

Life and Death at Teposcolula Yucundaa:
Mortuary, Archaeogenetic, and Isotopic Investigations
of the Early Colonial Period in Mexico

A dissertation presented

by

Christina Gertrude Warinner

to

The Department of Anthropology

in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy
in the subject of
Anthropology

Harvard University
Cambridge, MA

May 2010

Life and Death at Teposcolula Yucundaa:
Mortuary, Archaeogenetic, and Isotopic Investigations
of the Early Colonial Period in Mexico

Abstract

Two mid-16th century cemeteries are investigated at the Mixtec site of Teposcolula Yucundaa and shown to be related to the unidentified *cocoliztli* pandemic of 1545-1548. Through archaeogenetic and oxygen stable isotope analysis it is shown that the interred individuals are local Mixtecs, and mortuary analysis sheds light on both Christian and traditional religious practices at the site. Mitochondrial haplogroup frequencies do not support severe population bottlenecks during the 16th century epidemic period, and carbon and nitrogen stable isotope analysis does not support a shift away from maize consumption, despite evidence for increased wheat production at the site. In order to further refine Middle American stable isotope-based paleodietary models, a large-scale empirical study was conducted on the isotopic diversity of regional crop plants, and an experimental feeding study in swine was developed to determine the isotopic effects of nixtamalization on mineralized tissues.

Table of Contents

Title page	i
Copyright page.....	ii
Abstract.....	iii
Table of Contents.....	iv
List of Tables	vii
List of Figures.....	viii
List of Appendices	ix
Acknowledgements.....	xi
CHAPTER 1: INTRODUCTION	
1.1. Overview.....	1
1.2. Background.....	1
1.3. Dissertation structure	2
CHAPTER 2: ALKALINE COOKING AND STABLE ISOTOPE DIET-TISSUE DISCRIMINATION IN SWINE	
2.1. Chapter summary	6
2.2. Introduction.....	7
2.3. Materials and methods	10
2.3.1. Controlled diet study.....	10
2.3.2. Sample preparation	14
Food and water.....	14
Collagen	14
Apatite.....	14
2.3.3. Mass spectrometry	15
Collagen, food components, and water (C, O).....	15
Apatite carbonates (C, O)	15
2.3.4. Evaluation of sample bias in enamel samples.....	16
Upper and lower canines.....	16
2.4. Results.....	16
2.4.1. Isotopic discrimination across tissues.....	16
Humerus and mandible collagen.....	16
Bone and enamel apatite	16
2.4.2. Alkaline cooking	18
2.5. Discussion.....	19
2.5.1. Effects of alkaline cooking	19
2.5.2. Mineralized tissue selection.....	22
Humerus and mandible collagen.....	22
Bone and enamel apatite	23
2.5.3. Organic and inorganic source comparisons	26
Carbon.....	26
Oxygen	27

2.6 Conclusions	29
2.7 Bibliography	30
2.8 Appendices	35

CHAPTER 3: TISSUE ISOTOPIC ENRICHMENT ASSOCIATED WITH GROWTH DEPRESSION

IN A PIG

3.1. Chapter summary	50
3.2. Introduction.....	51
3.3. Materials and methods	53
3.3.1. Controlled diet study.....	53
3.3.2. Analytical methods	55
3.4. Results.....	56
3.4.1. Growth	56
3.4.2. Patterns of isotopic discrimination	57
Isotopic differences among the experimental pigs.....	57
Temporal trends in hair keratin.....	58
Temporal trends in mineralized tissues.....	60
3.5. Discussion	61
3.5.1. Comparison with previous studies	61
3.5.2. Evaluation of current isotopic models and observed relationships	63
3.6. Conclusion	64
3.7. Bibliography	65
3.8. Appendices.....	70

CHAPTER 4: ISOTOPIC DIVERSITY OF THE MIDDLE AMERICAN DIETOME

4.1. Chapter summary	72
4.2. Introduction.....	73
4.3. Data collection	78
4.3.1 Published data	79
4.3.2 Valley of Oaxaca.....	79
4.3.3 Coastal Tabasco	82
4.3.4 Herbarium samples	82
4.3.5 Human samples.....	82
4.4. Isotopic characterization of modern Middle American flora.....	82
4.4.1 Carbon.....	83
4.4.2 Nitrogen	88
4.4.3 Intra-taxonomic isotopic variation.....	90
4.4.4 Comparison of $\delta^{15}\text{N}$ in cultivated and wild plants.....	91
4.5. Reconstructing ancient food webs	93
4.5.1 Impact of industrial carbon inputs	94
4.5.2 Estimating isotopic offsets between meat and bone collagen.....	98
4.6. Reconstructed isotopic distribution of ancient Middle American foods	99
4.6.1 Regional differences	100
4.7. Dietary interpretation of Middle American human populations.....	102
4.7.1 Origins and spread of maize agriculture	102
Tehuacan Valley	104

Panama and Soconusco.....	105
4.7.2 Estimation of maize consumption in agricultural populations	107
4.7.3 Trophic level estimation	109
4.7.4 Humans as carnivores?	112
4.7.5 Role of agriculture	113
4.8. Conclusions.....	114
4.9. Bibliography	116
4.10. Appendices.....	130

CHAPTER 5: DEATH, DEMOGRAPHY, AND DIET IN EARLY COLONIAL NEW SPAIN: A SCIENTIFIC INVESTIGATION OF TWO 16TH CENTURY CEMETERIES AT TEPOSCOLULA YUCUNDAA

5.1. Chapter summary	186
5.2. Introduction.....	187
5.3. Site background	189
5.4. Excavation of the Grand Plaza and Churchyard cemeteries.....	194
5.5. Methods.....	196
5.5.1 Collection of mortuary and paleodemographic data.....	196
5.5.2 Ancient DNA extraction, amplification, and sequencing	197
5.5.3 Stable isotope analysis (C, N, O, H)	200
5.6. Mortuary and demographic analysis of the Teposcolula burial assemblages.....	201
5.6.1 Grand Plaza skeletal assemblage	201
5.6.2 Churchyard skeletal assemblage.....	207
5.6.3 Placing the Teposcolula cemeteries in context.....	208
Burial 27: a special case.....	213
5.7. Evidence for a catastrophic mortuary assemblage.....	218
5.8. Demographic implications of epidemic disease	226
5.8.1 Oxygen stable isotope analysis of the Teposcolula cemeteries	227
5.8.2 Ancient DNA analysis of the Teposcolula cemeteries	229
Spanish presence at Teposcolula	232
Ancient and modern mitochondrial haplogroup frequencies of indigenous populations	233
5.9. Parameters of social and economic change	236
5.9.1 Carbon and nitrogen stable isotope analysis of the Teposcolula cemeteries	239
5.9.2 Paleodietary lessons from Teposcolula enamel apatite data.....	240
5.10. Conclusions.....	242
5.11. Bibliography	244
5.12. Appendices.....	260

List of Tables

Table 2.1: Pre-diet experiment tissue isotopic values.....	11
Table 2.2: Experimental diet components and stable isotope ratios.....	11
Table 2.3: Isotopic ratios of experimental diets and water.....	12
Table 2.4: Mineralized tissue isotopic ratios in week 13 of the diet experiment.....	17
Table 2.5: Comparison of tissue δ using a two-tailed Student's <i>t</i> test.....	18
Table 2.6: Comparison of diet groups using a two-tailed Student's <i>t</i> test.....	19
Table 3.1: Isotopic ratios of diet and animal tissues.....	54
Table 4.1: Average plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ determined in empirical studies compared to estimates employed in Middle American paleodiet reconstructions.....	85
Table 4.2: Stable carbon and nitrogen isotopic ratios for Middle American humans predating 1000 BC.....	103
Table 5.1: Mitochondrial coding region primers.....	199
Table 5.2: Mortuary and physical characteristics of the Teposcolula-Yucundaa skeletal assemblage.....	204
Table 5.3: Published reports of excavated 16 th century cemeteries in New Spain.....	208
Table 5.4: Sex distribution of arm position.....	209
Table 5.5: Body orientation in the Grand Plaza and churchyard cemeteries.....	210
Table 5.6: Distribution of individuals within burials.....	211
Table 5.7: Mitochondrial haplogroup frequencies of colonial Teposcolula and selected Native American populations.....	234

List of Figures

Figure 2.1: Comparison of tissue-diet spacings.....	20
Figure 2.2: Relationship between diet and tissue carbon isotopic ratios in published swine and rodent studies	28
Figure 3.1: Comparative growth rates of experimental pigs.....	57
Figure 3.2: Association between final tissue isotopic value and growth rate.....	59
Figure 3.3: Isotopic trends in mineralized tissues as a function of weight increase.....	60
Figure 4.1: Stable isotope-based paleodietary studies of Middle American human populations.....	74
Figure 4.2: Middle American flora and fauna collection locations for stable isotope analysis.....	80
Figure 4.3: Carbon isotopic histogram of modern market plants	87
Figure 4.4: Nitrogen isotopic histogram of modern market plants.....	88
Figure 4.5: Boxplots of legume and non-legume $\delta^{15}\text{N}$	89
Figure 4.6: Average $\delta^{13}\text{C}$ of modern, historic, and archaeological Middle American C3 and C4 plants.....	97
Figure 4.7: Carbon and nitrogen isotopic offsets between paired bone collagen and muscle samples from mammals and fish	99
Figure 4.8: Carbon and nitrogen isotopic distributions of Middle American foodstuffs and human populations	101
Figure 4.9: Boxplots of flora and deer $\delta^{15}\text{N}$	110
Figure 4.10: Boxplots of trophic group $\delta^{15}\text{N}$	111
Figure 4.11: Boxplots of human bone collagen $\delta^{15}\text{N}$ among Middle American sub-regions.....	112
Figure 5.1: Location of Teposcolula and other communities discussed in the text.....	189
Figure 5.2: Timeline of events discussed in the text.....	191
Figure 5.3: Central zone of Teposcolula with enlarged insets of the Grand Plaza and Churchyard cemeteries.....	196
Figure 5.4: Textile impression fragments from burial 20.....	202
Figure 5.5: Preparation of the body for burial during Prehispanic and colonial times....	203
Figure 5.6: Examples of <i>chalchihuitles</i> from burial 27	213
Figure 5.7: Depictions of ceramic effigies of the Mixtec rain deity Dzahui from the Codex Zouche Nuttall and among the grave goods of burial 27	214
Figure 5.8: Depiction of bird sacrifice in association with funerary rites from the Codex Zouche-Nuttall.....	215
Figure 5.9: Images of Xipe Totec sacrificed with arrows on the San Pedro Topiltepec churchyard cross and in the Codex Zouche-Nuttall.....	217
Figure 5.10: Depictions of the 1545 <i>cocoliztli</i> epidemic in native documents.....	220
Figure 5.11: Comparisons of attritional and catastrophic mortality profiles	222
Figure 5.12: Range of oxygen isotopic values for enamel carbonate and bone and	

enamel phosphate.....	228
Figure 5.13: Simplified human mitochondrial DNA haplogroup tree.....	230
Figure 5.14: Carbon and nitrogen isotopic distribution of M3 enamel apatite and bone collagen of the Teposcolula Grand Plaza and Churchyard cemeteries.....	240

List of Appendices

Appendix 2.1: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of food components	35
Appendix 2.2: Measured $\delta^{18}\text{O}$ and δD of food components	36
Appendix 2.3: Measured $\delta^{18}\text{O}$ and δD of drinking water	36
Appendix 2.4: Weight of food component per unit of volume	36
Appendix 2.5: Pig growth table	37
Appendix 2.6: Carbon and nitrogen isotopic ratios of hair during first week of diet experiment.....	37
Appendix 2.7: Oxygen and hydrogen isotopic ratios of hair during first week of diet experiment.....	38
Appendix 2.8: Carbon and nitrogen isotopic ratios of hair during final week of diet experiment.....	38
Appendix 2.9: Oxygen and hydrogen isotopic ratios of hair during final week of diet experiment.....	38
Appendix 2.10: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of blood	39
Appendix 2.11: Measured $\delta^{18}\text{O}$ and δD of blood	39
Appendix 2.12: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of muscle	40
Appendix 2.13: Measured $\delta^{18}\text{O}$ and δD of muscle	40
Appendix 2.14: Measured $\delta^{13}\text{C}$ of subcutaneous fat	41
Appendix 2.15: Measured $\delta^{18}\text{O}$ and δD of subcutaneous fat	41
Appendix 2.16: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of humerus collagen	42
Appendix 2.17: Measured $\delta^{18}\text{O}$ and δD of humerus collagen	44
Appendix 2.18: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of humerus apatite	46
Appendix 2.19: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of mandible collagen	47
Appendix 2.20: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of permanent canine (C1) enamel apatite	48
Appendix 2.21: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of first permanent molar (M1) enamel apatite	49
Appendix 2.22: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of Deciduous second incisor (di2) enamel apatite	49
Appendix 3.1: Mathematical models employed in analysis	70
Appendix 4.1: Bone collagen isotopic ratios of Middle American humans	130
Appendix 4.2: Isotopic ratios of modern native Middle American economic plant resources	145
Appendix 4.3: Isotopic ratios of Middle American wild vegetation collected in a transect survey near the Guilá Naquitz rockshelter in the Valley of Oaxaca.....	155
Appendix 4.4: Isotopic ratios of archaeological carbonized plant remains from Middle America	159
Appendix 4.5: Isotopic ratios of historic Middle American economic plants	160
Appendix 4.6: Isotopic ratios of Middle American terrestrial fauna resources	162

Appendix 4.7: Isotopic ratios of Middle American aquatic fauna resources	172
Appendix 4.8: $\Delta_{\text{collagen-meat}}$ offset in modern terrestrial and aquatic fauna	176
Appendix 4.9: Photographic collection of January 2006 Valley of Oaxaca market samples	177
Appendix 4.10: Photographic collection of July 2006 Valley of Oaxaca market samples	181
Appendix 4.11: Photographic collection of July 2006 Villahermosa market samples	183
Appendix 5.A: Selected excerpts from 16 th century Spanish documents	261
Appendix 5.B: Selected details from 16 th -18 th century pictorial documents, maps, and paintings	290
Appendix 5.C: Photographs of Pueblo Viejo Teposcolula and San Pedro y San Pablo Teposcolula	302
Appendix 5.D: Excavation data from Pueblo Viejo Teposcolula Yucundaa.....	316
Appendix 5.E: Genetic data from the Teposcolula Grand Plaza and Churchyard Cemeteries, as well as outlying residential terraces.....	319
Appendix 5.F: Stable isotope data from the Teposcolula Grand Plaza and Churchyard cemeteries, as well as outlying residential terraces	335
Appendix 5.G: Stable isotope data and photographic collections for non-native crops sold in Mesoamerican markets.....	342

Acknowledgements

My dissertation research took me to many places and institutions and allowed me to explore a wide variety of intellectual interests. This would not have been possible without the support and encouragement of many kind and generous people, and I am deeply grateful for the many conversations and collaborations I have been fortunate to have had over the last six years.

I would first like to thank the members of my committee, Noreen Tuross, Bill Fash, and David Carrasco, for the diverse perspectives and depth of experience they have brought to my research. Through Noreen, I learned a diverse array of new skills and developed a confident writing style; Bill taught me to search for creative solutions to complicated problems and offered sage advice during rough patches; and David has always challenged me to consider the larger social significance of my data.

I would also like to thank additional members of the Anthropology faculty, especially Richard Meadow, for his kind words and thoughtful suggestions over the years, and for the many hours he has spent reading drafts of my articles, proposals, and chapters. I would like to thank all of the faculty for whom I have taught, including Marc Zender, Iain Davidson, Missy Holbrook, Jason Ur, David Carrasco, and Noreen Tuross; their confidence in my work allowed me to develop new teaching skills and provided me with many happy moments in the classroom. I would also like to thank Mike McCormick for his boundless enthusiasm and encouragement, and I look forward to continued conversations and future forays into medieval archaeology.

My dissertation research would not have been possible without the generosity and continued support of Nelly Robles Garcia and Ron Spores, directors of the Proyecto

Arqueológico Pueblo Viejo Teposcolula Yucundaa. I am indebted to them for the opportunity to excavate at Teposcolula Yucundaa and to analyze the colonial cemeteries, and I am deeply grateful for the great lengths Nelly went to ensure that I could export the samples I needed for analysis, even in the darkest times of the civil unrest that threatened the state of Oaxaca in the summer of 2006. Without her support and her deep commitment to Oaxacan archaeology, this project would not have been possible. I would also like to thank Ron for all the encouragement, advice, and suggestions he has offered over the years. His knowledge of Mixtec archaeology is astounding, and I feel privileged to have worked with such an eminent and vibrant scholar.

I would also like to thank the entire Teposcolula Yucundaa archaeological team for their friendship and collaboration, including Elizabeth Galeana, Emilie Duclos, Nobu Matsubara, Steve Brussé, Ronny Bakx, Nicholas Weitlaner, Verence Heredia, Gabriela García, Carl Kuttruff, Isis Martorell, and most especially Laura Diego and Laura Roldán. I have many fond memories of lions roaring in Japanese, pine cones on Buena Vista, “los animales de algodón,” rodeos, and too much mole negro. I would also like to offer a special thanks to Bertha Flores Canseco, who was the administrative glue of the project and who helped and supported me in numerous ways.

I would like to thank Filimón, who assisted me during excavation and from whom I learned so much about the kindness of the human spirit, and I would like to thank Barry Kiracofe, who wrote his dissertation in the 1990s on the architecture of Teposcolula and who generously shared with me not only the original copy of his dissertation, but also his many insightful thoughts and ideas on the early colonial history of Teposcolula.

I was fortunate to be able to spend a summer learning genetic techniques and protocols at the Smithsonian Institution Laboratories of Analytical Biology, and I am grateful for the support and assistance of Lee Weigt, Jeff Hunt, and David Erickson, and insightful conversations with Don Ortner, Bruce Smith, and Mindy Zeder. I was also able to visit the ancient DNA laboratory of Dongya Yang at Simon Fraser University, and I thank Dongya and his student, Camilla Speller, for being so generous with their time and for teaching me new techniques. I would additionally like to thank Christian Daly at Harvard University's Life Sciences Sequencing Facility for helping me to troubleshoot the vagaries of short sequence analysis on our Rosalind and Crick ABI Genetic Analyzers.

My stable isotope research benefited enormously from the skill and talent of Cyndi Kester, who maintains our mass spectrometer, and from the many productive conversations I have enjoyed with fellow labmates Karola Kirsanow, Cheryl Makarewicz, and Gideon Hartman. I would also like to thank Miriam Belmaker for all of her statistical advice and assistance. I am indebted to Cheryl, Josh Wright, David Díaz, and Antonio Martínez Tuñón for assisting me with my Oaxacan winter plant collection, and to Karola, Gideon, Josh, Ben Arbuckle, and Molly Fierer-Donaldson for helping me to transport the ton (literally) of corn that was consumed by the pigs in the alkaline cooking diet experiment. The "pig project" would not have been possible without the collaboration of Dan Lieberman and Katie Zink, the daily assistance of Pedro Ramirez, and the generosity of Don Schleppegrell of Azteca Milling. I would like to thank the Harvard University Herbaria for allowing me to collect plant samples from their extensive Middle American collections, and I would like to especially thank Henry

Kesner and Stephanie Zabel for their knowledge and assistance with the collections.

