM2	5+	33-45
28	URM2	1	<17
29	LLM1	5+	25-35
	LLM2	4	
	LLM3	3	
31	URM2	1	<17
32	LLM1	2	<17
	LLM2	1	
	LRM1	2	
	LRM2	1	

Sample No.	Tooth	Wear Stage	Age at Death
35	LLM2	4	33-45
38	LRM1	2+	17-25
	LRM2	3+	
40	URM1	1	<17
	URM2	2	
41	LRM2	2	<17
43	URM1	2	17-25
	URM2	2	
46	LRM2	5++	45+
47	LRM2	5++	45+
48	LRM2	4++	33-45
49	LLM1	1	<17
	LRM2	1	<17
	LLM3	1	<17
50	LRM2	2+	17-25
52	LRM2	2+	17-25
54	ULM3	5++	45+
56	ULM3	1	17-25
58	LRM2	2+	17-25
60	LRM1	3+	17-25
	LRM2	2	
	LRM3	1	
61	LLM1	5++	33-45
	LLM2	4	
	LLM3	3+	
	LRM1	5++	
	LRM2	5	
62	LRM1	4	25-35
63	LLM1	2	<17
	LLM2	1	
	LRM1	2	
	LRM2	1	
64	LLM1	4+	33-45
	LLM2	5	
	LLM3	5	
	LRM1	5	
	LRM2	3-	
	LRM2	2+	
66	LRM1	3	17-25
	LRM2	2+	17-25
68a	LRM2	1	17-25
68b	LRM2	1	17-25
68c	LRM2	3+	25-35

Sample No.	Tooth	Wear Stage	Age at Death
68d	LRM2	1	17-25
68e	URM1	2	<17
69	LLM1	4	25-35
70	LRM2	4+	33-45
	LRM2	4	
71	LRM2	2+	17-25
73	LRM2	4	25-35
78	ULM3	1	17-25
80	ULM1	2	<17
	ULM2	1	
	ULM3	1	
81	ULM2	4	33-45
82	LRM2	3+	25-35
83	LRM2	3	25-35
85	LRM1	1	<17
86	LRM2	1	17-25
88	ULM1	1	<17
90	URM2	2	<17
93	LRM1	5+	33-45
96	LRM2	5+	45+
98	LRM2	4+	33-45
101	ULM2	2	17-25
103	LRM2	2	17-25
106	LLM1	2+	17-25
	LLM2	2	
	LRM2	2	
	URM1	2	
	URM2	1	
107	LLM1	2	17-25
	LLM2	2+	
108	URM2	2	17-25
111	ULM2	2	17-25
114a	LLM2	5	33-45
114b	LLM2	3	25-35
115	LLM2	2	17-25
119	LRM1	3-	17-25
	LRM2	3-	
	LRM2	1	

B.2 Mérida

Site (no.)	Sample No.	Tooth	Wear stage	Age
Nova Romana (1021)	140	LLM1	4	25-35
		LLM2	3	
		LLM3	2+	
	141	ULM2	2	17-25
	149	LRM2	2+	17-25
Nova Romana III (7017)	16	LRM3	1	17-25
	25	LLM2	2	17-25
	69	LRM2	2	17-25
	84	LLM3	2+	25-35
	96	LRM2	3	25-35
	103	ULM2	2	17-25
	107	LLM2	4	25-35
	140	LRM3	1	17-25
	144	LRM2	2	17-25
	150	LRM2	2+	17-25
	153	LRM2	2	17-25
	162	LLM3	2	17-25
	174	LLM2	2+	17-25
Nuevo Mérida (7034)	17	LLM1	2	17-25
		LLM2	2+	
		LLM3	1	
	23	LLM1	2+	17-25
		LLM2	2+	
	26	LRM2	2+	25-35
	67	ULM1	3	17-25
		ULM2	2	17-25

Site (no.)	Sample No.	Tooth	Wear stage	Age
Velada (8060)	73	LRM2	1	17-25
	96	LRM1	5	25-35
		LRM2	3+	
		LRM3	2+	
	99	LLM3	1	17-25
	115	LLM2	2	17-25
	162	LRM3	1	17-25
	207	LLM2	4	25-35
	208	LLM2	5+	35-45
	216	LLM1	3	17-25
		LLM2	2+	
		LLM3	2	
	232	LLM2	5	35-45
	248	LLM1	3	25-35
		LLM2	2+	
	nn	LRM2	2	17-25
		LRM3	1	
	Tomb 17	LLM2	3+	25-35
		LLM3	2+	
Y.A.C. (83925)	16	LLM2	3	25-35
	27	LLM3	2	17-25
	31	LRM3	4	33-45