Throughout my graduate student career, I have never failed to be impressed by the vast collections of the Harvard Library system, and I continue to be amazed by the holdings of Tozzer Library in particular. My Carrel 33 “corner office” was located amid the SPAN.AM, CA, and MEX stacks, and it was a rare day when I came across a reference that was not on those shelves. I am deeply grateful for the assistance of the staff of Tozzer Library, especially Monica Hileman, Ralph Montillo, and Greg Finnegan.

I would also like to acknowledge the truly heroic administrative feats of Monica Munson, Marianne Fritz, and Judith Butler-Vincent. I am very thankful for all of their assistance, guidance, and support. I am also grateful for the close community of graduate students within the Archaeology Program and the Department of Human Evolutionary Biology (formerly Biological Anthropology), and I have many fond memories of Wine Hour, Beer Hour, costume parties, intradepartmental kickball, and jam nights featuring Flinders Petrie and the Egyptians in Michele Koons’ living room.

While at Harvard, I served as a resident tutor at Lowell House for many years, and I benefited greatly from the many friendships fostered in this residential cross-disciplinary community. I would like to say a special thanks to the Lowell House Masters Diana Eck and Dorothy Austin, the former Lowell Resident Dean, Ryan Spoering, and to my predecessor as Librarian of Lowell House and dear friend, Luis Campos.

Finally, I would like to thank my family – my mother, father, and brother, my grandmothers, my Aunt Lynn and Aunt Margaret, and all of the Gibsons – for all their love and support. And most especially, I would like to thank my fiancée, Anne Gibson, for her unwavering support, tireless encouragement, and endless strength.

CHAPTER 1: INTRODUCTION

1.1. Overview

This dissertation has two primary goals: 1) to explore and develop methods and analytical frameworks within two subdisciplines of archaeological science, light stable isotope and archaeogenetic analysis, and 2) to apply these methods in combination with mortuary analysis and paleodemographic analysis to the study of two 16th century colonial Mexican cemeteries. This multidisciplinary approach, grounded in experimental and empirical research, allows multiple hypotheses to be tested regarding the early Spanish colonial period in the Americas, and sheds light on the dynamic cultural and biological changes that accompanied the arrival of Spanish conquistadors and missionaries, the introduction of European epidemic disease, and the transition to colonial governmental and economic systems.

1.2. Background

The field of archaeology is rapidly evolving, and new scientific technologies are expanding the scope and depth of questions that can be asked of the past. In this dissertation, two of these new technologies, light stable isotope analysis and archaeogenetic analysis, are applied in combination with conventional techniques to the study of the early colonial period at the Mixtec site of Teposcolula Yucundaa in Oaxaca, Mexico. In order to refine stable isotope interpretation at Teposcolula, aspects of Middle American plant isotopic diversity and animal metabolism are discussed and further developed in this dissertation.

Light stable isotope analysis has been widely applied in archaeological studies as a method for characterizing subsistence and migration patterns. However, many of the

fundamental assumptions underlying the method have not been adequately tested in experimental or empirical studies. In particular, the natural range of isotopic variation, both at the level of the individual and the ecosystem, has been understudied and poorly defined. This is especially true within Middle America, where the isotopic effects of *nixtamalization*, a widely practiced form of alkaline cooking, have not been investigated in experimental feeding studies, and little is known about the regional isotopic diversity of agricultural crops. As a result, the interpretive framework conventionally used to analyze stable isotope data from Middle America relies on information gathered from other regions and different foodwebs. Through experimental and empirical research on Middle American economic plants and traditional cooking practices, significant revisions to the current isotopic interpretive framework are proposed.

1.3. Dissertation structure

This dissertation consists of four related papers that address methodological issues in stable isotope-based paleodietary reconstruction and archaeogenetics, and then apply these and other methods to an archaeological case study. Each chapter was conceived and written as a stand-alone research article, and two chapters (Chapters 2 and 3) had already been published at the time of dissertation submission. Chapters 2, 3, and 4 follow a standard scientific journal article format, consisting of an introduction with its own set of research questions and hypotheses, a methods section, a results section, and a discussion section that addresses the goals and hypotheses of the study, with little reference to the other chapters in the dissertation. Chapter 5 builds upon the empirical and theoretical results of the other chapters and applies them to a research questions within a specific archaeological context.

Chapters 2 and 3 examine the effects of dietary and physiological parameters on the stable isotopic values of skeletal and soft tissues in a cohort of model animals.

Chapter 2 explores the effects of a traditional Mesoamerican maize cooking technique, *nixtamalization*, on digestion and metabolism of maize in large-bodied, monogastric animals (pigs). Previous stable isotope-based paleodietary models had been based on studies of rats and pigs consuming raw or unprocessed maize. The goal of the experiment was to determine if *nixtamalization*, a common and ancient form of alkaline cooking technique practiced throughout Mesoamerica, improved the digestibility and metabolic potential of maize, thereby altering the isotopic values of consumers' skeletal and soft tissues. The results of the study demonstrate that *nixtamalization* impacts both the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of consumer tissues, two isotopic proxies that are commonly used to reconstruct ancient diet and migration patterns, and suggest that current paleodietary models may overestimate maize consumption in Mesoamerican archaeological populations.

Chapter 3 examines the effects of growth stunting on the tissue isotopic values of a model organism. This study grew out a natural experiment that occurred unintentionally during the experiment described above. During the course of the *nixtamalization* cooking experiment, it was observed that one of the pigs in the control group failed to grow at a normal rate. By the end of the experiment, the reduced growth pig weighed approximately one third that of the other pigs. When the skeletal and soft tissues of the reduced growth pig were analyzed, it was found that the isotopic values of these tissues differed markedly from the other pigs in unexpected patterns. This fortuitous, natural experiment illuminates the poorly explored parameter of physiological status in paleodietary and paleomigratory reconstruction models, and suggests that more research

in this area is necessary in order to accurately model archaeological populations of unknown health and physiological status.

Chapter 4 further explores the theoretical underpinnings of stable isotope-based paleodietary analysis by examining isotopic diversity at the base of the food web.

Surprisingly little isotopic research has been conducted on agricultural plants, especially with respect to variation in plant $\delta^{15}\text{N}$. As a result, previous paleodietary analysis of ancient Middle American populations has been based largely on generalized models derived from widely dispersed, non-local data. This study takes a regional approach and explores isotopic diversity among modern, historic, and ancient Middle American plants within both wild and cultivated contexts. These data were then compared to new and published faunal and human data in order to test hypotheses about the isotopic structure of Middle American foodwebs. The results of this study demonstrate that the isotopic patterning of food webs in Mesoamerica deviates in important ways from generalized models and indicates that many previous paleodietary claims for the region require reevaluation and reinterpretation.

Chapter 5 applies scientific archaeological techniques to the study of two early colonial cemeteries at the Mixtec site of Teposcolula Yucundaa in Oaxaca, Mexico. The early colonial period was a time of dynamic social and biological change. Teposcolula, located high in the mountains of northwest Oaxaca, was the central staging ground for Dominican missionary efforts in the Mixteca Alta and an early adopter of European modes of economic production, including wheat agriculture, sericulture (silkworm raising), and sheep and goat pastoralism. Recent excavation of the site's two principal

colonial cemeteries reveals that it was also an early focal point of European-introduced epidemic disease.

This chapter explores evidence for changing health, demography, economy, and religious practices at early colonial Teposcolula through mortuary, paleodemographic, stable isotopic, and archaeogenetic analysis. The results of Chapters 2-4 are used to refine the interpretation of the Teposcolula human stable isotope data, and a new method for extracting ancient DNA from skeletal remains is described.

Four primary conclusions can be drawn from the Teposcolula study: 1) epidemic disease extended beyond the areas of historical record and played an important role in facilitating the Spanish coerced resettlement program known as *congregación*; 2) although 16th century population decline was severe, evidence of increased genetic drift through altered haplogroup frequencies is not apparent; 3) the adoption of Christianity did not mean the total abandonment traditional practices, even at mission sites; and 4) in contrast to production, consumption of European agricultural staples was minimal. This study reaffirms the importance of archaeological and bioarchaeological evidence in investigating complex social and biological processes of the past that continue to shape the present.

CHAPTER 2: ALKALINE COOKING AND STABLE ISOTOPE DIET-TISSUE DISCRIMINATION IN SWINE¹

The results of this study were presented in part at the 2006 Society for American Archaeology meetings in San Juan, Puerto Rico, and a version of this chapter has been published as a research article in the *Journal of Archaeological Science* (see below). The raw data for the study, which do not appear in the published article, can be found in the appendices at the end of this chapter.

Warinner, Christina, Tuross, Noreen. 2009. Alkaline cooking and stable isotope diet-tissue discrimination in swine. *Journal of Archaeological Science* 36(8):1690-1697.

2.1. Chapter summary

In this chapter I examine the effects of alkaline cooking on carbon and oxygen stable isotopic ratios of mineralized tissues from nine pigs raised on monotonous mixed C3/C4 vegetarian diets. Two sources of collagen (humerus and mandible) and two sources of apatite (humerus and enamel) were analyzed. Within each diet group, humerus and mandible collagens were found to record equivalent $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ ratios; however, enamel apatite was found to be enriched over bone apatite by 2.3‰ in carbon and 1.7‰ in oxygen. Alkaline cooking was found to slightly, but significantly increase the $\Delta^{13}\text{C}_{\text{collagen-diet}}$ and $\Delta^{18}\text{O}_{\text{collagen-diet}}$ of bone collagen. A similar trend towards enrichment was observed in bone and enamel $\Delta^{13}\text{C}_{\text{apatite-diet}}$ and $\Delta^{18}\text{O}_{\text{apatite-diet}}$, but the differences were not significant. Observed isotopic shifts were consistent with increased nutrient utilization of the alkaline-cooked maize as compared to raw maize. In addition, a reexamination of the relationship between diet and tissue carbon isotopic values suggests that species and alimentary type should be considered in interpreting ancient diets.

¹ This study was conducted under Harvard University Faculty of Arts and Sciences Animal Experimentation Protocol Number 24-19. I would like to thank Dan Lieberman and Katherine Zink for assistance with experimental design and development, Cynthia Kester for technical assistance with the mass spectrometer, and Pedro Ramirez, who served as the primary handler of the pigs at the Concord Field Station. I would especially like to thank Don Schleppegrell of Azteca Milling, LLP for donating all of the maize products used in this study, as well as Karola Kirsanow for assisting with multiple parts of the study.

2.2. Introduction

Stable isotope analysis is now a widely used analytical tool in archaeology. Body tissue isotopic ratios of carbon and oxygen have been shown to record biologically meaningful information that may persist in the archaeological record for hundreds or thousands of years (Schoeninger et al. 1983; Koch et al. 1997; Trueman et al. 2004; Wang and Cerling 1994). This analytical approach has contributed to our knowledge of the dynamic history of past human societies on topics that include subsistence strategies, ecological change, and mobility patterns (Rose 2008; West et al. 2006; Budd et al. 2004). Mineralized tissues (bones and teeth) are the most commonly analyzed body tissues for stable isotope analysis. Within these tissues, bone collagen and bone and tooth apatite can be analyzed for organic and inorganic sources of carbon and oxygen. Each of these isotopic proxies provides a semi-independent line of evidence for the investigation of complex topics such as paleodiet (Hu et al. 2006; Finucane et al. 2006) and migration history (e.g., White et al. 2002; Quinn et al. 2008). Accurate reconstruction of dietary or migratory history, however, requires a precise understanding of the multiple isotopic fractionations that accompany the conversion of dietary inputs (food and water) into consumer tissues. Controlled diet experiments on model organisms are essential to refine our understanding of the complex factors that influence isotopic enrichment or depletion of biological tissues during this process.

Previous experimental stable isotope studies have focused primarily on rodents (*Mus musculus* and *Rattus norvegicus*) to model the incorporation of dietary isotopic ratios into consumer tissues (Ambrose 2000; Ambrose and Norr 1993; Tieszen and Fagre 1993; Jim et al. 2004). Rodents, however, differ markedly from humans with respect to metabolic

rate, digestive physiology, and feeding habits (Baker 2008; Blaxter 1989). Many of these studies additionally lack basic information about the health status of their subjects, including growth profiles (see Tieszen and Fagre 1993 for an exception). Recently, researchers have turned to swine as an alternative animal model (Hare et al. 1991; Howland et al. 2003; Passey et al. 2005). Like humans, swine are large-bodied and omnivorous, and the two species share similar digestive physiology, including a simple, monogastric gastrointestinal tract (Miller and Ullrey 1987; Tumbleson 1986).

In addition to digestive and metabolic differences between species, environmental factors, such as aridity (Ambrose 2000), canopy cover (van der Merwe et al. 1991; Cerling et al. 2004), and nutritional stress (e.g., Gaye-Siessegger et al. 2003, 2007; Hobson and Clark 1992; Hobson et al. 1993; Trueman et al. 2005) have also been shown to influence apparent tissue-diet isotope fractionation. In this study, I sought to explore whether cultural factors, such as cooking, could also influence perceived tissue-diet isotope fractionation.

In the Americas, populations subsisting on a staple diet of maize (*Zea mays*) frequently practice a specialized form of cooking known as alkaline cooking (Katz et al. 1974). Alkaline cooking is an intensive food preparation technique that involves soaking and boiling dried maize kernels in an alkaline water solution (FAO 1992). In Mesoamerica (Mexico, Guatemala, Belize, Honduras) and parts of the U.S. Southwest, where the alkali agent employed is calcium hydroxide (lime), this cooking technique is called nixtamalization (Katz et al. 1974).

The effects of alkaline cooking have been studied extensively in nutritional and food science literature (FAO 1992). Although alkaline cooking has been shown to decrease the

total nutritional content of maize (Bressani et al. 1958), it enhances its apparent nutritional value, as measured by increased protein efficiency ratios (Bressani 1990) and weight gain in experimental animals (e.g., Cravioto et al. 1952; Kodicek et al 1956; Laguna and Carpenter 1951; Pearson et al. 1957; Squibb et al. 1959; Bressani et al. 1966).

The potential for alkaline cooking to affect the isotopic values of maize agricultural populations has been previously noted (Marino and DeNiro 1987; Wright 1994). However, these studies measured the effect of alkaline cooking on the stable isotope ratios of maize itself, rather than the changes induced in consumer tissues. For example, after noting that selective loss of maize fiber and increased digestibility of essential amino acids could shift the isotopic composition of maize and/or alter its digestibility, Wright (1994) conducted nixtamalization experiments on maize, but found that alkaline cooking had no significant effect on the $\delta^{13}\text{C}$ of the alkali-treated maize. This confirmed the results of previous research by Marino and DeNiro (1987) that nixtamalization had little effect on the $\delta^{13}\text{C}$ isotope ratios of laboratory grade alpha cellulose and maize cellulose. The results of these studies were interpreted to mean that nixtamalization had no significant isotopic impact on maize-based diets. However, nutritional studies have indicated that alkaline cooking changes tertiary protein structure, insoluble fiber content, and phytic acid activity, which are all factors that primarily affect digestion and bioavailability of nutrients and minerals (FAO 1992; Wachter 2003). The potential downstream isotopic effects of these changes have not been investigated.

In this study, I employed a multi-proxy approach to investigate the effects of alkaline cooking on isotopic discrimination in the mineralized tissues of swine. Nine pigs were

raised on experimental diets containing either unprocessed (raw) or nixtamalized maize. After 13 weeks on the experimental diets, the pigs' mineralized tissues were analyzed for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. In order to assess whether the effects of alkaline cooking were tissue specific, both apatite and collagen were measured. In addition, two sources of apatite (bone and enamel) and collagen (humerus and mandible) were investigated to determine if apatite and collagen represent isotopically homogenous tissues throughout the body.

2.3. Materials and Methods

2.3.1 Controlled Diet Study

Eleven pigs (*Sus domesticus*, Yorkshire cross) were born and farm-raised until six weeks of age. At six weeks they were weaned and transferred to the Harvard University Concord Field Station in Bedford, MA. Hair samples were collected from each pig on the first day of the study. No significant difference was observed in the $\delta^{13}\text{C}$ of hair keratin between the pigs who would later be divided into two diet groups (data not shown). One pig (pig 1) was randomly selected and sacrificed upon arrival at the field station, and its humerus was collected for isotopic analysis (Table 2.1). At the end of the diet experiment, a deciduous lower second incisor (di_2) was collected post mortem from each diet experiment pig and analyzed for isotopic composition (Table 2.1). Because di_2 maturation was complete at the start of the diet experiment, the enamel isotopic ratios of this tooth reflect a pre-diet experiment signal. No significant difference was observed in the $\delta^{13}\text{C}$ or $\delta^{18}\text{O}$ of the enamel apatite between the pigs who would be later divided into the two diet groups (data not shown).

Table 2.1. Pre-Diet Experiment Tissue Isotopic Values

	$\delta^{13}\text{C}_{\text{coll}}^{\text{a}}$	$\delta^{13}\text{C}_{\text{bone ap}}$	$\delta^{13}\text{C}_{\text{enam ap}}^{\text{b}}$	$\delta^{18}\text{O}_{\text{coll}}^{\text{c}}$	$\delta^{18}\text{O}_{\text{bone ap}}$	$\delta^{18}\text{O}_{\text{enam ap}}^{\text{b}}$
Pig 1	-14.2 ± 0.3	-8.0	-	5.4 ± 0.2	20.6	-
Pigs 2-10	-	-	-4.8 ± 0.6	-	-	21.3 ± 0.4

Notes:

^aAverage value and standard deviation for five humerus collagen replicates.

^bEach incisor was measured once, and the average and standard deviation of pooled samples is reported.

^cAverage value and standard deviation for four humerus apatite replicates.

At the Concord Field Station, the pigs were divided into two diet groups and raised on experimental diets for 13 weeks. The first diet group (pigs 2-6) was fed Diet_{nix}, while the second diet group (pigs 7-11) was fed Diet_{raw}. By weight, the nixtamalized diet, Diet_{nix} was composed of 25% nixtamalized yellow maize flour and 75% C3 feed, while the unprocessed maize diet, Diet_{raw}, was composed of 23% dried yellow maize kernels and 77% C3 feed. Both maize products derive from the same stock and were provided courtesy of Don Schleppegrell of Masa Mixta (Azteca Milling, LP, Irving, TX). The feed was purchased from Purina (LabDiet Mini-Pig Grower Diet 5081, PMI, Richmond, IN). To facilitate consumption of the maize flour, the nixtamalized diet was rehydrated with local tap water to make a thick slurry; the raw diet was not rehydrated. Isotopic composition of the individual dietary components is provided in Table 2.2.

The total $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of the dehydrated experimental diets were calculated using a mass balance equation:

$$\delta X_{\text{diet}} = \frac{W_m * P_m * \delta X_m + W_f * P_f * \delta X_f}{W_m * P_m + W_f * P_f}$$

Where W_m is the percentage by weight of maize in the experimental diet, W_f is the percentage by weight of feed in the diet, P_m is the measured proportion of X element in the maize component of the diet, P_f is the measured proportion by weight of the X

Table 2.2. Experimental Diet Components and Stable Isotopic Ratios (‰)

Diet Components	$\delta^{13}\text{C}^{\text{a}}$	%C ^a	$\delta^{18}\text{O}^{\text{b}}$	%O ^b
Nixtamalized Maize (dry)	-11.5±0.1	48.8	27.1±0.6	43.2
Raw Maize (dry)	-11.8±0.2	48.4	27.8±0.3	43.7
Feed (dry)	-26.5±0.3	48.4	22.3±0.4	39.3

Notes:

^aNixtamalized maize (n=10), raw maize (n = 16), feed (n = 10)

^bNixtamalized maize (n=5), raw maize (n = 4), feed (n = 5)

element in the feed component of the diet, δX_{m} is the measured maize product δ , and δX_{f} is the measured feed δ . X can refer to any element. The calculated total diet isotopic ratios are reported in Table 2.3.

Although the diets were isotopically similar, Diet_{raw} was slightly more enriched than Diet_{nix} with respect to both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. During the 13-week study, the pigs were allowed to eat and drink local tap water *ad libitum*, as well as exercise freely in large runs. The pigs were weighed five times over the course of the experiment to monitor growth.

Because mammalian feeding experiments require a diet switch at weaning, it is a concern that the bones of growing animals may be heterogeneous in their isotopic signatures and contain a mosaic of both pre- and post-experimental diet signals. In order to mitigate this problem, the pigs in the present study were allowed to grow until they had more than tripled their starting weight during the first week of the diet experiment. By week 13 of the diet experiment, pigs 2-10 had added an average of 42kg to their mean starting weight of 11.8kg, an increase of 320%. Their growth rate was similar to that observed in other well-fed “large white” pigs (Tonge and McCance 1973). One pig, pig 11, fell over two standard deviations below the average weight and was excluded from this study.

Table 2.3. Isotopic ratios of experimental diets^a and water^b

Experimental diets	% maize	% feed	$\delta^{13}\text{C}$ (‰)	$\delta^{18}\text{O}$ (‰)
Calculated diet _{nix}	23.3	76.7	-23.0	23.5
Calculated diet _{raw}	29.2	70.8	-22.2	24.1
Measured tap water	-	-	-	-7.8

Notes:

^aDiet isotopic ratios are provided for dehydrated diets. All consumed water, both that used to rehydrate food and to provide drinking water, derived from a single tap water source. Because the pigs were given access to water *ad libitum*, total consumed $\delta^{18}\text{O}$ could not be calculated.

^bTap water $\delta^{18}\text{O}$ is reported as an average of six runs.

At 19 weeks of age (after 13 weeks on the experimental diets), the pigs were sacrificed according to approved procedures. Samples of sub-periosteal bone from the humerus and mandible were collected, as well as erupted upper and lower permanent canines. Canines were selected for harvest because published tooth maturation data for pigs indicated that they would form entirely during the period of the controlled diet experiment (Tonge and McCance 1973). To confirm that the canines of the pigs were mineralizing during the diet experiment, injections of fluorochromatic bone label calcein (Sigma, St. Louis, MO) were administered IM every two weeks during the diet study, for a total of 6 injections. The calcein was administered at a dosage of 30mg per kg body weight. The erupted canines were fluorescent in UV light, indicating calcein incorporation. Additionally, pig 1, which was sacrificed on the first day of the experiment, did not show gross evidence of permanent canine formation. After collection, all tissue samples were frozen until further treatment or lyophilization.

2.3.2 Sample Preparation

Food and water

Food components were ground to a fine powder using mortar and pestle and weighed into tin capsules for isotopic analysis. Water samples were manually injected through a septum fitted injection port.

Collagen

Humeri and mandibles were dissected and scraped free of the periosteum. A Dremel multi-pro rotary drill was used to remove bone fragments. The bone fragments were degreased by soaking in 3:1 chloroform:methanol for 3 days. Humerus and mandible bone fragments were prepared for collagen extraction as described by Tuross et al. (2008) and demineralized in 0.5M EDTA for 1-3 weeks. The collagen pseudomorphs were transferred to fresh tubes, soaked overnight in deionized distilled water, washed 15 times, frozen, and lyophilized. For carbon analysis, the collagen pieces were each subsampled five times and weighed into tin capsules for $\delta^{13}\text{C}$ analysis. For oxygen analysis, the collagen pieces were subsampled 3-5 times and weighed into silver capsules for $\delta^{18}\text{O}$ analysis.

Apatite

Bone powder was obtained by drilling the mechanically cleaned and defatted humerus fragments (see above) with a mounted press drill. Teeth were mechanically cleaned and wiped with deionized distilled water before sampling. Tooth powder was obtained by drilling enamel from erupted upper and lower C1s using a mounted press drill. Bone and tooth powders were frozen, lyophilized, and weighed into sealed glass vials until analysis.

2.3.3. Mass Spectrometry

Collagen, food components, and water (C, O)

Samples were analyzed for $\delta^{13}\text{C}$ in continuous flow mode on a Finnegan Delta XL isotope ratio mass spectrometer at a reaction temperature of 1020°C. Isotopic composition of $\delta^{13}\text{C}$ is reported relative to PDB (Fry et al. 1992). The analytical precision for the $\delta^{13}\text{C}$ determination is ± 0.2 ‰.

Samples were analyzed for $\delta^{18}\text{O}$ by continuous flow isotope ratio mass spectrometry using a Thermo Temperature Conversion Elemental Analyzer (TC/EA) coupled to a Thermo Delta Plus XP mass spectrometer (Sharp et al. 2001). The factory installed GC column in the TC/EA was replaced with a 1.8 m packed 5Å molecular sieve column and operated at 125°C to allow for better separation of CO gases. The reactor temperature is set to 1425°C and helium flow (approximately 100mL/min) is top fed. Oxygen isotope composition of the water samples is reported relative to Vienna Standard Mean Ocean Water (VSMOW) and normalized using VSMOW and SLAP. Oxygen isotope composition of the food and collagen samples is reported relative to VSMOW and calibrated against IAEA-601 ($\delta^{18}\text{O} = 23.3$ ‰) and IAEA-602 ($\delta^{18}\text{O} = 71.4$ ‰). Analytical error of oxygen isotope values is ± 1 ‰.

Apatite carbonates (C, O)

Samples were analyzed by continuous flow mass spectrometry using a Thermo Gas Bench II coupled to a Thermo Delta Plus XP mass spectrometer (Paul and Skrzypek 2007). Isotopic composition of $\delta^{13}\text{C}$ is reported relative to PDB, and oxygen isotope compositions are reported relative to Vienna Standard Mean Ocean Water (VSMOW). Samples were calibrated using NBS 18 ($\delta^{13}\text{C}$ PDB = -5.01; $\delta^{18}\text{O}$ VSMOW = 7.20) and

NBS 19 ($\delta^{13}\text{C}$ PDB = 1.95; $\delta^{18}\text{O}$ VSMOW = 28.60). Observed analytical error for standards is $\pm 0.08\text{‰}$ for $\delta^{13}\text{C}$ values and $\pm 0.16\text{‰}$ for $\delta^{18}\text{O}$ values.

2.3.4 Evaluation of Sample Bias in Enamel Samples

Upper and Lower Canines

Enamel apatite was collected from both upper and lower canines and was evaluated for sampling bias between the two teeth. Although upper and lower canines in swine have been shown to form simultaneously (Tonge and McCance 1973), and thus should record equivalent isotopic values, a two-tailed Student's *t*-test was performed on the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of the upper and lower canines to ensure that there was no isotopic bias between the two sets of teeth (data not shown). In both diet groups, no significant difference was observed between the upper and lower canines in either carbon or oxygen isotopic ratios. Thus, upper and lower canines were pooled together for further analysis.

2.4. Results

2.4.1. Isotopic Discrimination across Tissues

Humerus and Mandible Collagen

In both diet groups, isotopic incorporation into collagen was not statistically different between the humerus and mandible samples with respect to $\delta^{13}\text{C}$ (Table 2.4 and 2.5). Because the $\delta^{13}\text{C}$ of the humerus and mandible samples were not significantly different, an average bone collagen $\delta^{13}\text{C}$ was calculated for each individual and used in all subsequent analyses.

Bone and Enamel Apatite

In contrast to the collagen data, carbon isotopic values in enamel apatite differed significantly from bone apatite (Table 2.4). Enamel apatite $\delta^{13}\text{C}$ was found to be enriched

Table 2.4. Mineralized Tissue Isotopic Ratios (‰) in Week 13 of the Diet Experiment

Diet Group	Humerus $\delta^{13}\text{C}_{\text{collagen}}^{\text{a}}$	Mandible $\delta^{13}\text{C}_{\text{collagen}}^{\text{a}}$	Humerus $\delta^{13}\text{C}_{\text{apatite}}^{\text{b}}$	Canine $\delta^{13}\text{C}_{\text{apatite}}^{\text{c}}$	Humerus $\delta^{18}\text{O}_{\text{collagen}}^{\text{d}}$	Humerus $\delta^{18}\text{O}_{\text{apatite}}^{\text{b}}$	Canine $\delta^{18}\text{O}_{\text{apatite}}^{\text{c}}$
Diet_{nix}							
Pig 2	-18.5± 0.1	-18.4± 0.1	-10.6	-8.4± 0.1	5.9± 0.4	19.1	21.2± 0.3
Pig 3	-19.3± 0.0	-19.4± 0.2	-10.6	n.r.	6.4± 0.2	20.1	n.r.
Pig 4	-19.1± 0.1	-18.7± 0.7 ²	-11.5	-8.8	5.9± 0.5	19.1	21.1
Pig 5	-18.7± 0.3	-19.0± 0.1	-10.8	-8.9± 0.1	6.4± 0.4	19.6	21.3± 0.2
Pig 6	-18.6± 0.1	-18.7± 0.0	-10.6	n.r.	6.0± 0.3	20.0	n.r.
Average:	-18.8± 0.3	-18.8± 0.4	-10.8± 0.4	-8.7± 0.3	6.1± 0.3	19.6± 0.5	21.2± 0.1
$\Delta_{\text{Tissue-Diet}}$	4.2	4.2	12.2	14.3	-17.4	-3.9	-2.3
$\Delta_{\text{Tissue-Water}}$	-	-	-	-	13.9	27.4	29.0
Diet_{raw}							
Pig 7	-18.7± 0.1	-18.5± 0.1	-10.0	-8.1	6.6± 0.3	19.5	21.4
Pig 8	-19.7± 0.0	-19.8± 0.2	-11.3	-8.5	6.4± 0.3	19.9	21.8
Pig 9	-18.7± 0.2	-18.7± 0.3	-9.3	-7.5± 0.1	6.2± 0.3	20.2	21.8± 0.1
Pig 10	-18.6± 0.1	-18.8± 0.1	-10.2	-8.3	6.4± 0.2	20.0	21.5
Average:	-18.9± 0.5	-18.9± 0.6	-10.2± 0.8	-8.1± 0.4	6.4± 0.2	19.9± 0.3	21.6± 0.2
$\Delta_{\text{Tissue-Diet}}$	3.3	3.3	12.0	14.1	-17.7	-4.2	-2.5
$\Delta_{\text{Tissue-Water}}$	-	-	-	-	14.2	27.7	29.4

Notes:

Not recorded (n.r.)

^aEach humerus and mandible was sampled five times for collagen $\delta^{13}\text{C}$. The mean and standard deviation are presented.

^bEach humerus was sampled once for apatite $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$.

^cCanines from only seven pigs were available. For pigs 2, 5, and 9 both upper and lower canines were sampled and the mean and standard deviation is presented above. For pigs 4, 7, 8, and 10, either an upper or a lower canine was sampled.

^dEach humerus was sampled between three and five times for collagen $\delta^{18}\text{O}$. The mean and standard deviation are presented.

over bone apatite by 2.2‰ in the Diet_{nix} group and 2.3‰ in the Diet_{raw} group. Enamel apatite $\delta^{18}\text{O}$ was likewise enriched over bone apatite by 1.6‰ in the Diet_{nix} group and 1.7‰ in the Diet_{raw} group (Table 2.5). On average for both diet groups the degree of isotopic enrichment observed in the enamel apatite over the bone apatite was 2.3‰ in carbon and 1.7‰ in oxygen (Figure 2.1b).

2.4.2. Alkaline Cooking

The effects of alkaline cooking were compared across three tissues (bone collagen, bone apatite, and enamel apatite) using carbon and oxygen isotopic ratios.

Carbon and oxygen were selected because both have been shown to correlate with diet,

Table 2.5. Comparison of tissue δ using a two-tailed Student's t test

Tissue vs. tissue	Avg. Difference ^a (tissue - tissue)	p value
Humerus vs. Mandible		
$\delta^{13}\text{C}_{\text{collagen}}$		
Diet _{nix}	0.0	0.94
Diet _{raw}	0.0	0.98
Enamel vs. Humerus $\delta^{13}\text{C}_{\text{apatite}}$		
Diet _{nix}	2.2 (s)	0.002
Diet _{raw}	2.3 (s)	0.004
Enamel vs. Humerus $\delta^{18}\text{O}_{\text{apatite}}$		
Diet _{nix}	1.6 (s)	0.001
Diet _{raw}	1.7 (s)	< 0.001

Notes:

^aDifferences significant at the 0.05 level are marked by an (s).

both can be measured from more than one tissue, and because the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of food inputs were isotopically diverse in both diet groups. Before comparing the effects of alkaline cooking on the mineralized tissues of the two diet groups, a correction was performed to account for the slightly different isotopic ratios of the two diets. This was accomplished by subtracting the isotopic ratio of the diet from the mineralized tissue ($\delta_{\text{tissue}} - \delta_{\text{diet}}$) to yield the $\Delta_{\text{tissue-diet}}$. Given a null hypothesis that alkaline cooking has no effect on downstream tissue isotopic ratios of consumers, $\delta^{13}\text{C}_{\text{tissue-diet}}$ and $\delta^{18}\text{O}_{\text{tissue-diet}}$ should be identical for both experimental diet groups.

In order to evaluate the hypothesis that alkaline cooking improves maize digestibility and thereby increases the proportion of maize-derived $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in consumer tissues, a two-tailed Student's t -test was performed comparing the $\Delta^{13}\text{C}_{\text{tissue-diet}}$ and $\Delta^{18}\text{O}_{\text{tissue-diet}}$ of bone collagen, bone apatite, and tooth apatite between the two diet groups (Table 6). With respect to bone collagen, differential carbon and oxygen isotope incorporation was observed as a function of food processing (Figure 2.1a). The $\Delta^{13}\text{C}_{\text{collagen-diet}}$ of the Diet_{nix} group was found to be significantly enriched over the collagen of Diet_{raw} group by an average of 0.9‰. Similarly, the $\Delta^{18}\text{O}_{\text{collagen-diet}}$ of the

Table 2.6. Comparison of diet groups using a two-tailed Student's *t* test

Diet _{nix} vs. diet _{raw}	Avg. difference ^a (diet _{nix} – diet _{raw})	<i>p</i> value
$\Delta^{13}\text{C}_{\text{collagen-diet}}$	0.9 (s)	0.02
$\Delta^{13}\text{C}_{\text{humerus apatite-diet}}$	0.2	> 0.10
$\Delta^{13}\text{C}_{\text{enamel apatite-diet}}$	0.2	> 0.10
$\Delta^{18}\text{O}_{\text{collagen-diet}}$	0.3 (s)	0.05
$\Delta^{18}\text{O}_{\text{humerus apatite-diet}}$	0.3	> 0.10
$\Delta^{18}\text{O}_{\text{enamel apatite-diet}}$	0.2	> 0.10

Notes:

^aDifferences significant at the 0.05 level are marked by an (s).

Diet_{nix} group was found to be significantly enriched over the collagen of the Diet_{raw} group by an average of 0.3‰ (Figure 1A). Although bone and enamel apatite also showed a trend towards enrichment in the Diet_{nix} group (Figure 2.1b), the differences between the two diet groups were not significant with respect to carbon or oxygen.

2.5. Discussion

2.5.1 Effects of Alkaline Cooking

In contrast to previous studies, the results of this experiment demonstrate that alkaline cooking is an important factor that affects carbon and oxygen stable isotope ratios and is therefore relevant for accurate diet and migration modeling. Alteration of intraspecific $\Delta_{\text{tissue-diet}}$ spacing in this experiment violates model assumptions that intraspecific $\Delta_{\text{tissue-diet}}$ spacings are constant. To explain this, I hypothesize that alkaline cooking improved the bioavailability of carbon and oxygen of maize, thereby enriching the effective δ_{diet} of Diet_{nix}. If intraspecific $\Delta_{\text{tissue-diet}}$ spacing was indeed constant in this experiment, then the $\Delta_{\text{tissue-diet}}$ spacing would be added to the effective δ_{diet} ; however, because only absolute δ_{diet} was measured the result would be an apparent increase in the $\Delta_{\text{tissue-diet}}$ spacing of the Diet_{nix} cohort.

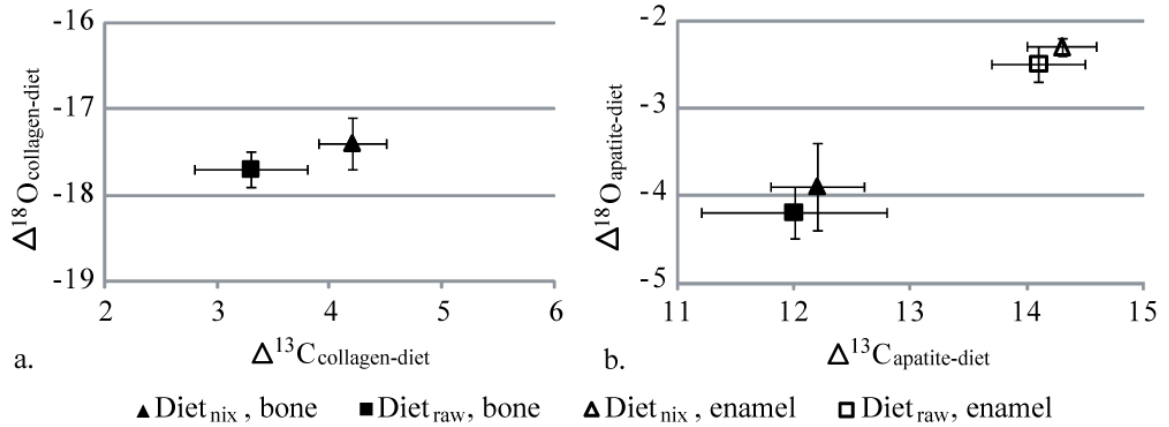


Figure 2.1a-b. Comparison of tissue-diet spacings in a) bone collagen and b) bone and enamel apatite between experimental diet groups.

A trend towards greater $\Delta_{\text{tissue-diet}}$ was observed in the Diet_{nix} group across all tissues in both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. This trend was significant in collagen and resulted in an average enrichment of 0.9‰ in carbon and 0.3‰ in oxygen over the Diet_{raw} group. A greater isotopic offset between the diet groups was expected in carbon since the $\delta^{13}\text{C}$ of the feed and maize components of the experimental diets differed by approximately 15‰, while the $\delta^{18}\text{O}$ of the feed and maize components differed by only 5‰.

Although the trend toward tissue isotopic enrichment was significant in collagen, the isotopic ratios of the Diet_{nix} and Diet_{raw} groups were less distinct with respect to apatite. Failure to observe significant apatite enrichment in the Diet_{nix} group may have resulted in part from the reduced number of replicates measured for bone and enamel apatite isotopic ratios. The method of tissue preparation (mechanical drilling) may have also played a role since the apatite was homogenized prior to sampling, unlike the collagen, which was sampled from histologically intact pseudomorphs removed from the bone surface (the

most recently created bone in a growing animal). Alternatively, the isotopic differences observed between the two tissues may reflect distinctive processes governing the incorporation of stable isotopes into collagen and apatite. Alkaline cooking is known to alter the bioavailability of maize proteins (Bressani 1990; Bressani et al. 1958; Bressani and Scrimshaw 1958), and the discrepancy between collagen and apatite may reflect differential utilization of amino acids during collagen and apatite metabolism, as suggested by Schwarcz (2000).