Appendix C: Results

C.1 Sanisera

Individual	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPVD	$\delta^{15}N$ (‰) AIR
7	Human	*Mandible*	*0.5*	*41.3*	*13.2*	*3.7*	*-19.3*	*11.7*
		LRM2	12.1	35.7	12.6	3.3	-18.5	12.3
9	Human	Mandible	10.7	39.8	14.4	3.2	-17.7	12.2
		LRM2	17.2	39.2	13.9	3.3	-18.6	13.1
10	Human	LRM2	11.9	39.3	14.3	3.2	-18.9	12.1
11	Human	LRM2	6.7	37.3	13.5	3.2	-19.5	11.7
15	Human	LLM2	10.5	39.1	14.0	3.3	-19.2	12.6
16	Human	LLM2	11.0	40.7	14.4	3.3	-18.6	12.4
18	Human	Mandible	5.7	41.7	15.0	3.2	-18.6	10.5
		LLM2	16.8	34.6	12.4	3.3	-19.1	11.1
21B	Human	LLM2	4.5	32.5	11.6	3.3	-20.0	11.4
26	Human	LLM2	*0.0*	-	-	-	-	-
29	Human	Mandible	7.8	45.6	16.1	3.3	-17.9	12.1
		LLM2	12.3	37.2	12.2	3.6	-19.4	12.7
31	Human	URM2	6.6	39.8	14.3	3.3	-19.1	12.1
32	Human	Mandible	8.1	41.4	14.8	3.3	-18.5	10.3
		LLM2	14.3	51.6	19.1	3.2	-18.8	11.7
35	Human	LLM2	10.0	40.6	14.5	3.3	-18.9	12.1
38	Human	Mandible	3.4	41.1	34.7	3.4	-18.2	12.0
		LLM2	8.2	38.4	13.5	3.3	-18.7	12.2
40	Human	Maxilla	7.8	44.1	35.2	3.3	-18.6	9.2
		URM2	16.3	39.7	14.4	3.2	-18.9	9.1
43	Human	Maxilla	3.3	40.5	34.8	3.4	-18.2	12.5
		URM2	11.0	42.3	15.5	3.2	-18.4	13.1
52	Human	LLM2	6.3	31.7	11.3	3.3	-20.1	11.0
58	Human	LRM2	10.0	40.5	14.6	3.2	-18.8	12.0

Individual	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPVD	$\delta^{15}N$ (‰) AIR
60	Human	*Mandible*	*0.2*	*39.8*	*13.0*	*3.6*	*-20.0*	*12.4*
		LRM2	7.0	43.0	15.4	3.3	-19.4	10.7
61	Human	Mandible	1.8	37.0	12.8	3.4	-17.9	10.9
		LRM2	13.4	34.3	12.2	3.3	-18.4	11.4
62	Human	*Mandible*	*0.0*	-	-	-	-	-
		LRM2	5.0	27.5	9.5	3.4	-18.6	10.2
63	Human	Mandible	5.4	41.3	14.7	3.3	-17.9	11.1
		LRM2	13.0	40.9	14.6	3.3	-18.7	12.6
64	Human	Mandible	3.7	34.0	11.8	3.4	-19.5	11.6
		LRM2	9.9	39.3	14.2	3.2	-18.3	11.6
70	Human	*Mandible*	*0.0*	-	-	-	-	-
		LRM2	*0.0*	-	-	-	-	-
71	Human	*Mandible*	*0.6*	*12.31*	*3.67*	*3.92*	*-20.37*	*9.95*
		LRM2	*0.0*	-	-	-	-	-
80	Human	Maxilla	5.0	43.3	34.5	3.4	-17.9	11.8
		ULM3	12.0	42.5	15.5	3.2	-18.1	11.8
81	Human	Mandible	5.0	43.0	35.4	3.3	-17.2	12.4
		LRM2	18.0	40.0	14.3	3.3	-18.3	11.4
86	Human	Mandible	9.0	44.1	15.7	3.3	-18.1	12.5
		LRM2	11.4	39.2	13.9	3.3	-18.8	13.5
98	Human	LRM2	7.8	43.7	15.4	3.3	-18.9	12.1
103	Human	LRM3	8.1	43.0	15.4	3.3	-18.7	12.1
106	Human	Maxilla	7.9	43.6	35.2	3.3	-18.0	9.2
		URM2	13.1	40.0	14.4	3.3	-18.2	9.9
107	Human	Maxilla	2.9	16.1	5.6	3.4	-20.1	9.0
		URM2	10.7	35.6	12.6	3.3	-17.8	10.5
114 A	Human	LLM2	8.1	38.0	13.6	3.3	-18.6	11.9
114 B	Human	LLM2	8.2	41.7	14.9	3.3	-19.0	12.1
115	Human	LLM2	10.0	41.6	14.9	3.3	-19.1	12.2