The systematic enrichment of bone collagen as a function of alkaline cooking has important implications for accurate diet reconstruction of archaeological populations. Human populations consuming disparate terrestrial diets have been shown to vary in their collagen $\delta^{13}\text{C}$ by approximately 12‰. Neolithic Chinese rice agriculturalists at the site of Jiahu, for example, have an average $\delta^{13}\text{C}$ of -20.4‰ (Hu et al. 2006), while Classic Maya maize agriculturalists at the site of Pacbitun, Belize have an average $\delta^{13}\text{C}$ of -8.5‰ (White et al. 1993). This accords roughly with data from controlled feeding experiments on mice (-21.9‰), rats (-21.4‰), and pigs (-19.6‰) raised on pure C3 diets, and mice (-9.8‰) and rats (-7.9‰) raised on pure C4 diets (Tieszen and Fagre 1993; Ambrose and Norr 1993; Howland et al. 2003).

Given a total known range of 12‰ in the collagen $\delta^{13}\text{C}$ of human populations, the isotopic shift observed as an effect of alkaline cooking in this experiment (0.9‰) represents 7.5% of the total range of $\delta^{13}\text{C}$ observed in humans. Although the observed offset in this study was relatively small, it may scale with an increasing maize proportion of the diet. In populations where maize protein contributes a significant portion of the total diet, and in areas where maize processing techniques are unknown or variable, this

could increase the uncertainty associated with dietary reconstruction across time periods and among populations. This uncertainty also makes direct comparison between populations practicing different maize cooking techniques problematic, as the magnitude of $\Delta^{13}\text{C}_{\text{collagen-diet}}$ is unknown at dietary maize protein percentages other than that tested in this study.

2.52 Mineralized tissue selection

Humerus and Mandible Collagen

In archaeological isotopic studies, bone is frequently treated as a homogenous tissue, and samples may be collected from a variety of bone types (e.g., long bones, flat bones, irregular bones, and short bones), as well as from different structural forms (e.g., compact bone and cancellous bone). Rather than being homogenous, however, bone is both ontogenetically and histologically complex, forming fetally through either endochondral or intramembranous ossification, and organizing into lamellar, woven, fibrolamellar, and secondary osteon forms in the adult skeleton (Currey 2002). The consistency of isotopic ratios across diverse bone types of differing ontogeny has not been extensively tested. To address this problem, I compared collagen $\delta^{13}\text{C}$ from two bones classified into different types and formed by different ontogenetic processes.

I found no significant isotopic difference between the humerus, which is a long bone formed through endochondral ossification, and the mandible, an irregular bone formed through intramembranous ossification. The consistency of ^{13}C incorporation into both the humerus and mandible samples has important implications for archaeologists, for whom choices regarding sample selection may be limited. My results indicate that, excluding

taphonomic factors, collagen samples collected from different bones of the same rapidly growing animals produce equivalent $\delta^{13}\text{C}$ data sets.

Bone and Enamel Apatite

Within the context of apatite studies, the majority of controlled feeding experiments on laboratory animals has focused on the measurement of apatite from bone (Ambrose and Norr 1993; Tieszen and Fagre 1993; Howland et al. 2003; Jim et al. 2004). For modern samples, bone apatite is a preferred substrate for $\delta^{13}\text{C}$ comparison to bone collagen because both are cogenetic in the same tissue and undergo remodeling together (Currey 2002). Enamel apatite, by contrast, forms only once and is never remodeled. Thus, enamel apatite and bone collagen of adult animals represent temporally segregated isotopic deposition events. However, because of the taphonomic problems associated with archaeological bone apatite (Koch et al. 1997; Tuross et al. 1989; Wang and Cerling 1994), enamel apatite $\delta^{13}\text{C}$ is more commonly measured and reported in archaeological studies.

Although current diet reconstruction models (e.g., Kellner and Schoeninger 2007) employ bone apatite data to establish empirical relationships between apatite and diet isotopic ratios, it is unclear whether or not these relationships can be extended to enamel isotopic ratios for archaeological applications. Additionally, some migration studies (e.g., Tutken et al. 2008), posit that oxygen isotopic differences between paired enamel and bone apatite samples would constitute evidence for migration, but the oxygen isotopic relationship between enamel and bone apatite has not been extensively studied. In this study, simultaneously forming bone and enamel apatite samples were collected from each pig and compared. Bone and enamel apatite were not found to be isotopically equivalent

tissues under the experimental conditions of this study. Enamel apatite was consistently enriched over bone apatite by an average of 2.3‰ in $\delta^{13}\text{C}$ and 1.7‰ in $\delta^{18}\text{O}$ (Table 2.4). This is the first study to report differences in simultaneously forming paired tooth and bone samples from a controlled diet experiment.

Although bone and enamel apatite discrepancies have been observed in other studies, complicating factors in each study made the evaluation of apparent offsets difficult. Howland et al. (2003), for example, reported $\Delta^{13}\text{C}_{\text{apatite-diet}}$ values in bone ranging from 8.7-12.1‰ in pigs raised on six different diets. In a separate study, Passey et al. (2005) measured offsets between enamel apatite and diet in pigs fed a C3 diet and observed a $\Delta^{13}\text{C}_{\text{enamel-diet}}$ of 13.1‰. Passey et al. (2005) interpreted the discrepancy between their data and Howland et al. (2003) to be the result of preferential digestion of isotopically variant dietary components in the mixed diets consumed by the pigs in the Howland et al. (2003) study.

However, in a study of carbon isotope fractionation in marine mammals, Clementz et al. (2007) found that mean $\Delta^{13}\text{C}_{\text{enamel-bone}}$ varied among species from -3.2‰ to 2.8‰. Paired bone and tooth samples from manatees, dugongs, harbor porpoises, and sea otters were found to have positive $\Delta^{13}\text{C}_{\text{enamel-bone}}$ offsets, while harbor seals, elephant seals, California sea lions, and northern fur seals were found to have negative offsets. Thus, discrepancies observed between bone and enamel apatite cannot be entirely attributed to differential digestion, although the effects of seasonal variation in diet and discrepancies in the timing of enamel formation and ongoing bone remodeling could not be resolved.

In this study it is clear that bone and enamel apatite in pigs have different diet offsets that cannot be attributed to preferential or differential digestion since the carbonate in

both the bone and enamel apatite was deposited from dissolved blood bicarbonate during the same experimental period. Over the course of the diet experiment, the pigs increased their weight by an average of 320%, thus attesting to their growth and the incorporation of the experimental diets into their tissues. The concomitant formation of enamel and bone mineral during this period mitigates complicating factors common in ecological studies, such as seasonal variation in diet and ontogenetic dietary changes. However, even if the bone apatite of the pigs carried a partial residual isotopic signature from the pre-weaning diet, it could not account for the $\delta^{13}\text{C}$ isotopic spacing observed between the humerus and canine apatite in the pigs. The pre-weaning diet was more enriched than both experimental diets, as evidenced by the bone apatite $\delta^{13}\text{C}$ of -8.2 ± 0.2 measured in Fig 1, which was sacrificed during the first week of the experiment. Thus, inclusion of a partial pre-diet experiment isotopic signature would serve to narrow, rather than widen, the $\Delta^{13}\text{C}_{\text{bone-enamel}}$ of the adult pigs. The same pattern of differential enrichment was also seen in the oxygen isotopic ratios. Compared to bone apatite, pig canine $\delta^{18}\text{O}$ was found to be systematically enriched by +1.7‰. Differences in apatitic maturation may account for some of the variation in the magnitude of fractionation between carbonate mineral and blood bicarbonate in bone and enamel apatites (e.g. Smith et al. 2005). Enamel is more highly mineralized than bone apatite, and enamel hydroxyapatite crystals are larger with fewer defects and substitutions (LeGeros 1981). Although there are many good theoretical reasons to expect differences between the isotopic ratios of bone and enamel apatites, current paleodietary models do not acknowledge these differences. This study provides empirical evidence that bone and enamel apatites are not isotopically equivalent tissues in mammals and should be treated separately in isotopic models.

Differential offsets in the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of bone and enamel apatite suggest that local biological factors regulating carbonate incorporation into apatites have the potential to impact paleodietary and paleoenvironmental isotopic-based interpretations. If humans have a similar $\Delta^{13}\text{C}_{\text{tooth-bone}}$ to that observed in the pigs in this study, inferring diet $\delta^{13}\text{C}$ from tooth apatite would lead to a systematic overestimation of the relative amount of C4 plants in the diet.

Further studies are necessary to determine if isotopic offsets between tooth and bone are consistent across and within species, given a constant diet, and if the $\Delta^{13}\text{C}_{\text{tooth-bone}}$ of 2.3‰ and the $\Delta^{18}\text{O}_{\text{tooth-bone}}$ 1.7‰ observed in pigs is representative of the offset in humans.

2.5.3. Organic and Inorganic Source Comparisons

Carbon and oxygen isotopic ratios can be obtained from both organic (e.g., keratin, collagen) and inorganic (apatitic) sources. Previous studies have found marked offsets between the isotopic ratios of inorganic and organic sources of carbon (Kruger and Sullivan 1984; Lee-Thorp et al. 1989; Harrison and Katzenberg 2003) and oxygen (Podlesak et al. 2008). These offsets are thought to be informative about dietary components and digestive and metabolic processes, but the exact relationships remain unknown.

Carbon

Observed offsets between apatite and collagen in wild animals generally fall between 4-7‰ (Koch et al. 1994), but offsets from 1.2‰ to 14‰ have been observed in cases of extreme diet manipulation (e.g., Ambrose and Norr 1993) and in animals with complex digestive systems, such as ruminants (Clementz et al. 2007). The non-linear relationship

between collagen and apatite $\delta^{13}\text{C}$ has been argued to reflect fundamental differences in macronutrient metabolism (e.g., protein routing in collagen) and differential fractionation of carbon pools during apatite formation (Schwarcz 2000; Passey et al. 2005). On the basis of published experimental feeding studies, Kellner and Schoeninger (2007) recently suggested that apatite is a better indicator than collagen of whole diet carbon isotopic values, and they reported a higher correlation between diet and bone apatite $\delta^{13}\text{C}$ ($R^2 = 0.97$) than between diet and collagen $\delta^{13}\text{C}$ ($R^2 = 0.54$). However, this analysis relied primarily on data from studies of rodents consuming highly manipulated laboratory diets. Rodent feeding habits (e.g., coprophagy), digestive physiology, and metabolism differ in a number of ways from humans, and it is unclear if rodents are a good model organism for understanding isotopic incorporation in humans. By contrast, swine are thought to be a good model organism for studying human digestion and metabolism (Baker 2008; Miller and Ullrey 1987; Schook 2007; Tumbleson 1986). My data, combined with those from other published swine studies, indicate that the correlation between collagen $\delta^{13}\text{C}$ and diet $\delta^{13}\text{C}$ is as good as, if not better than, the correlation between diet $\delta^{13}\text{C}$ and bone apatite $\delta^{13}\text{C}$ in large bodied mammals fed naturalistic diets (Figure 2.2). Further work is necessary to determine if this relationship holds for humans, but the results of this study contradict the previous general claims that bone apatite $\delta^{13}\text{C}$ is necessarily a better indicator of whole diet $\delta^{13}\text{C}$ than collagen $\delta^{13}\text{C}$ and that dietary protein will “route” in to collagen.

Oxygen

Although the mechanisms of oxygen fractionation and incorporation into consumer tissues are highly complex and remain poorly understood, it is thought that body oxygen

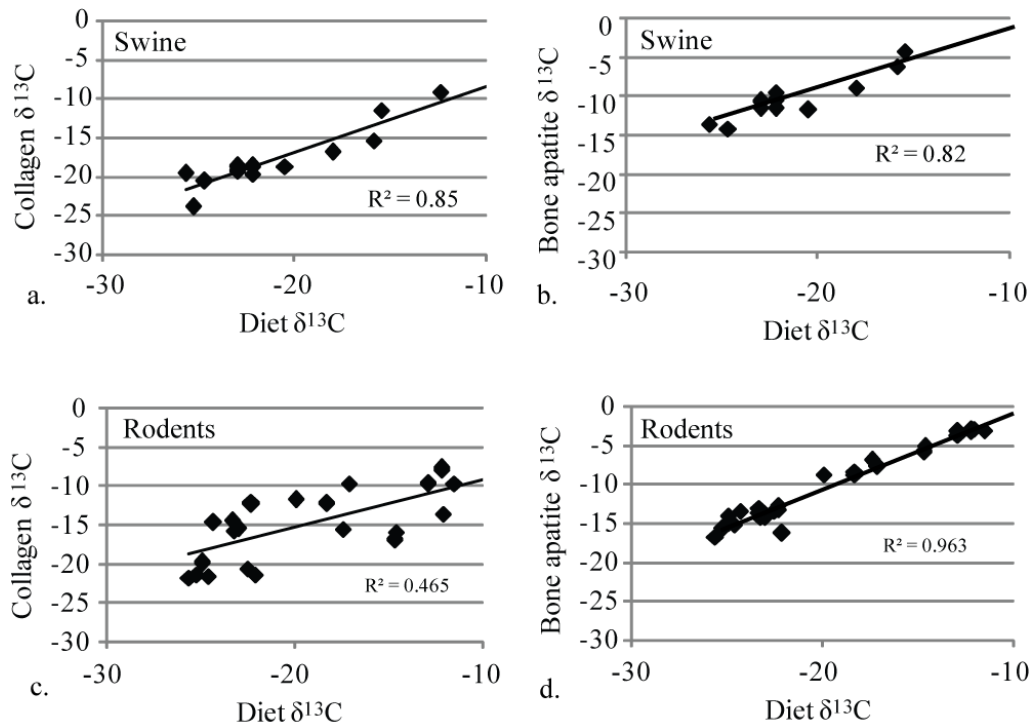


Figure 2.2a-d. Relationship between diet and tissue isotopic ratios in published swine (a, b) and rodent (c, d) studies. Rodent data collected from: Ambrose and Norr (1993), Tieszen and Fagre (1993), and Jim et al. (2004). Swine data collected from Hare et al. (1991), Howland et al. (2003), and this study.

derives from three principal sources: drinking water, food, and atmospheric oxygen (Luz et al. 1984; Bryant and Froelich 1995; Gretebeck et al. 1997; Podlesak 2008). The measurement of $\delta^{18}\text{O}$ from multiple tissues can be an informative about the systems and variables that affect oxygen incorporation. The recent availability of organic oxygen data has raised questions about the relationship between oxygen isotopic ratios in apatite and collagen. This is the first study to report paired organic and inorganic $\delta^{18}\text{O}$ in swine. The organic oxygen isotopic ratios of bone collagen were found to differ from those derived from inorganic sources of oxygen, bone and enamel apatite, by approximately 12‰ and 15‰, respectively. These offsets mirror those observed for $\delta^{13}\text{C}$ in the same tissues and likely relate to a variety of physical and biological factors, including different bond energies in the respective oxygen species, as well as differential metabolic processes and

locally variable micronutrient and body water pools contributing to the incorporation of carbon and oxygen isotopes into collagen and apatitic tissues.

2.6. Conclusions

In order to accurately model ancient diets from mineralized tissues, it is essential that we evaluate the untested assumptions that underlie our methodology and interpretive framework. In this study, I demonstrated that two longstanding assumptions in stable isotopic modeling are not true. First, bone and enamel apatite are not isotopically equivalent tissues. I have demonstrated that tooth apatite is consistently more enriched than bone apatite with respect to both $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$. This systematic offset may be related to the differential crystallinity indices of the two mineral types or to poorly understood local fractionation factors in different body water and micronutrient pools, but further work is needed to establish causation. Second, food preparation methods do affect the isotopic ratios of consumer tissues. Unlike previous studies, which tested the effects of alkaline cooking on maize isotopic ratios and found no effect, I examined the impact of alkaline cooking on consumer tissues, thereby accounting for alterations in maize digestibility and bioavailability induced by alkaline treatment. I found that alkaline cooking results in a trend toward greater maize-derived isotope ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) incorporation in collagen and apatite tissues, although this effect was only significant in collagen. Further experiments are needed to explore causation and to evaluate the effects of scaling maize consumption with respect to alkaline cooking offsets.

2.7. Bibliography

- Ambrose S. 2000. Controlled diet and climate experiments on nitrogen isotope ratios of rats. In: Biogeochemical Approaches to Paleodietary Analysis, Ambrose and Katzenberg, eds. New York: Plenum Publishers.
- Ambrose S and Norr L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: Prehistoric human bone: Archaeology at the molecular level. Edited by Lambert JB and Grupe G. New York: Springer-Verlag, p. 121-155.
- Baker DH. 2008. Animal models in nutrition research. *Journal of Nutrition* 138:391-396.
- Blaxter K. 1989. Energy metabolism in animals and man. Cambridge, UK: Cambridge University Press.
- Bressani R. 1990. Chemistry, technology and nutritive value of maize tortillas. *Food Reviews International* 6: 225-264.
- Braham JE, Bressani R and Guzmán MA. 1966. Effect of lysine and tryptophan supplementation on nicotinic acid metabolism in pigs given raw or limetreated corn diets. *Metabolism* 15: 548-556.
- Bressani, R., Paz y Paz, R. & Scrimshaw, N.S. 1958. Chemical changes in corn during preparation of tortillas. *Journal of Agricultural Food Chemistry* 6: 770774.
- Bressani R, and Scrimshaw NS. 1958. Effect of lime treatment on *in vitro* availability of essential amino acids and solubility of protein fractions in corn. *Journal of Agricultural and Food Chemistry* 6(10):774-778.
- Bryant JD and Froelich PN. 1995. A model of oxygen-isotope fractionation in body-water of large mammals. *Geochimica et Cosmochimica Acta* 59(21): 4523-4537.
- Budd P, Millard A, Chenery C, Lucy S and Roberts C. 2004. Investigation population movement by stable isotope analysis: a report from Britain. *Antiquity* 78(299): 127-141.
- Cerling TE, Hart JA and Hart TB. 2004. Stable isotope ecology in the Ituri Forest, *Oecologia* 138: 5-12.
- Clementz MT, Koch PL, and Beck CA. 2007. Diet induced differences in carbon isotope fractionation between sirenians and terrestrial ungulates. *Marine Biology* 151(5):1773-1784.
- Craviato RO, Massieu HG, Craviato OY, and Figueroa F de M. 1952. Effect of untreated corn and Mexican tortilla upon the growth of rats on a niacin-tryptophan deficient diet. *Journal of Nutrition* 48(4):453-459.
- Currey, J. *Bones: Structure and Mechanics*. 2002. Princeton, NJ: Princeton University Press.
- Finucane B, Agurto PM, and Isbell WH. 2006. Human and animal diet at Conchopata, Peru: stable isotope evidence for maize agriculture and animal management

- practices during the Middle Horizon. *Journal of Archaeological Science* 33:1766-1776.
- Food and Agriculture Organization (FAO) of the United Nations. 1992. Maize in human nutrition. Rome. Accessed May 2008.
<<http://www.fao.org/docrep/t0395e/T0395E00.htm#Contents>>
- Fry B, Brand W, Mersch FJ, Tholke K, and Garritt R. 1992. Automated analysis system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements. *Analytical Chemistry* 64(3):288–291.
- Gretebeck RJ, Schoeller DA, Socki RA, Davis-Street J, Gibson EK, Schulz LO, and Lane HW. 1997. Adaptation of the doubly labeled water method for subjects consuming isotopically enriched water. *Journal of Applied Physiology* 82: 563-570.
- Hare PE, Fogel ML, Stafford TW, Mitchell AD and Hoering TC. 1991. The isotopic composition of carbon and nitrogen in individual amino acids isolated from modern and fossil proteins. *Journal of Archaeological Science* 18:277-292.
- Harrison RG and Katzenberg MA. 2003. Paleodiet studies using stable carbon isotopes from bone apatite and collagen: examples from Southern Ontario and San Nicolas Island, California. *Journal of Anthropological Archaeology* 22:227-244.
- Hobson KA, Alisauskas RT, and Clark RG. 1993. Stable-nitrogen isotope enrichment in avian tissues due to fasting and nutritional stress: implications for isotopic analyses of diet. *Condor* 95(2): 388-394.
- Howland MR, Corr LT, Young SMM, Jones V, Jim S, Van der Merwe NJ, Mitchell AD, and Evershed RP. 2003. Expression of the dietary isotope signal in the compound-specific $\delta^{13}\text{C}$ values of pig bone lipids and amino acids. *International Journal of Osteoarchaeology* 13(1-2):54-65.
- Hu YW, Ambrose SH, and Wang CS. 2006. Stable isotopic analysis on ancient human bones in Jiahu site. *Science in China Series D-Earth Sciences* 50(4):563-570.
- Jim S, Ambrose SH, and Evershed RP. 2004. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: Implications for their use in palaeodietary reconstruction. *Geochimica Et Cosmochimica Acta* 68(1):61-72.
- Katz SH, Hediger ML, and Valleroy LA. 1974. Traditional maize processing techniques in the New World. *Science* 184(4138):765-773.
- Kellner CM, and Schoeninger MJ. 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology* 133(4):1112-1127.
- Koch PL, Fogel ML and Tuross N. 1994. Tracing the diets of fossil animals using stable isotopes. In: *Stable Isotopes in Ecology and Environmental Science*. Lathja K and Michener RH, eds. Cambridge, MA: Blackwell Scientific Publications.
- Koch PL, Tuross N, and Fogel ML. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. *Journal of Archaeological Science* 24(5):417-429.