Individual	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPVD	$\delta^{15}N$ (‰) AIR
119	Human	Mandible	1.9	40.1	13.8	3.4	-18.1	10.9
		LRM2	11.4	30.7	10.8	3.3	-18.6	10.6
F 1	*Bos taurus*	Maxilla	3.8	41.0	14.7	3.3	-19.7	6.1
F 2	*Bos taurus*	Maxilla	2.2	31.3	10.5	3.5	-20.4	10.6
		M2	9.6	21.1	7.5	3.3	-22.8	9.1
F 4	*Bos taurus*	M3	12.2	34.3	12.2	3.3	-22.5	5.7
F 5	*Bos taurus*	M2	11.5	36.9	13.4	3.2	-20.9	7.8
F 8	*Canis canis*	Mandible	2.0	16.7	5.8	3.4	-21.2	9.0
F 9	*Sus domesticus*	Mandible	7.8	44.8	16.0	3.3	-21.3	7.5
F 10	*Sus domesticus*	Mandible	5.8	42.5	35.3	3.3	-20.8	7.6
F 11	*Sus domesticus*	Mandible	6.8	40.4	35.3	3.3	-21.3	8.1
F 12	*Sus domesticus*	Mandible	4.6	30.9	35.9	3.3	-20.9	9.3
F 13	*Sus domesticus*	Mandible	9.8	37.5	13.4	3.3	-21.5	9.3
F 14	*Sus domesticus*	Maxilla	7.8	33.5	12.1	3.3	-20.4	7.0
F 15	*Sus domesticus*	Mandible	3.0	40.8	13.9	3.4	-20.9	6.6
F 16	*Sus domesticus*	Maxilla	7.7	30.1	10.7	3.3	-21.6	10.4
F 17	*Sus domesticus*	Mandible	12.2	42.0	35.9	3.3	-20.7	8.4
F 18	*Sus domesticus*	Maxilla	4.2	37.6	35.5	3.3	-20.6	5.7
F 19	Ovicaprid	Mandible	4.6	26.8	9.4	3.3	-20.7	5.1
F 20	Ovicaprid	Mandible	5.8	40.5	35.4	3.3	-18.9	4.6
F 21	Ovicaprid	Mandible	4.7	35.8	35.6	3.3	-20.4	6.9
F 22	*Ovicaprid*	Mandible	*0.0*	-	-	-	-	-
F 23	Ovicaprid	Maxilla	5.4	36.6	13.1	3.3	-21.5	5.3
F 25	Ovicaprid	Mandible	4.8	40.8	35.1	3.3	-19.3	7.6
F 26	Ovicaprid	Mandible	7.0	42.0	35.9	3.3	-18.5	6.4
F 27	Ovicaprid	Mandible	9.1	44.2	35.3	3.3	-19.3	4.4
F 28	Ovicaprid	Mandible	4.9	43.2	15.4	3.3	-19.0	4.5

C.2: Mérida

Sample	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
Casa Herrera (8265)								
A	*Bos taurus*	Mandible	5.4	24.5	8.1	3.5	-18.5	8.7
		M2	10.4	36.1	12.8	3.3	-15.3	8.7
B	*Bos taurus*	*Mandible*	*0.5*	*8.2*	*1.4*	*7.2*	*-16.8*	*7.8*
		M2	1.0	32.8	11.2	3.4	-19.7	8.9
Nova Romana (1021)								
140	Human	Mandible	1.3	31.4	11.3	3.3	-18.7	8.8
		M1	*1.1*	*5.6*	*1.4*	*4.8*	*-21.3*	*8.2*
		M2	3.3	31.1	11.0	3.3	-18.8	11.2
		M3	4.1	35.2	12.4	3.3	-19.2	9.0
141	Human	Maxilla	1.9	18.4	6.3	3.4	-18.9	10.2
		M2 Cervical	3.6	34.0	12.1	3.3	-19.0	11.1
		M2 Apical	3.6	29.2	10.4	3.3	-19.1	12.0
149	Human	*Mandible*	*2.1*	*3.5*	*1.1*	*3.9*	*-20.6*	*8.9*
		M1	*0.6*	*5.1*	*0.2*	*30.9*	*-4.8*	*-0.1*
		M2	*0.5*	*2.2*	*0.1*	*18.8*	*-27.3*	*-6.4*
Nova Romana III (7017)								
16	Human	*M3 Cervical*	*2.1*	*7.7*	*1.0*	*8.7*	*-7.8*	*10.2*
		M3 Apical	1.7	22.7	8.0	3.3	-18.9	11.7
25	Human	Mandible	5.2	39.6	13.8	3.4	-18.1	11.9
		M2	7.1	34.3	12.0	3.3	-18.9	8.3
69	Human	*M2*	*1.7*	*5.8*	*0.8*	*8.5*	*-7.5*	*7.4*
84	Human	Mandible	2.7	25.7	10.9	3.4	-19.8	11.9
		M3	*0.0*	-	-	-	-	-
96	Human	*M2*	*2.6*	*6.3*	*1.3*	*5.6*	*-23.1*	*8.6*
103	Human	M2 Cervical	2.4	31.3	11.1	3.3	-18.5	10.3
		M2 Apical	1.8	29.9	10.3	3.4	-18.4	10.6

Sample	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
107	Human	*M2 Cervical*	*0.8*	*7.2*	*0.8*	*10.0*	*-12.0*	*8.6*
		M2 Apical	*4.0*	*3.0*	*0.6*	*5.6*	*-22.6*	*6.1*
140	Human	M3 Cervical	5.4	31.3	11.2	3.3	-14.0	9.2
		M3 Apical	*3.2*	*2.9*	*0.5*	*6.4*	*-23.4*	*4.6*
144	Human	M2 Cervical	5.7	33.3	12.1	3.2	-14.2	9.9
		M2 Apical	*5.0*	*3.3*	*0.2*	*16.9*	*-5.2*	*5.0*
150	Human	*M2 Cervical*	*0.5*	*4.6*	*1.2*	*4.5*	*-20.9*	*8.1*
		M2 Apical	3.2	60.5	22.1	3.2	-18.9	11.2
153	Human	*Mandible*	*0.1*	*2.3*	*0.3*	*9.3*	*-23.3*	*4.2*
		M2	1.9	22.9	7.9	3.4	-18.3	8.2
162	Human	*M3 Cervical*	*0.4*	-	-	-	-	-
		M3 Apical	*1.5*	*8.4*	*2.5*	*4.0*	*-20.3*	*9.3*
174	Human	M2 Cervical	2.8	36.7	13.1	3.3	-18.9	10.9
		M2 Apical	6.9	33.9	12.0	3.3	-18.7	10.8
Nuevo Mérida (7034)								
17	Human	*Mandible*	*1.3*	*7.7*	*2.7*	*3.7*	*-22.4*	*6.5*
		M1 Cervical	5.9	34.5	12.3	3.3	-18.8	11.3
		M1 Apical	2.6	30.5	10.7	3.3	-18.9	11.6
		M2 Cervical	1.9	30.2	10.7	3.3	-19.3	11.4
		M2 Apical	3.7	27.0	9.4	3.4	-19.5	10.9
		M3	24.8	23.1	8.0	3.4	-19.2	9.8
23	Human	Mandible	1.3	2.5	0.4	8.9	-23.8	4.0
		M1	*2.1*	*2.6*	*0.2*	*22.8*	*-27.4*	*-3.4*
		M2	*0.0*	-	-	-	-	-
26	Human	Mandible	4.9	25.4	8.6	3.4	-18.9	10.5
		M2	10.0	43.4	15.7	3.2	-18.3	11.6
67	Human	*Maxilla*	*1.6*	*2.5*	*0.3*	*9.0*	*-23.2*	*6.2*
		M1	1.9	21.1	7.2	3.4	-19.0	10.5
		M2	8.6	44.4	16.1	3.2	-18.5	9.8