- Kodicek E, Braude R, Kon SK and Mitchell KG. 1956. The effect of alkaline hydrolysis of maize on the availability of its nicotinic acid to the pig. *British Journal of Nutrition* 10(1): 51-67.
- Kruger HW and Sullivan CH. 1984. Models for carbon isotope fractionation between diet and bone. In: JF Turnland and PE Johnson, eds., *Stable Isotopes in Nutrition*. American Chemical Society Symposium Series 258: 205-222.
- Laguna, J and Carpenter K.J. 1951. Raw versus processed corn in niacin deficient diets. *Journal of nutrition* 45(1):21-28.
- Lee-Thorp J, Sealy J, and van der Merwe NJ. 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* 16:585-599.
- LeGeros RZ. 1981. Apatites in biological systems. *Progress in Crystal Growth and Characterization of Materials* 4(1-2):1-45.
- Longinelli A. 1984. Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta* 48: 385-390.
- Luz B, Kolodny Y, and Horowitz M. 1984. Fractionation of oxygen isotopes between mammalian bone-phosphate and environmental drinking water. *Geochimica et Cosmochimica Acta* 48:1689-1693.
- Marino BD and Deniro MJ. 1987. Isotopic analysis of archaeobotanicals to reconstruct past climates – effects of activities associated with food preparation on carbon, hydrogen and oxygen isotope ratios of plant cellulose. *Journal of Archaeological Science* 14(5):537-548.
- Miller ER and Ullrey DE. 1987. The pig as a model for human nutrition. *Annual Review of Nutrition* 7:361-382.
- Passey BH, Robinson TF, Ayliffe LK, Cerling TE, Sponheimer M, Dearing MD, Roeder BL, and Ehleringer JR. 2005. Carbon isotope fractionation between diet, breath CO₂, and bioapatite in different mammals. *Journal of Archaeological Science* 32(10):1459-1470.
- Paul D and Skrzypek G. 2007. Assessment of carbonate-phosphoric acid analytical technique performed using GasBench II in continuous flow isotope ratio mass spectrometry. *International Journal of Mass Spectrometry* 262: 180-186.
- Pearson NW, Stepfel SJ, Valenzuela JS, Utley MH and Darby WJ. 1957. The influence of cooked vs. raw maize on the growth of rats receiving a 9% casein ration. *Journal of Nutrition* 62(3): 445-463.
- Podlesak DW, Torregrossa A, Ehleringer JR, Dearing MD, Passey BH and Cerling TE. 2008. Turnover of oxygen and hydrogen isotopes in the body water, CO₂, and enamel of a small mammal. *Geochimica et Cosmochimica Acta* 72: 19-35.
- Quinn RL, Tucker BD and Krigbaum J. Diet and mobility in Middle Archaic Florida: stable isotopic and faunal evidence from the Harris Creek archaeological site (8Vo24), Tick Island. *Journal of Archaeological Science* 35(8): 2346-2356.

- Rose F. 2008. Intra-community variation in diet during the adoption of a new staple crop in the Eastern Woodlands. *American Antiquity* 73(3): 413-439.
- Schoeninger M, DeNiro M, Tauber H. 1983. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220: 1381-1382.
- Schook LB. 2007. The porcine genome initiative: implications for digestive physiology. *Livestock Science* 108(1-3):6-12.
- Schwarcz HP. 2000. Some biochemical aspects of carbon isotopic paleodiet studies. In: SH Ambrose and MA Katzenberg, eds., *Biogeochemical Approaches to Paleodietary Analysis*. New York: Kluwer Academic/Plenum, pp. 189-209.
- Sharp ZD, Atudorei V, and Durakiewicz T. 2001. A rapid method for determination of hydrogen and oxygen isotope ratios from water and hydrous minerals. *Chemical Geology* 178: 197-210.
- Smith CE, Chong DL, Bartlett JD and Margolis HC. 2005. Mineral acquisition rates in developing enamel on maxillary and mandibular incisors of rats and mice: Implications to extracellular acid loading as apatite crystals mature. *Journal of Bone and Mineral Research* 20(2): 240-249.
- Squibb RL, Braham JE, Guillermo Arroyave and Scrimshaw NS. 1959. A comparison of the effect of raw corn and tortillas (lime-treated corn) with niacin, tryptophan or beans on the growth and muscle niacin of rats. *Journal of Nutrition* 67(3): 351-361.
- Tieszen LL and Fagre T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO₂, bone collagen, bioapatite and soft tissues. In: JB Lambert and G Grupe, eds., *Prehistoric Human Bone – Archaeology at the Molecular Level*. Berlin: Springer-Verlag, pp. 121-155.
- Tonge CH, and McCance RA. 1973. Normal development of jaws and teeth in pigs, and delay and malocclusion produced by calorie deficiencies. *Journal of Anatomy* 115(May):1-22.
- Trueman CN, McGill RAR, and Guyard PH. 2005. The effect of growth rate on tissue-diet isotopic spacing in rapidly growing animals. An experimental study with Atlantic salmon (*Salmo salar*). *Rapid Communications in Mass Spectrometry* 19:3239-3247.
- Trueman CN, Behrensmeyer AK, Tuross N, and Weiner S. 2004. Mineralogical and compositional changes in bones exposed on soil surfaces in Amboseli National Park, Kenya: diagenetic mechanisms and the role of sediment pore fluids. *Journal of Archaeological Science* 31:721-739.
- Tumbleson M. 1986. *Swine in biomedical research*. New York: Plenum Press.
- Tuross N, Behrensmeyer AK, Eanes ED. 1989. Strontium increases and crystallinity changes in taphonomic and archaeological bone. *Journal of Archaeological Science* 16(6): 661-672.

- Tuross N, Warinner C, Kirsanow K and Kester C. 2008. Organic oxygen and hydrogen isotopes in a porcine controlled dietary study. *Rapid Communications in Mass Spectrometry* 22: 1741-1745.
- Tutken T, Langenegger E and Wild W. 2008. Native or not? Isotope analysis of a female skeleton on the 9th century AD from Elsau Canton Zurich, Switzerland. *Anthropologischer Anzeiger* 66(1): 19-50.
- van der Merwe and Medina E. 1991. The canopy effect, carbon isotope ratios and foodwebs in Amazonia. *Journal of Archaeological Science* 18:249-259.
- Wacher C. 2003. Nixtamalization, a Mesoamerican technology to process maize at small-scale with great potential for improving the nutritional quality of maize based foods. *Voies alimentaires d'amélioration des situations nutritionnelles*, p. 735–744.
- Wang Y, and Cerling TE. 1994. A model of fossil tooth and bone diagenesis – implications for paleodiet reconstruction from stable isotopes. *Palaeogeography Palaeoclimatology Palaeoecology* 107(3-4):281-289.
- West JB, Bowen GJ, Cerling TE and Ehleringer JR. 2006. Stable isotopes as one of nature's ecological recorders. *Trends in Ecology and Evolution* 21(7): 408-414.
- White C, Healy PF, and Schwarcz HP. 1993. Intensive agriculture, social status and Maya diet at Pacbitun, Belize. *Journal of Anthropological Research* 49(4): 347-375
- White C, Spence MW, Longstaffe FJ, Stuart-Williams H, and Law KR. 2002. Geographic identities of the sacrificial victims at the Temple of Quetzalcoatl: Implications for the nature of state power. *Latin American Antiquity* 13: 217-236.
- Wright LE. 1994. The sacrifice of the earth: Diet, health, and inequality in the Pasión Maya lowlands. Unpublished dissertation. University of Chicago.

2.8. Appendices

Appendix 2.1. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of food components

Food	Sample type	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%	C:N
Nixtamal	Scoop 1	-11.2	48.3	4.4	1.8	27.0
Nixtamal	Scoop 1	-11.4	48.6	4.3	1.8	26.4
Nixtamal	Scoop 1	-11.4	48.7	4.4	1.7	28.2
Nixtamal	Scoop 1	-11.5	48.9	4.4	1.8	27.9
Nixtamal	Scoop 1	-11.4	48.8	4.3	1.6	30.3
Nixtamal	Scoop 2	-11.4	48.8	4.3	1.7	28.2
Nixtamal	Scoop 2	-11.5	48.2	4.1	1.7	29.0
Nixtamal	Scoop 2	-11.7	49.5	3.3	1.9	25.5
Nixtamal	Scoop 2	-11.4	49.4	4.6	1.8	27.7
Nixtamal	Scoop 2	-11.5	48.8	4.0	1.6	29.6
Average		-11.5± 0.1	48.8± 0.4	4.2± 0.4	1.7± 0.1	28.0± 1.4
Dried corn	Kernel 1	-11.6	48.4	3.8	1.5	31.7
Dried corn	Kernel 1	-11.5	48.0	3.6	1.5	32.9
Dried corn	Kernel 1	-11.6	47.5	3.6	1.4	33.0
Dried corn	Kernel 1	-11.6	48.3	3.8	1.5	32.2
Dried corn	Kernel 1	-11.6	47.9	3.6	1.5	32.7
Dried corn	Kernel 2	-11.5	48.8	4.4	1.7	28.2
Dried corn	Kernel 2	-11.7	48.4	4.5	1.7	28.9
Dried corn	Kernel 2	-11.8	48.4	4.6	1.7	28.1
Dried corn	Kernel 2	-11.8	48.4	4.4	1.7	27.9
Dried corn	Kernel 2	-11.8	47.8	4.7	1.7	29.0
Dried corn	Kernel mix 1	-12.2	47.4	2.7	1.6	30.0
Dried corn	Kernel mix 1	-12.3	50.5	2.6	1.7	29.3
Dried corn	Kernel mix 2	-12.0	48.2	3.2	1.2	39.6
Dried corn	Kernel mix 2	-11.8	48.8	2.2	1.7	29.3
Dried corn	Kernel mix 3	-12.1	48.4	2.5	1.6	31.2
Dried corn	Kernel mix 3	-11.8	48.7	3.3	1.5	31.5
Average		-11.8± 0.2	48.4± 0.7	3.6± 0.8	1.6± 0.1	31.0± 2.9
Pig chow	Pellet 1	-26.5	49.1	1.4	2.8	17.6
Pig chow	Pellet 1	-26.7	48.0	1.4	3.2	15.1
Pig chow	Pellet 1	-26.9	49.1	1.7	3.0	16.4
Pig chow	Pellet 1	-26.4	48.4	1.6	3.3	14.7
Pig chow	Pellet 1	-26.0	48.2	1.9	2.9	16.5
Pig chow	Pellet 2	-26.7	39.9	1.6	2.5	15.8
Pig chow	Pellet 2	-26.6	29.6	1.3	2.1	14.4
Pig chow	Pellet 2	-26.6	48.9	1.7	3.0	16.5
Pig chow	Pellet 2	-26.8	49.0	1.8	3.0	16.1
Pig chow	Pellet 2	-26.5	44.6	1.9	2.8	16.1
Pig chow	Pellet 3	-26.2	49.2	1.6	3.3	15.0
Pig chow	Pellet 3	-26.4	49.1	1.7	3.1	15.9
Average		-26.5± 0.3	46.1± 5.9	1.6± 0.2	2.9± 0.3	15.8± 0.9

Appendix 2.2. Measured $\delta^{18}\text{O}$ and δD of food components

Food	Sample type	$\delta^{18}\text{O}_{\text{VSMOW}}$	Amt%	$\delta\text{D}_{\text{VSMOW}}$	Amt%
Nixtamal	Scoop	27.6	38.6	-28	5.7
Nixtamal	Scoop	26.4	42.4	-26	5.9
Nixtamal	Scoop	27.4	42.7	-30	6.2
Nixtamal	Scoop	26.3	45.7	-32	6.5
Nixtamal	Scoop	27.7	43.7	-23	6.3
Nixtamal	Scoop	27.6	44.5	-30	6.9
Nixtamal	Scoop	26.6	44.8	-37	6.5
Average		27.1 \pm 0.6	43.2 \pm 2.3	-29 \pm 4	6.3 \pm 0.4
Dried corn	Kernel	27.9	44.8	-32	6.5
Dried corn	Kernel	28.2	42.6	-36	6.4
Dried corn	Kernel	27.5	43.6	-25	6.4
Average		27.8 \pm 0.3	43.7 \pm 1.1	-31 \pm 5	6.5 \pm 0.1
Pig chow	Pellet	21.9	39.2	-102	5.9
Pig chow	Pellet	22.2	39.7	-100	6.0
Pig chow	Pellet	22.8	38.0	-103	5.9
Pig chow	Pellet	22.7	39.9	-106	6.0
Pig chow	Pellet	22.1	39.5	-110	6.0
Average		22.3 \pm 0.4	39.3 \pm 0.8	-104 \pm 4	6.0 \pm 0.0

Appendix 2.3. Measured $\delta^{18}\text{O}$ and δD of drinking water

Water	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
Water	-7.2	-
Water	-7.8	-
Water	-8.6	-
Water	-	-44
Water	-	-50
Average		-7.8 \pm 0.7

Notes: Water was collected from the tap which was used to fill the pigs' water dishes.

Appendix 2.4. Weight of food component per unit of volume

Trial	Nixtamal	Corn kernel	Pig Chow
1	37.67	52.97	43.13
2	40.93	53.79	44.32
3	38.02	50.21	41.06
4	39.4	53.24	42.59
5	38.19	54.21	42.36
Average	38.8 \pm 1.3	52.9 \pm 1.6	42.7 \pm 1.2

Notes: Weight measured in grams; volume equivalent to 0.25 cups.

Table 2.5. Pig Growth Table

Week of feeding experiment, weight in kg							
	Week 1	Week 2	Week 3	Week 5	Week 13 [†]	Absolute Growth (kg)	Percentage Growth (%)
Weanling							
489	n.r.	n/a	n/a	n/a	n/a	n/a	n/a
Diet 1							
482	14.6	16.8	21.2	29.7	61.0	46.4	317.8%
483	12.8	14.4	19.0	25.3	53.0	40.2	314.7%
484	14.5	16.5	20.8	27.8	54.0	39.5	272.4%
485	11.7	13.2	16.7	22.1	40.6	28.9	247.0%
486	13.8	15.8	20.1	27.0	53.0	39.2	282.9%
Average:	13.5	15.3	19.5	26.4	52.3	38.8	288.0%
Diet 2							
487	13.9	16.7	20.5	28.1	63.5	49.6	355.9%
488	11.8	14.0	18.2	25.6	61.0	49.2	418.7%
490	12.3	13.7	17.3	24.1	56.0	43.7	354.5%
491	11.4	13.5	16.9	23.0	55.3	43.9	385.1%
Average:	12.4	14.5	18.2	25.2	59.0	46.6	377.2%
492	10.9	11.9	13.4	14.9	19.0	8.1	73.7%

Notes:

Information not recorded is noted n.r.

[†]Week 13 weights are not significantly different between Diet 1 and Diet 2 (Two-tailed Student's *t*-test = 0.151); the week 13 weight of 492, however, falls more than 5 standard deviations below the mean weight of the other pigs.

Appendix 2.6. Carbon and nitrogen isotopic ratios of hair during first week of diet experiment

Collection date	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%
May 2, 2005	489	-15.0	47.9	4.7	15.6
May 2, 2005	489 [†]	-14.3	46.2	4.7	15.0
May 9, 2005	482	-13.8	46.5	5.0	15.0
May 9, 2005	483	-14.2	46.7	5.1	15.0
May 9, 2005	484	-14.0	45.8	4.5	15.0
May 9, 2005	485	-14.1	46.6	4.6	15.1
May 9, 2005	486	-14.6	46.7	4.8	15.2
May 9, 2005	487	-14.3	46.9	5.2	15.3
May 9, 2005	488	-15.2	46.9	4.4	15.2
May 9, 2005	490	-14.0	45.9	5.0	15.0
May 9, 2005	491	-13.8	46.0	4.9	15.0
May 9, 2005	492	-14.0	46.6	4.7	15.2

Notes:

[†]Duplicate hair sample.

Appendix 2.7. Oxygen and hydrogen isotopic ratios
of hair during first week of diet experiment

Date collected	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
May 2, 2005	489	1	8.1	-105
May 2, 2005	489	2	8.6	-105
May 9, 2005	487	1	9.0	-104
May 9, 2005	487	2	9.3	-104
May 9, 2005	488	1	8.6	-105
May 9, 2005	488	2	9.0	-101
May 9, 2005	490	1	8.9	-101
May 9, 2005	490	2	8.7	-103
May 9, 2005	491	1	9.2	-100
May 9, 2005	491	2	8.6	-106
May 9, 2005	492	1	8.9	-103
May 9, 2005	492	2	8.7	-106

Appendix 2.8. Carbon and nitrogen isotopic ratios of hair
during final week of diet experiment

Collection date	Diet group	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%
July 26, 2005	Nixtamal	482	-19.2	40.8	4.5	13.3
July 28, 2005	Nixtamal	483	-17.9	46.2	4.5	15.0
	Nixtamal	484	-18.8	47.4	4.4	15.0
	Nixtamal	485	-19.1	47.5	4.5	15.5
July 25, 2005	Nixtamal	486	-17.6	47.5	4.8	15.1
	Nixtamal	486†	-17.6	47.4	4.8	15.0
	Raw	487	-19.0	45.6	4.2	15.0
July 25, 2005	Raw	488	-19.2	47.3	4.4	14.9
July 26, 2005	Raw	490	-16.5	47.7	4.9	15.0
July 26, 2005	Raw	491	-19.2	46.5	4.1	15.2
July 28, 2005	Raw	492	-14.6	42.2	5.3	13.8

Notes:

†Duplicate hair sample.

Appendix 2.9. Oxygen and hydrogen isotopic ratios
of hair during final week of diet experiment

Date collected	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
July 25, 2005	487	1	9.1	-107
July 25, 2005	487	2	9.3	-102
July 26, 2005	488	1	9.8	-107
July 26, 2005	488	2	9.7	-103
July 26, 2005	490	1	9.7	-105
July 26, 2005	490	2	9.9	-101
July 26, 2005	491	1	9.0	-107
July 26, 2005	491	2	9.0	-105
July 28, 2005	492	1	9.0	-107
July 28, 2005	492	2	9.4	-104

Appendix 2.10. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of blood

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%
None†	489	1	-17.6	54.3	3.8	16.7
None†	489	2	-17.5	39.5	3.5	12.8
Nixtamal	482	1	-20.4	44.6	3.4	12.9
Nixtamal	483	1	-21.0	41.6	3.6	12.0
Nixtamal	484	1	-21.2	41.5	3.7	12.0
Nixtamal	484	2	-22.0	51.5	3.8	14.9
Nixtamal	485	1	-20.8	41.9	3.7	11.9
Nixtamal	486	1	-21.4	51.1	3.7	14.6
Nixtamal	486	2	-21.3	51.0	3.9	14.5
Raw	487	1	-20.7	43.9	4.1	12.7
Raw	488	1	-22.5	48.6	4.1	13.9
Raw	490	1	-21.0	50.5	4.1	14.2
Raw	491	1	-21.2	47.6	3.6	12.3
Raw	492	1	-15.1	41.2	4.1	12.5

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.11. Measured $\delta^{18}\text{O}$ and δD of blood

Diet group	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
None†	489	1	14.5	-124
None†	489	2	14.5	-130
None†	489	3	14.2	-125
Nixtamal	482	1	12.5	-139
Nixtamal	482	2	13.2	-179
Nixtamal	484	1	8.9	-124
Nixtamal	484	2	10.8	-123
Nixtamal	485	1	11.7	-141
Nixtamal	485	2	12.9	-138
Nixtamal	486	1	10.8	-120
Nixtamal	486	2	11.7	-125
Raw	487	1	10.9	-125
Raw	487	2	12.1	-135
Raw	488	1	10.4	-127
Raw	488	2	10.8	-120
Raw	490	1	12.4	-223
Raw	490	2	13.5	-276
Raw	491	1	11.8	-134
Raw	491	2	12.1	-161
Raw	492	1	13.7	-124
Raw	492	2	13.2	-125

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.12. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of muscle

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%
None†	489	1	-17.6	47.7	4.8	13.7
None†	489	2	-17.7	47.9	4.8	1.9
Nixtamal	482	1	-19.8	47.7	3.8	13.9
Nixtamal	483	1	-20.9	49.7	4.1	12.2
Nixtamal	484	1	-20.7	49.2	4.5	13.2
Nixtamal	484	2	-20.7	49.3	4.4	12.8
Nixtamal	485	1	-20.0	47.6	4.4	11.1
Nixtamal	486	1	-19.9	47.9	4.3	13.3
Nixtamal	486	2	-20.1	47.2	4.5	12.4
Raw	487	1	-19.6	50.2	4.1	11.6
Raw	488	1	-21.5	51.7	4.4	13.4
Raw	490	1	-19.7	49.6	4.3	13.2
Raw	491	1	-20.0	41.6	3.4	11.9
Raw	492	1	-14.4	49.6	4.9	10.8

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.13. Measured $\delta^{18}\text{O}$ and δD of muscle

Diet group	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
None†	489	1	12.5	-134
None†	489	2	13.5	-133
None†	489	3	15.3	-129
Nixtamal	482	1	11.7	-120
Nixtamal	482	2	11.1	-139
Nixtamal	482	3	11.9	-144
Nixtamal	483	1	14.0	-117
Nixtamal	483	2	12.0	-147
Nixtamal	483	3	13.8	-154
Nixtamal	484	1	11.0	-137
Nixtamal	484	2	12.2	-134
Nixtamal	485	1	14.1	-129
Nixtamal	486	1	11.9	-133
Nixtamal	486	2	12.3	-127
Raw	487	1	14.1	-152
Raw	487	2	13.7	-134
Raw	488	1	12.5	-131
Raw	488	2	13.0	-143
Raw	490	1	13.5	-131
Raw	490	2	12.8	-132
Raw	490	3	15.7	-291
Raw	492	1	16.1	-264
Raw	492	2	15.2	-198

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.14. Measured $\delta^{13}\text{C}$ of subcutaneous fat

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%
None†	489	1	-17.5	79.9
None†	489	2	-17.5	78.7
Nixtamal	482	1	-23.6	79.1
Nixtamal	483	1	-23.0	76.4
Nixtamal	484	1	-22.9	75.8
Nixtamal	484	2	-22.2	78.5
Nixtamal	485	1	-23.8	79.4
Nixtamal	486	1	-21.1	78.1
Nixtamal	486	2	-21.1	76.7
Raw	487	1	-20.6	77.5
Raw	488	1	-23.3	75.2
Raw	490	1	-20.2	79.7
Raw	491	1	-21.7	78.2
Raw	492	1	-16.4	75.3

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.15. Measured $\delta^{18}\text{O}$ and δD of subcutaneous fat

Diet group	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
None†	489	1	14.5	-241
None†	489	2	14.4	-254
None†	489	3	15.2	-269
None†	489	4	13.8	-248
Nixtamal	482	1	14.4	-242
Nixtamal	482	2	14.1	-279
Nixtamal	483	1	14.0	-268
Nixtamal	483	2	14.2	-280
Nixtamal	484	1	13.6	-270
Nixtamal	484	2	15.2	-305
Nixtamal	485	1	15.9	-123
Nixtamal	486	1	15.0	-304
Nixtamal	486	2	14.6	-282
Raw	487	1	15.7	-295
Raw	487	2	14.2	-283
Raw	488	1	15.4	-290
Raw	488	2	14.0	-293
Raw	490	1	15.1	-292
Raw	491	1	15.5	-287
Raw	491	2	15.2	-289

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.16. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of humerus collagen

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%	C:N
None†	489	1	-13.7	46.4	5.0	16.4	3.3
None†	489	2	-13.9	45.8	4.8	16.2	3.3
None†	489	3	-14.3	46.0	4.7	16.2	3.3
None†	489	4	-14.3	45.0	4.6	16.0	3.3
None†	489	5	-14.3	45.4	4.5	16.1	3.3
Average			-14.1± 0.3		4.7± 0.2		
Nixtamal	482	1	-18.5	46.6	3.9	16.3	3.3
Nixtamal	482	2	-18.4	46.2	3.9	16.2	3.3
Nixtamal	482	3	-18.4	45.8	3.8	16.2	3.3
Nixtamal	482	4	-18.4	45.6	3.8	16.1	3.3
Nixtamal	482	5	-18.6	45.7	4.0	16.1	3.3
Average			-18.5± 0.1		3.9± 0.1		
Nixtamal	483	1	-19.2	46.0	3.8	16.2	3.3
Nixtamal	483	2	-19.3	45.8	3.7	16.0	3.3
Nixtamal	483	3	-19.3	46.0	3.8	16.1	3.3
Nixtamal	483	4	-19.3	45.5	3.7	16.0	3.3
Nixtamal	483	5	-19.3	44.8	3.6	15.9	3.3
Average			-19.3± 0.0		3.7± 0.1		
Nixtamal	484	1	-19.2	46.4	3.7	16.5	3.3
Nixtamal	484	2	-19.2	45.9	3.5	16.6	3.2
Nixtamal	484	3	-19.2	46.0	3.6	16.5	3.3
Nixtamal	484	4	-19.0	44.9	3.6	15.9	3.3
Nixtamal	484	5	-18.9	45.2	3.8	15.9	3.3
Average			-19.1± 0.1		3.7± 0.1		
Nixtamal	485	1	-18.8	44.7	3.9	16.1	3.2
Nixtamal	485	2	-18.8	46.0	4.1	16.2	3.3
Nixtamal	485	3	-18.8	45.7	4.0	16.2	3.3
Nixtamal	485	4	-18.2	41.8	4.0	13.7	3.6
Nixtamal	485	5	-18.9	45.6	3.9	16.3	3.3
Average			-18.7± 0.3		4.0± 0.1		
Nixtamal	486	1	-18.7	46.7	3.9	16.5	3.3
Nixtamal	486	2	-18.7	46.5	4.0	16.4	3.3
Nixtamal	486	3	-18.5	45.1	3.8	16.2	3.3
Nixtamal	486	4	-18.7	46.0	3.9	16.3	3.3
Nixtamal	486	5	-18.6	45.4	3.9	16.1	3.3
Average			-18.6± 0.1		3.9± 0.1		
Raw	487	1	-18.8	44.9	3.8	16.1	3.3
Raw	487	2	-18.8	45.0	3.8	16.0	3.3
Raw	487	3	-18.7	45.0	3.9	16.1	3.3
Raw	487	4	-18.6	44.3	3.9	16.0	3.2
Raw	487	5	-18.6	44.9	4.0	16.1	3.3
Average			-18.7± 0.1		3.9± 0.1		
Raw	488	1	-19.7	46.3	3.8	16.4	3.3
Raw	488	2	-19.8	46.0	3.9	16.3	3.3
Raw	488	3	-19.7	45.5	3.8	16.3	3.3
Raw	488	4	-19.7	44.9	3.8	16.0	3.3
Raw	488	5	-19.6	44.3	3.8	15.8	3.3
Average			-19.7± 0.0		3.8± 0.0		

Appendix 2.16. continued

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%	C:N
Raw	490	1	-18.8	46.3	3.9	16.2	3.3
Raw	490	2	-18.5	46.0	3.8	16.2	3.3
Raw	490	3	-18.9	45.7	3.9	16.0	3.3
Raw	490	4	-18.7	45.7	3.9	16.0	3.3
Raw	490	5	-18.6	44.8	3.8	15.9	3.3
		Average	-18.7± 0.2		3.9± 0.1		
Raw	491	1	-18.5	45.6	3.6	16.4	3.2
Raw	491	2	-18.7	46.3	3.9	16.3	3.3
Raw	491	3	-18.5	45.6	3.7	16.2	3.3
Raw	491	4	-18.6	45.3	3.8	16.0	3.3
Raw	491	5	-18.6	45.5	3.8	16.3	3.3
		Average	-18.6± 0.1		3.8± 0.1		
Raw	492	1	-12.7	46.0	5.3	16.2	3.3
Raw	492	2	-12.8	46.1	5.3	16.2	3.3
Raw	492	3	-12.5	45.1	5.3	16.2	3.3
Raw	492	4	-12.0	46.4	5.6	16.3	3.3
Raw	492	5	-12.7	45.8	6.0	15.8	3.4
		Average	-12.5± 0.3		5.5± 0.3		

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.17. Measured $\delta^{18}\text{O}$ and δD of humerus collagen

Diet group	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
None†	489	1	-	-74
None†	489	2	-	-74
None†	489	3	5.5	-
None†	489	4	5.5	-
None†	489	5	5.0	-70
None†	489	6	5.6	-70
		Average	5.4 ± 0.2	-72 ± 2
Nixtamal	482	1	-	-66
Nixtamal	482	2	-	-71
Nixtamal	482	3	6.1	-
Nixtamal	482	4	6.5	-
Nixtamal	482	5	5.9	-67
Nixtamal	482	6	5.7	-66
Nixtamal	482	7	5.5	-66
		Average	5.9 ± 0.4	-67 ± 2
Nixtamal	483	1	-	-76
Nixtamal	483	2	-	-69
Nixtamal	483	3	6.3	-
Nixtamal	483	4	6.7	-
Nixtamal	483	5	6.5	-67
Nixtamal	483	6	6.3	-69
		Average	6.4 ± 0.2	-70 ± 4
Nixtamal	484	1	-	-69
Nixtamal	484	2	-	-77
Nixtamal	484	3	5.9	-
Nixtamal	484	4	6.5	-
Nixtamal	484	5	5.3	-65
Nixtamal	484	6	5.7	-66
		Average	5.9 ± 0.5	-69 ± 5
Nixtamal	485	1	-	-72
Nixtamal	485	2	-	-71
Nixtamal	485	3	6.5	-
Nixtamal	485	4	6.7	-
Nixtamal	485	5	5.9	-67
		Average	6.4 ± 0.4	-70 ± 3
Nixtamal	486	1	-	-70
Nixtamal	486	2	-	-73
Nixtamal	486	3	6.3	-
Nixtamal	486	4	6.4	-
Nixtamal	486	5	5.7	-66
Nixtamal	486	6	5.8	-67
		Average	6.0 ± 0.3	-69 ± 3
Raw	487	1	-	-65
Raw	487	2	-	-68
Raw	487	3	6.6	-
Raw	487	4	6.8	-
Raw	487	5	6.7	-59
Raw	487	6	6.1	-61
		Average	6.6 ± 0.3	-63 ± 4

Appendix 2.17. continued

Diet group	Subject	Replicate	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
Raw	488	1	-	-68
Raw	488	2	-	-73
Raw	488	3	6.4	-
Raw	488	4	6.7	-
Raw	488	5	6.1	-61
		Average	6.4 ± 0.3	-67.5 ± 6
Raw	490	1	-	-68
Raw	490	2	-	-72
Raw	490	3	6.5	-
Raw	490	4	6.3	-
Raw	490	5	5.8	-65
Raw	490	6	6.1	-65
		Average	6.2 ± 0.3	-67.5 ± 4
Raw	491	1	-	-68
Raw	491	2	-	-73
Raw	491	3	6.5	-
Raw	491	4	6.4	-
Raw	491	5	6.4	-61
Raw	491	6	6.1	-61
		Average	6.4 ± 0.2	-66 ± 6
Raw	492	1	-	-73
Raw	492	2	-	-76
Raw	492	3	7.6	-
Raw	492	4	7.0	-
Raw	492	5	7.3	-83
		Average	7.3 ± 0.3	-77 ± 5

Notes:

†Pig sacrificed on day one of the experiment. All other measurements were collected from tissues harvested at the end of week 13 of the experiment.

Appendix 2.18. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of humerus apatite

Treatment	Diet group	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
Untreated	None	489	-8.0	20.6
Untreated	Nixtamal	482	-10.6	19.1
Untreated	Nixtamal	483	-10.6	20.1
Untreated	Nixtamal	484	-11.5	19.1
Untreated	Nixtamal	485	-10.8	19.6
Untreated	Nixtamal	486	-10.6	20.0
Untreated	Raw	487	-10.0	19.5
Untreated	Raw	488	-11.3	19.9
Untreated	Raw	490	-9.3	20.2
Untreated	Raw	491	-10.2	20.0
Untreated	Raw	492	-5.7	20.6
Treated	None	489	-8.3	20.2
Treated	Nixtamal	482	-10.9	19.4
Treated	Nixtamal	483	-10.7	20.3
Treated	Nixtamal	484	-11.7	19.7
Treated	Nixtamal	485	-10.8	20.0
Treated	Nixtamal	486	-11.0	19.6
Treated	Raw	487	-10.5	19.4
Treated	Raw	488	-11.8	19.7
Treated	Raw	490	-9.6	20.2
Treated	Raw	491	-10.7	20.0
Treated	Raw	492	-6.5	20.6
		Average	-10.7 ± 0.9	19.8 ± 0.3

Appendix 2.19. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of mandible collagen†

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%	C:N
Nixtamal	482	1	-18.3	50.1	4.4	18.5	3.2
Nixtamal	482	2	-18.5	36.0	4.6	12.0	3.5
Nixtamal	482	3	-18.3	50.4	4.1	17.5	3.4
Nixtamal	482	4	-18.5	51.1	4.4	17.5	3.4
Nixtamal	482	5	-18.4	51.0	3.9	17.7	3.4
Average			-18.4±0.1		4.3±0.3		
Nixtamal	483	1	-19.2	49.2	3.8	17.7	3.3
Nixtamal	483	2	-19.5	49.8	3.9	17.4	3.3
Nixtamal	483	3	-19.2	48.9	3.8	17.5	3.3
Nixtamal	483	4	-19.2	48.6	3.7	17.5	3.2
Nixtamal	483	5	-19.7	48.5	4.0	17.0	3.3
Average			-19.4±0.2		3.9±0.1		
Nixtamal	484	1	-19.2	51.1	4.3	18.8	3.2
Nixtamal	484	2	-19.2	51.0	4.2	17.4	3.4
Nixtamal	484	3	-19.1	50.6	4.1	17.4	3.4
Nixtamal	484	4	-18.2	50.7	4.2	17.5	3.4
Nixtamal	484	5	-17.7	49.2	4.1	17.1	3.3
Average			-18.7±0.7		4.2±0.1		
Nixtamal	485	1	-19.2	51.5	4.4	18.1	3.3
Nixtamal	485	2	-19.0	50.9	4.1	17.5	3.4
Nixtamal	485	3	-19.0	50.1	3.9	17.3	3.4
Nixtamal	485	4	-19.0	50.2	4.1	17.2	3.4
Nixtamal	485	5	-18.8	50.1	3.9	17.2	3.4
Average			-19.0±0.1		4.1±0.2		
Nixtamal	486	1	-18.7	47.3	3.4	17.5	3.2
Nixtamal	486	2	-18.7	47.5	3.4	17.4	3.2
Nixtamal	486	3	-18.7	47.5	3.4	17.5	3.2
Nixtamal	486	4	-18.7	46.4	3.3	17.2	3.1
Nixtamal	486	5	-18.7	68.4	3.8	24.7	3.2
Average			-18.7±0.0		3.5±0.2		
Raw	487	1	-18.5	50.6	4.3	18.8	3.1
Raw	487	2	-18.6	50.4	4.0	17.5	3.4
Raw	487	3	-18.5	50.0	4.0	17.4	3.3
Raw	487	4	-18.3	49.8	4.1	17.4	3.3
Raw	487	5	-18.5	49.5	4.1	17.3	3.3
Average			-18.5±0.1		4.1±0.1		
Raw	488	1	-20.0	47.9	3.5	17.6	3.2
Raw	488	2	-19.8	48.2	3.6	17.7	3.2
Raw	488	3	-19.6	46.1	3.5	17.3	3.1
Raw	488	4	-19.7	47.6	3.9	17.5	3.2
Raw	488	5	-19.8	47.2	3.6	17.4	3.2
Average			-19.8±0.2		3.6±0.2		
Raw	490	1	-18.7	47.5	3.6	17.5	3.2
Raw	490	2	-18.4	47.9	3.4	17.6	3.2
Raw	490	3	-19.2	48.3	3.8	17.4	3.2
Raw	490	4	-18.6	47.9	3.6	17.5	3.2
Raw	490	5	-18.5	48.3	3.6	17.7	3.2
Average			-18.7±0.3		3.6±0.1		

Appendix 2.19. continued

Diet group	Subject	Replicate	$\delta^{13}\text{C}_{\text{VPDB}}$	Amt%	$\delta^{15}\text{N}_{\text{AIR}}$	Amt%	C:N
Raw	491	1	-18.9	48.7	3.6	17.5	3.2
Raw	491	2	-18.9	47.5	3.6	17.3	3.2
Raw	491	3	-18.7	46.4	3.7	17.0	3.2
Raw	491	4	-18.8	47.7	3.5	17.4	3.2
Raw	491	5	-18.7	46.9	3.6	17.1	3.2
Average			-18.8±0.1		3.6±0.1		
Raw	492	1	-12.0	47.6	5.3	17.4	3.2
Raw	492	2	-12.3	47.2	5.3	17.3	3.2
Raw	492	3	-13.3	47.2	5.5	16.9	3.3
Raw	492	4	-12.0	46.8	5.3	17.0	3.2
Raw	492	5	-12.3	47.4	5.3	17.4	3.2
Average			-12.4±0.5		5.3±0.1		

Notes:

†The mandible of Pig 489 was not analyzed isotopically.