Sample	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
Velada (8060)								
73	Human	*Mandible*	*1.9*	*2.7*	*0.4*	*8.5*	*-22.2*	*9.3*
		M2	*0.9*	*7.9*	*2.2*	*4.2*	*-20.8*	*9.4*
96	Human	*Mandible*	*0.4*	*1.7*	*0.2*	*10.7*	*-23.8*	*8.0*
		M1 Cervical	3.1	35.0.3	12.6	3.3	-19.0	9.8
		M1 Apical	2.6	30.7	10.8	3.3	-19.3	10.4
		M2	13.1	41.6	15.0	3.2	-18.2	11.4
		M3 Cervical	3.1	32.7	11.8	3.2	-19.0	11.4
		M3 Apical	5.0	33.4	12.0	3.3	-19.2	11.8
99	Human	*Mandible*	*2.6*	*1.5*	*0.1*	*15.7*	*-23.7*	*7.8*
		M3	1.5	17.3	5.8	3.5	-19.3	8.5
115	Human	*Mandible*	*0.4*	*3.9*	*0.9*	*5.2*	*-19.6*	*6.5*
		M2	*1.2*	*2.7*	*0.4*	*8.6*	*-24.7*	*4.4*
162	Human	*Mandible*	*3.1*	*6.3*	*1.6*	*4.6*	*-19.5*	*8.2*
		M3	6.3	25.5	8.9	3.4	-18.3	9.9
207	Human	*Mandible*	*0.5*	*5.0*	*0.5*	*11.5*	*-10.6*	*7.2*
		M2	*4.1*	*1.6*	*0.3*	*7.1*	*-20.7*	*10.0*
208	Human	*Mandible*	*0.5*	*8.9*	*2.0*	*5.3*	*-23.2*	*10.1*
		M2	13.3	29.1	10.3	3.3	-18.0	10.9
216	Human	*Mandible*	*0.7*	*7.5*	*5.8*	*1.5*	*-20.1*	*11.3*
		M1 Cervical	2.6	30.4	11.0	3.2	-19.4	10.1
		M1 Apical	*1.1*	*1.6*	*0.1*	*15.7*	*-26.7*	*-3.8*
		M2 Cervical	*1.1*	*3.2*	*0.4*	*11.6*	*-20.2*	*4.6*
		M2 Apical	*0.0*	-	-	-	-	-
		M3	2.2	28.4	10.0	3.3	-18.9	9.5
232	Human	*Mandible*	*0.7*	*2.1*	*0.5*	*8.6*	*-25.3*	*1.7*
		M1	*2.1*	*3.6*	*0.2*	*27.1*	*-28.8*	*-0.2*
		M2	*3.2*	*1.9*	*0.3*	*8.1*	*-21.5*	*4.4*

Sample	Species	Material	% Collagen	%C	%N	C:N	$\delta^{13}C$ (‰) VPDB	$\delta^{15}N$ (‰) AIR
248	Human	Mandible	2.5	12.4	4.2	3.4	-19.9	10.6
		M1 Cervical	2.1	24.4	8.3	3.5	-19.5	9.3
		M1 Apical	2.2	23.1	7.9	3.4	-19.9	9.7
		M2	*1.6*	*9.4*	*2.8*	*4.0*	*-20.7*	*8.8*
nn	Human	*Mandible*	*0.5*	*2.0*	*0.2*	*10.6*	*-21.7*	*8.7*
		M2	10.6	31.8	11.3	3.3	-13.4	9.1
		M3 Cervical	2.8	35.9	12.9	3.2	-18.6	11.4
		M3 Apical	2.6	33.4	11.7	3.3	-19.4	10.6
Tomb 17	Human	Mandible*	0.9	28.3	9.8	3.4	-19.5	11.0
		M2	3.5	29.9	10.4	3.4	-18.6	9.3
		M3	2.2	24.1	8.4	3.4	-19.4	9.3
YAC (83925)								
16	Human	Mandible*	2.8	18.1	6.0	3.5	-18.6	9.2
		M2	12.4	35.0	12.6	3.2	-16.4	9.3
27	Human	Mandible	1.5	38.9	14.2	3.2	-18.9	11.6
		M3	7.5	27.7	9.9	3.4	-18.3	9.8
31	Human	Mandible	3.6	24.3	8.5	3.4	-18.7	11.5
		M3	1.2	29.5	10.4	3.4	-18.2	11.9