Appendix 2.20. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of permanent canine (C1) enamel apatite

Treatment	Diet group	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
Untreated	Nixtamal	482	-8.3	21.4
Untreated	Nixtamal	482	-8.5	20.9
Untreated	Nixtamal	484	-8.8	21.1
Untreated	Nixtamal	485	-8.9	21.1
Untreated	Nixtamal	485	-8.8	21.4
Untreated	Raw	487	-8.1	21.4
Untreated	Raw	488	-8.5	21.8
Untreated	Raw	490	-7.4	21.9
Untreated	Raw	490	-7.6	21.8
Untreated	Raw	491	-8.3	21.5
Treated	Nixtamal	482	-8.2	20.6
Treated	Nixtamal	482	-8.4	20.9
Treated	Nixtamal	484	-9.0	19.7
Treated	Nixtamal	485	-8.9	20.6
Treated	Nixtamal	485	-9.0	20.8
Treated	Raw	487	-8.1	19.9
Treated	Raw	488	-8.6	20.6
Untreated	Raw	490	-7.8	20.5
Treated	Raw	490	-7.6	21.7
Treated	Raw	491	-8.3	20.6

Appendix 2.21. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of first permanent molar (M1) enamel apatite

Treatment	Diet group	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
Untreated	Nixtamal	482	-8.6	21.0
Untreated	Nixtamal	482	-8.3	21.4
Untreated	Nixtamal	483	-8.4	21.6
Untreated	Raw	490	-6.9	21.6
Untreated	Raw	491	-8.2	21.4
Treated	Nixtamal	482	-8.2	21.5
Treated	Nixtamal	482	-8.5	21.2
Treated	Nixtamal	483	-8.2	21.4
Treated	Nixtamal	483	-6.6	21.8
Treated	Nixtamal	484	-7.9	22.1
Treated	Nixtamal	485	-8.8	21.5
Treated	Nixtamal	486	-6.5	22.3
Treated	Raw	487	-8.1	21.1
Treated	Raw	488	-8.6	20.5
Treated	Raw	491	-8.1	21.6
Treated	Raw	492	-3.2	21.5
Treated	Raw	492	-3.5	21.4

Appendix 2.22. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of deciduous second incisor (di2) enamel apatite

Treatment	Diet group	Subject	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
Untreated	Nixtamal	482	-4.2	21.2
Untreated	Nixtamal	483	-4.0	21.9
Untreated	Nixtamal	484	-5.4	21.8
Untreated	Nixtamal	485	-5.9	20.7
Untreated	Nixtamal	486	-4.5	21.3
Untreated	Raw	487	-5.2	21.4
Untreated	Raw	490	-4.6	21.3
Untreated	Raw	491	-4.4	20.9
Untreated	Raw	492	-4.8	20.9
Treated	Nixtamal	482	-4.0	21.1
Treated	Nixtamal	483	-3.5	21.2
Treated	Nixtamal	484	-2.6	22.6
Treated	Nixtamal	485	-3.8	22.5
Treated	Nixtamal	486	-3.9	21.7
Treated	Raw	487	-3.6	21.7
Treated	Raw	488	-4.7	22.3
Treated	Raw	490	-3.9	22.2
Treated	Raw	491	-3.6	21.9
Treated	Raw	492	-4.3	22.3

CHAPTER 3: TISSUE ISOTOPIC ENRICHMENT ASSOCIATED WITH GROWTH DEPRESSION IN A PIG²

The results of this study were presented in part at the 2006 Society for American Archaeology meetings in San Juan, Puerto Rico. A version of this chapter was published as a brief communication in the *American Journal of Physical Anthropology* (see below). The raw data for the study, which do not appear in the published article, can be found in the appendices at the end of Chapter 2.

Warinner, Christina, Tuross, Noreen. 2010. Tissue isotopic enrichment associated with growth depression in a pig: implications for archaeology and ecology. *American Journal of Physical Anthropology* 141:486-493.

3.1. Chapter summary

Stressors such as fasting or poor diet quality are thought to potentially alter the observed nitrogen and carbon isotopes in animal tissues. In this study, I demonstrate an inverse correlation between growth rate and multiple tissue enrichment of $\delta^{15}\text{N}$, $\delta^{13}\text{C}$, and, to a lesser degree, $\delta^{18}\text{O}$ in a juvenile pig. A more complex pattern is observed with respect to tissue δD and growth rate. The observed association between growth rate and tissue isotopic fractionation has important implications for paleodietary and migratory reconstructions of archaeological populations that may have been affected by famine, malnutrition, seasonal variation in food availability, and/or other factors that can affect childhood growth rates.

² This study was conducted under Harvard University Faculty of Arts and Sciences Animal Experimentation Protocol Number 24-19. We'd like to thank Dan Lieberman and Katherine Zink for assistance with experimental design and development, Cynthia Kester for technical assistance with the mass spectrometer, and Pedro Ramirez, who served as the primary handler of the pigs at the Concord Field Station. We'd especially like to thank Don Schleppegrell of Azteca Milling, LLP for donating the maize products used in this study, as well as Karola Kirsanow for assisting with multiple parts of the study.

3.2. Introduction

Stable isotope analysis is now a widely used analytical tool in ecology and archaeology. Body tissue isotopic ratios of carbon, nitrogen, oxygen, and hydrogen are routinely measured and utilized as proxies for dietary strategies, ecological change, and mobility patterns (Kelly 2000; Koch 1998; Koch et al. 1994; Lee-Thorp 2008; Quinn et al. 2008; Rubenstein and Hobson 2004; Schwarcz and Schoeninger 1991; West et al. 2006). However, many questions persist regarding the mechanisms that drive the patterns of isotopic enrichment observed in ecological systems and among different tissues within a single individual (e.g., Schoeller 1999; Gaye-Siessegger et al. 2004; Vanderkluft and Ponsard 2003; McCutchan et al. 2003; Robbins et al. 2005; Vander Zanden and Rasmussen 2001). Understanding these mechanisms is critical to creating accurate isotopic models that can be applied to studies of diet and mobility.

Current paleodietary models based on carbon and nitrogen stable isotopes generally reconstruct diet by interpolating between idealized isotopic inputs and adding a fixed, tissue-specific fractionation factor (e.g., Schwarcz 1991; Phillips and Koch 2002) or by using empirical data to create regression lines that describe the relationship between diet and tissue isotopic ratios in experimental animals (e.g., Kellner and Schoeninger 2007). Oxygen and hydrogen isotopic fractionation models must additionally account for drinking water intake (as well as respiration of atmospheric oxygen) and generally rely on empirical data from human and animal studies to derive isotopic relationships between oxygen and hydrogen inputs and tissue isotopic ratios (e.g., Cerling et al. 2007; Ehleringer et al. 2008; Gretebeck et al. 1997; Hobson et al. 1999; Podlesak 2008). Implicit in each of these models is the assumption that intra-specific metabolic processes

of fractionation are relatively constant, and that tissue isotopic variation is largely driven by isotopic variation of the underlying diet (carbon, nitrogen, oxygen, and hydrogen), water (oxygen and hydrogen) and air (oxygen).

A growing number of studies, however, have pointed to nutritional stress as a factor affecting stable isotope fractionation in consumer tissues. Significant correlations have been found between tissue isotopic enrichment of nitrogen and daily food ration size (Gaye-Siessegger et al. 2003, 2007; Focken 2001; Hobson et al. 1993), water availability (Ambrose and DeNiro 1987), diet quality (Hobson and Clark 1992; Robbins et al. 2005), fasting (Hobson et al. 1993), and growth rate (Trueman et al. 2005; Martinez del Rio and Wolf 2005). However, with few exceptions (e.g., Katzenberg and Lovell 1999; White and Armelagos 1997; Hedges and Reynard 2007), consideration of nutritional or physiological stress in isotopic diet modeling has been limited to ecological studies, in spite of a considerable body of osteological literature on nutritional stress in archaeological populations (e.g., Angel 1975, 1981, 1984; Danforth 1994; Ivanhoe 1995; Larsen 1997; Ortner 2003; Prendergast Moore et al. 1986; Saul 1977; Sobolik 2002; Ubelaker 1994; White 1988, 1999).

In this study, I examine the correlation between natural growth rate variability and tissue carbon, nitrogen, oxygen and hydrogen isotopic ratios in a controlled diet experiment of juvenile pigs. As large-bodied omnivores, pigs share many important physiological characteristics with humans and are considered a good model organism for the study of human digestion and metabolism (Baker 2008; Miller and Ullrey 1987; Schook 2007; Tumbleson 1986). This study additionally has important implications for archaeozoologists who are interested in understanding patterns of isotopic discrimination

in managed or domesticated animal populations that may have experienced growth-related stress. Although this study was adventitious, and suffers from the comparison of only one growth-limited animal in a larger cohort, the data point to the need for additional experimental work on the effects of stress and growth depression on large animals. I report the impact of growth rate on all four of the major natural abundance isotopic pairs ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, δD) in multiple hard and soft tissues employed in dietary and mobility research.

3.3 Materials and Methods

3.3.1. Controlled Diet Study

The six pigs (*Sus domesticus*, Yorkshire cross) in this study are part of a larger experiment designed to examine factors that affect isotopic fractionation in swine (see details in Warinner and Tuross 2009). The pigs were housed together and raised for 13 weeks on a vegetarian, mixed C3/C4 experimental diet composed of yellow maize and C3-pelleted feed. Isotopic composition of the diet components and the total diet are provided in Table 3.1. During the 13-week study, the pigs were weighed at regular intervals, and they were allowed to eat and drink local tap water *ad libitum*, as well as exercise freely in a large run. The pigs were sacrificed according to approved procedures during week 13 of the diet experiment. Multiple tissues were collected (hair, muscle, blood, subcutaneous fat, bone, and a permanent first molar), frozen, and lyophilized. In order to facilitate comparison of enamel apatite isotopic ratios across the entire cohort, the permanent first molar was sampled. Although mineralization of this tooth begins *in utero*, mineralization continues for several months after birth, including during the period of the diet experiment (Tonge and McCance 1973). To confirm that mineralization

Table 3.1. Isotopic ratios of diet and animal tissues

	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{Air}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
Diet				
Raw Maize (dry) ^a	-11.8 ± 0.2	3.6 ± 0.8	27.8 ± 0.3	-31 ± 5
Feed (dry) ^b	-26.5 ± 0.3	1.7 ± 0.2	22.3 ± 0.4	-104 ± 4
Calculated Total Diet	-22.2	2.0	24.1	-82
Measured Tap Water ^c	-	-	-7.8 ± 0.6	-48 ± 4
Animal Tissues (Pre-Diet Experiment Pig) ^d				
Humerus (apatite)	-8.0	-	20.6	-
Humerus (collagen)	-14.1 ± 0.3	4.7 ± 0.2	5.4 ± 0.2	-70 ± 2
Hair (Week 1)	-15.0	4.7	8.4 ± 0.4	-105 ± 0
Animal Tissues (Control Pig Averages) ^e				
M1	-7.9 ± 0.8	-	21.1 ± 0.5	-
Humerus (apatite)	-10.2 ± 0.8	-	19.9 ± 0.3	-
Humerus (collagen)	-18.9 ± 0.5	3.8 ± 0.0	6.4 ± 0.2	-62 ± 2
Muscle	-20.2 ± 0.9	4.1 ± 0.5	13.5 ± 0.7	-
Blood	-21.4 ± 0.8	4.0 ± 0.3	11.8 ± 1.0	-
Subcutaneous Fat	-21.5 ± 1.4	-	-	-
Hair (Week 1)	-14.4 ± 0.6	4.7 ± 0.2	8.8 ± 0.3	-103 ± 1
Hair (Week 13)	-18.5 ± 1.3	4.4 ± 0.4	9.4 ± 0.4	-105 ± 1
Animal Tissues (Reduced Growth Pig)				
M1	-3.5**	-	21.4	-
Humerus (apatite)	-5.7**	-	20.6*	-
Humerus (collagen)	-12.5 ± 0.3**	5.5 ± 0.3**	7.3 ± 0.3*	-83**
Muscle	-14.4**	4.9	15.6 ± 0.6*	-
Blood	-15.1**	4.1	13.5 ± 0.4	-
Subcutaneous Fat	-16.4*	-	-	-
Hair (Week 1)	-14.5	4.6	8.8 ± 0.2	-105 ± 2
Hair (Week 13)	-14.6*	5.3*	9.2 ± 0.3	-105 ± 2

*More than 2 standard deviations from the mean of the control pigs.

**More than 4 standard deviations from the mean of the control pigs.

^a $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, n=16; $\delta^{18}\text{O}$ and δD , n=4.

^b $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, n=10; $\delta^{18}\text{O}$ and δD , n=5.

^c $\delta^{18}\text{O}$, n=6; δD , n=3.

^dCollagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, n=5; collagen $\delta^{18}\text{O}$, n=3-5; collagen δD , n=2; hair $\delta^{18}\text{O}$ and δD , n=2.

^eAverage of four pigs.

continued during the period of the diet experiment, injections of fluorochromatic bone label calcein (Sigma, St. Louis, MO) were administered intramuscularly every two weeks during the diet study, for a total of six injections at a dosage of 30 mg/kg body weight.

3.3.2. Analytical Methods

Samples of food, water, bone collagen, and bone apatite were prepared according to the methods described in Warinner and Tuross (2009). Enamel powder was soaked overnight in a calcium acetate buffered 1M acetic acid solution. Soft tissues (muscle, blood, and fat) were dissected at the time of death from the right forelimb of each pig. During the course of the experiment, hairs were plucked for later analysis. Only the first centimeter of hair from the root was analyzed.

Carbon and nitrogen isotopes were measured in continuous flow using a Costech ECS 4010 elemental analyzer coupled to a Thermo Delta Plus XP mass spectrometer (Fry et al. 1992). Isotopic compositions of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ are reported relative to Pee Dee Belemnite (PDB) and Air, respectively, and calibrated against USGS 40 ($\delta^{13}\text{C} = -26.2\text{‰}$, $\delta^{15}\text{N} = -4.5\text{‰}$) and USGS 41 ($\delta^{13}\text{C} = 37.8\text{‰}$, $\delta^{15}\text{N} = 47.6\text{‰}$). Observed analytical error is $\pm 0.2\text{‰}$ for both C and N. Elemental compositions were determined using acetanilide (%C = 71.09, %N = 10.36).

Oxygen and hydrogen isotopic ratios were analyzed by continuous flow isotope ratio mass spectrometry using a Thermo Temperature Conversion Elemental Analyzer (TC/EA) coupled to a Thermo Delta Plus XP mass spectrometer (Sharp et al. 2001). The factory installed GC column in the TC/EA was replaced with a 1.8 m packed 5Å molecular sieve column (Tuross et al. 2008). Hydrogen and oxygen isotope composition of the water samples are reported relative to Vienna Standard Mean Ocean Water (VSMOW) and normalized using VSMOW and Standard Light Antarctic Precipitation (SLAP). Hydrogen and oxygen isotope composition of the food and collagen samples are reported relative to VSMOW and calibrated against IAEA-601 ($\delta^{18}\text{O} = 23.3\text{‰}$) and

IAEA-602 ($\delta^{18}\text{O} = 71.4\text{‰}$). Internal secondary standards of keratin, gelatin and polyethylene were included in each run. As with all similar studies of natural abundance hydrogen and oxygen isotopes, the lack of molecularly identical primary standards presents a challenge for cross laboratory comparisons. Observed analytical errors of hydrogen and oxygen isotope values is $\pm 3\text{‰}$ and $\pm 1\text{‰}$, respectively.

Apatite was analyzed for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ using a Thermo Gas Bench coupled to a Thermo Delta Plus XP mass spectrometer (Paul and Skrzypek, 2007). Carbon and oxygen isotopic compositions are reported relative to PDB and VSMOW, respectively, using NBS 18 ($\delta^{13}\text{C} = -5.01$, $\delta^{18}\text{O} = 7.20$) and NBS 19 ($\delta^{13}\text{C} = 1.95$, $\delta^{18}\text{O} = 28.60$). Analytical precision for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values is $\pm 0.08\text{‰}$ and $\pm 0.16\text{‰}$, respectively.

3.4 Results

3.4.1. Growth

At the end of the 13-week diet experiment, four of the five pigs (hereafter called “controls”) had added an average of 46.6 kg to their mean starting weight of 12.4 kg, an increase of over 360%. Their growth rate was similar to that observed in other well-fed “large white” pigs (Tonge and McCance 1973). By contrast, one pig (hereafter called “reduced growth”) added only 8.1 kg to its starting weight of 10.9 kg, an increase of less than 75%. The reduced growth pig was not distinct from the control pigs at the beginning of the diet experiment, but began to diverge from the group by week 3, when its weight fell more than two standard deviations below the rest of the cohort. The final weight, absolute weight gain, percentage weight increase, and average growth rate of the reduced growth pig were more than 10 standard deviations below those of the control pigs (Figure 3.1).

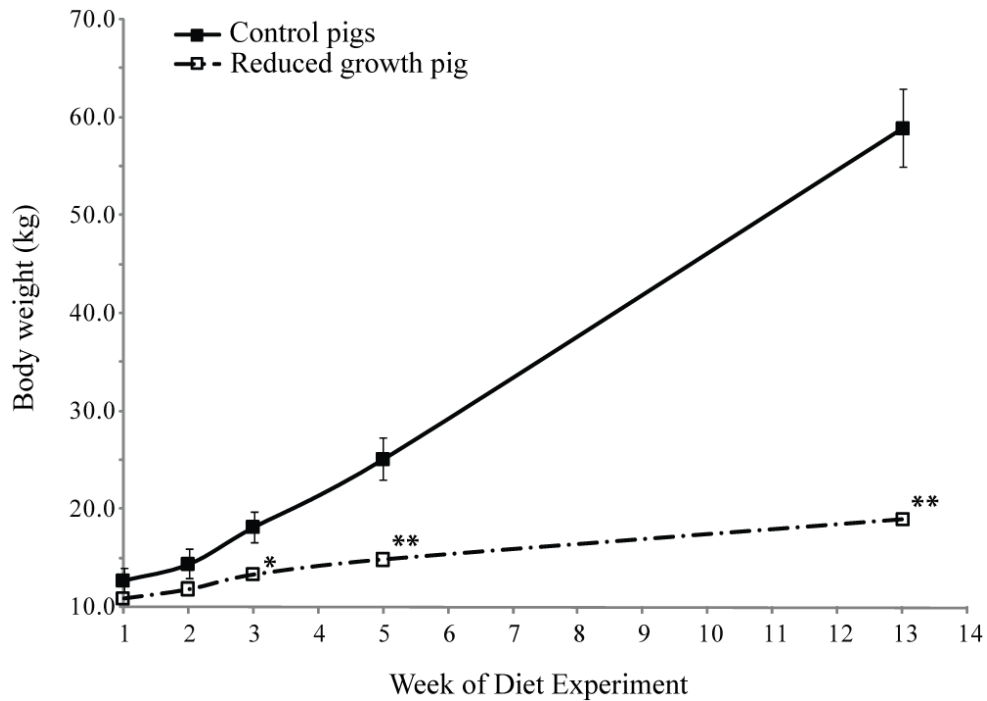


Figure 3.1. Comparative growth rates of the experimental pigs. Control group pigs exhibited a normal rate of growth over the course of the diet experiment, while the reduced growth pigs experienced a markedly depressed growth rate. By week 13, the weight of the reduced growth pig was more than two standard deviations (*) below the mean of the control pigs, and afterward differed by more than four standard deviations (**).

The cause of the growth suppression exhibited by the reduced growth pig is not known, but she displayed a general lack of interest in food. The reduced growth pig was in satisfactory health without infection (per station veterinarian) and displayed normal anatomy and an absence of dwarfism.

3.4.2. Patterns of isotopic discrimination

Isotopic differences among the experimental pigs

Compared to the rest of the diet cohort, the reduced growth pig was isotopically enriched in carbon, nitrogen, and oxygen in a majority of measured tissues, and depleted in deuterium (Table 3.1). With respect to hard tissues, the isotopic values of the reduced growth pig fell more than two standard deviations from the average of the normal growth

pigs for all measured isotopes and tissues except enamel $\delta^{18}\text{O}_{\text{apatite}}$. Bone collagen $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and δD and enamel and bone apatite $\delta^{13}\text{C}$ of the slow growth pig differed from the averages of the normal growth pigs by over four standard deviations.

Among soft tissues, the $\delta^{13}\text{C}$ of the slow growth pig's muscle, blood, and subcutaneous fat was more than three standard deviations above the respective means of the normal growth pigs, but no difference was observed in the nitrogen ratios of muscle or blood. With regard to oxygen isotopic values, bone collagen and muscle tissue were enriched in the reduced growth pig relative to the control group. Overall, a negative trend was observed between growth rate and the final $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{18}\text{O}$ of a majority of tissues, while a positive trend was observed between growth rate and tissue δD (Figure 3.2).

Temporal trends in hair keratin

Hair samples collected upon the pigs' arrival at the Concord Field Station were analyzed for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, and δD and compared to those collected 13 weeks later (Table 3.1). The reduced growth pig's hair isotopic values were indistinguishable from controls at the start of the experiment. Hair $\delta^{13}\text{C}$ of the control pigs decreased by an average of 4.2‰, which is consistent with isotopic turnover following a switch to a more depleted experimental diet. The hair of the reduced growth pig, by contrast, remained virtually unchanged, throughout the course of the experiment. Control pigs all decreased or maintained their original $\delta^{15}\text{N}$ values, while the reduced growth pig displayed an increase of 0.7‰ over its starting nitrogen isotopic ratio, rising more than two standard deviations above the mean of the normal growth pigs. The differences in carbon and nitrogen isotopic values between the two groups strongly suggest different assimilation

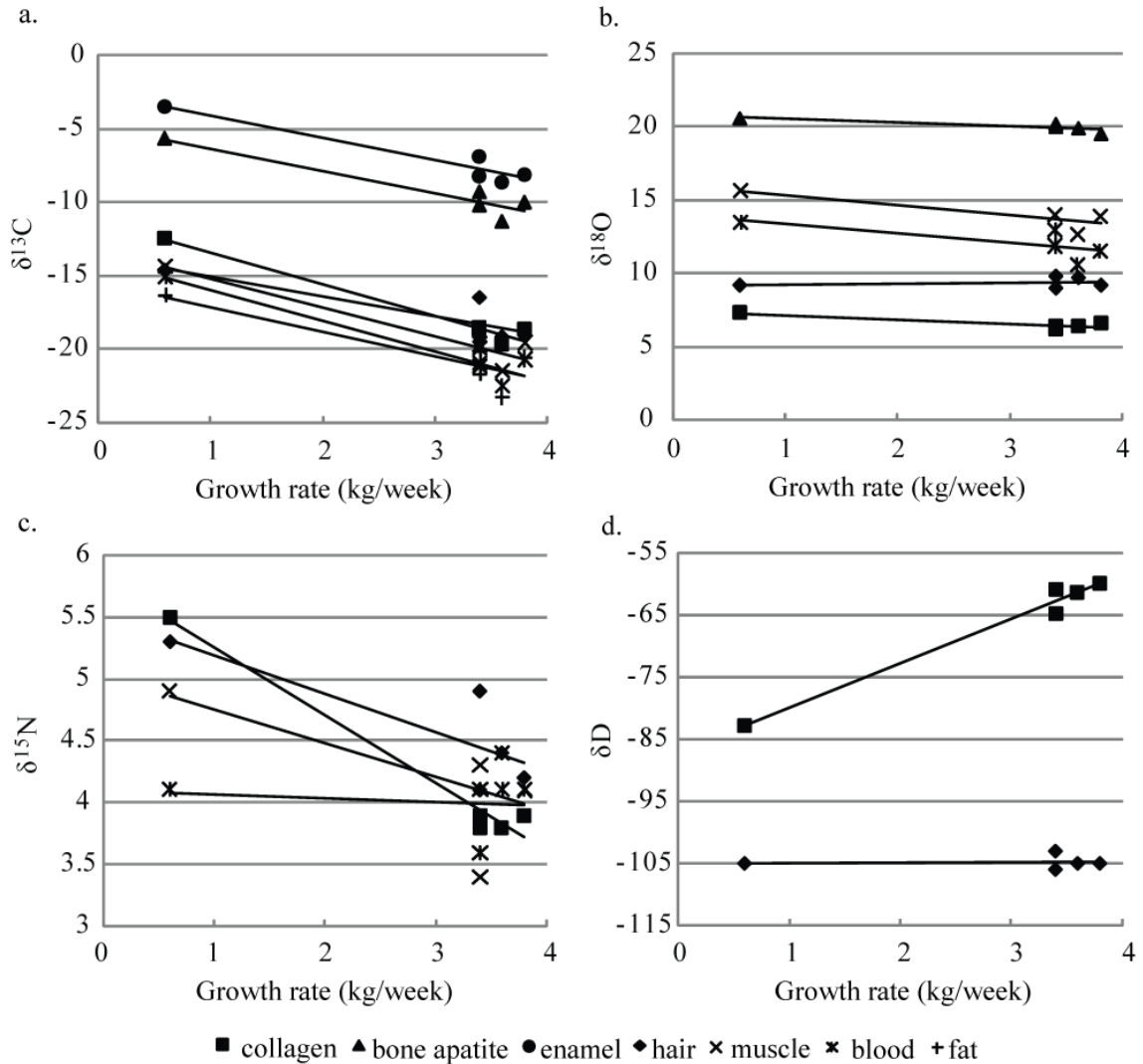


Figure 3.2a-d. Association between final tissue isotopic value and growth rate for all pigs. The control pigs grew at an average rate of 3-4 kg/week, while the reduced growth pig grew at a rate of less than 1 kg/week. Solid lines represent a line of best fit for each tissue. If growth rate had no effect on isotopic values, all trendlines would have a slope of 0.

and/or fractionation of the new diet in the reduced growth pig compared to the controls.

In contrast to carbon and nitrogen, hair hydrogen isotopic ratios have been shown to be relatively poor indicators of short-term isotopic change, while hair oxygen isotopic ratios function as moderate indicators (O'Brien and Wooller 2007). No appreciable difference was observed between the initial hair oxygen or hydrogen isotopic ratios of the

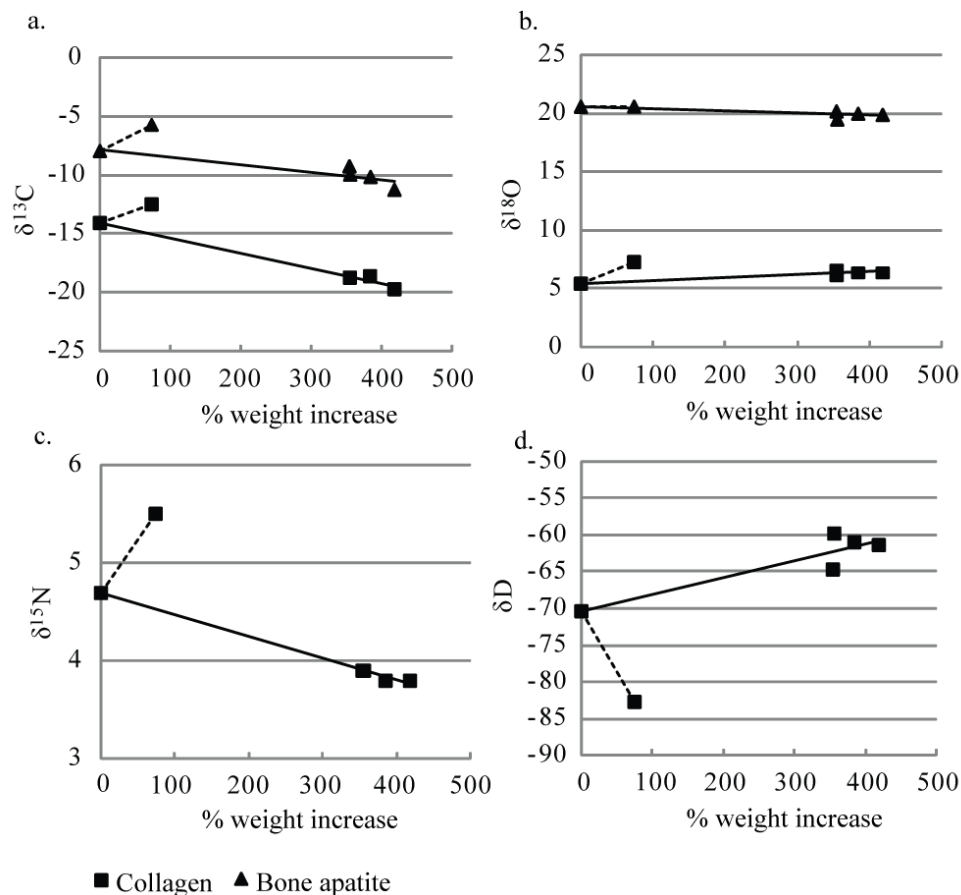


Figure 3.3a-d. Isotopic trends in mineralized tissues as function of weight increase. Solid lines represent the line of best fit between the pre-experiment and final tissue values of control pigs. Dashed lines represent the line of best fit between the pre-experiment and final tissue values of the reduced growth pig. Note that in most tissues the isotopic values of the reduced growth pig are not intermediate between the week 1 pig and the other week 13 pigs, but instead display a reversal of the isotopic trend seen in the normal sized-cohort.

controls and the reduced growth pig, and both hair $\delta^{18}\text{O}$ and δD remained relatively unchanged over the course of the diet experiment.

Temporal trends in mineralized tissues

The mineralized tissue isotopic values of the experimental pigs were compared to a pig sacrificed on the first day of the diet experiment, thus serving as a proxy for pre-diet experiment tissue isotopic ratios (Figure 3.3). With respect to bone collagen, the final

$\delta^{13}\text{C}$ of the reduced growth pig increased over those of the pre-experiment values, magnitude of difference was greater in the reduced growth pig than in the controls. The δD of the slow growth pig was found to be more than 10‰ depleted relative to the pre-experiment value, while the normal growth pigs were enriched by nearly 10‰ over the same pre-experiment value.

Bone apatite $\delta^{13}\text{C}$ increased in the reduced growth pig relative to the pre-experiment value, but decreased in the control pigs. Bone apatite $\delta^{18}\text{O}$ of the reduced growth pig did not differ from pre-experiment values, and only a small depletion in $\delta^{18}\text{O}$ was observed in the bone apatite of the control group.

3.5. Discussion

3.5.1. Comparison with previous studies

Although a number of studies have explored the relationship between nutritional stress and carbon isotopic ratios, the results have been equivocal. While some studies have shown a negative correlation between $\Delta^{13}\text{C}_{\text{tissue-diet}}$ and factors such as diet quality and quantity (Doucett et al. 1999; Gaye-Siessegger et al. 2004, 2007; Hatch et al. 2006; Hatch et al. 1995; Haubert et al. 2005; Miller et al. 1985; Oelbermann and Scheu 2002; Olive et al. 2003; Schmidt et al. 1999), others show no relationship (Boag et al. 2006; Gorokhova and Haansson 1999; Hobson et al. 1993; Kempster et al. 2007; McCue 2007; McCue 2008; McCue and Pollock 2008; Schmidt et al. 1999), or a relative depletion of carbon isotopes (Williams et al. 2007) compared with controls. The results of these studies are complicated by the fact that some studies report whole body or mixed-tissue isotopic ratios, while others report purified tissue isotopic ratios, a fact that may partly explain the apparent contradictory nature of the results. Recent studies of fish, however,

have shown a clear negative relationship between diet quantity and carbon fractionation in lipids (Gaye-Siessegger et al. 2004, 2007). In the present study, I find evidence for substantial $\delta^{13}\text{C}$ enrichment in apatitic (molar enamel and bone apatite) and proteinaceous (bone collagen, hair, muscle, and blood) tissues, as well as subcutaneous fat, in the reduced growth pig as compared to controls. This suggests that growth rate is a factor that may affect $\Delta^{13}\text{C}_{\text{tissue-diet}}$ in multiple tissues.

With respect to nitrogen, a number of studies have demonstrated a clear negative correlation between nitrogen isotopic enrichment and various dietary factors, including protein quality (Adams and Sterner 2000; Gaye-Siessegger et al. 2003; Robbins et al. 2005; Vanderklift and Ponsard 2003; Webb et al. 1998), food quantity (Adams and Sterner 2000; Gaye-Siessegger et al. 2003, 2004, 2007; Oelbermann and Scheu 2002; Tibbets 2008), and growth rate (Martinez del Rio and Wolf 2005; Trueman et al. 2005). My results confirm that depressed growth in a juvenile mammal can result in elevated tissue $\Delta^{15}\text{N}_{\text{tissue-diet}}$. Notably, I found that this effect is seen most clearly in bone collagen and to a lesser extent in hair, but not in muscle or blood. Thus, ecological studies of $\Delta^{15}\text{N}_{\text{tissue-diet}}$, which rely primarily on blood or muscle samples, may underestimate the isotopic impact of nutritional or physiological stress in tissues of greater relevance for archaeologists, such as bone collagen.

This is the first study to examine the relationship between growth rate and oxygen and hydrogen isotopic ratios in organic and inorganic tissues. Compared to controls, I found evidence for minor $\delta^{18}\text{O}$ enrichment in bone collagen, bone apatite, and muscle of the reduced growth pig. The largest difference, however, was seen in bone collagen δD , which fell more than 10 standard deviations from the mean of the control pigs.

3.5.2. Evaluation of current isotopic models and observed relationships

A number of studies have demonstrated that isotopic models can lead to inaccurate results if input assumptions are incorrect (e.g., McCutchan et al. 2003; Gaye-Siessegger et al. 2004). To evaluate the impact of physiological status on isotopic reconstructions using current methods, I applied my isotopic data to a suite of dietary (Schwarcz 1991; Phillips and Koch 2002; Kellner and Schoeninger 2007), trophic level (Post 2002), and precipitation (Reynard and Hedges 2008) models and observed relationships.

Using the isotopic models proposed by Schwarcz (1991) and Phillips and Koch (2002), the estimated dietary maize percentage (actual was 23%) in the control pigs and the reduced growth pig varied widely, from 18% using the bone collagen carbon and nitrogen isotopic values in the control pigs to more than 50% in calculations from all sources of the reduced growth pig. Kellner and Schoeninger (2007) have proposed a suite of alternative models to estimate average dietary $\delta^{13}\text{C}$, from which the proportion of dietary maize could be theoretically calculated by interpolation. Using these models, dietary $\delta^{13}\text{C}$ was accurately predicted from bone collagen in the control pigs, but was overestimated by more than 5‰ in the reduced growth pig. By contrast, bone apatite $\delta^{13}\text{C}$ accurately predicted dietary $\delta^{13}\text{C}$ in the reduced growth pig, but resulted in a 6‰ underestimate in the control pigs. In paleodietary studies of archaeological populations, differences in estimated dietary maize contribution of the magnitude seen between the control pigs and the reduced growth pig would likely be interpreted as evidence for a fundamental shift in subsistence strategy, such as a transition between insipient and moderate scale maize agriculture (e.g., Coltrain and Leavitt 2002; Rose 2008; Schurr 1992).

Trophic level estimation (Post 2002) of the pigs in this study using known dietary inputs and bone collagen $\delta^{15}\text{N}$ results in an underestimated reconstructed trophic level (λ) for the control pigs of 1.5, placing them at an intermediate trophic level between primary producers and primary consumers. The reduced growth pig, by contrast, is accurately characterized at a trophic position of 2.0, the level of a primary consumer.

Precipitation δD reconstruction from bone collagen using the relationship described by Reynard and Hedges (2008) for large-bodied mammals (including humans) resulted in a 20‰ discrepancy between the normal growth pigs and the slow growth pig.

Additionally, the measured tap water δD for Massachusetts, where the diet study and all subsequent analysis took place, is more than 50‰ heavier than that predicted by the bone collagen-based observations of Reynard and Hedges (2008).

3.6. Conclusion

Current paleodiet models have assumed that metabolic processes of fractionation are relatively constant, and that tissue isotopic variation is largely driven by isotopic variation of the underlying diet. This study demonstrates, however, that animals fed an identical diet and raised together under uniform conditions may yield substantially different tissue isotopic ratios and lead to downstream interpretive problems. I found a correlation between depressed growth rate and isotopic enrichment of $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, and $\delta^{18}\text{O}$ and isotopic depletion of δD across some, but not all, tissues. The effect of reduced growth on light stable isotopic values was most pronounced in hard tissues, but differences based on growth rate were also observed in muscle, blood, fat, and hair for individual isotopes.

3.7. Bibliography

- Adams TS and Sterner RW. 2000. The effect of dietary nitrogen content on trophic level ^{15}N enrichment. *Limnol Oceanogr* 45(3): 601-607.
- Ambrose SH and DeNiro MJ. 1987. Bone nitrogen isotope composition and climate. *Nature* 325:201.
- Angel JL. 1975. Paleoecology, paleodemography, and health. In: Polgar S, editor. *Population, Ecology, and Social Evolution*. The Hague: Mouton. p. 167-190.
- Angel JL. 1981. History and development of paleopathology. *Am J Phys Anthropol* 56(4):509-515.
- Angel JL. 1984. Health as a crucial factor in the changes from hunting to developed farming in the eastern Mediterranean. In: Cohen MN, Armelagos GJ, editors. *Paleopathology at the Origins of Agriculture*. Orlando: Academic Press. p. 51-69.
- Baker DH. 2008. Animal models in nutrition research. *J Nutr* 138:391-396.
- Boag B, Neilson R, Scrimgeour CM. 2006. Degrowth phenomenon in the planarian *Arthurdendyus triangulatus* (Tricladida: Terricola) as measured by stable isotopes. *Biol Fert Soils* 43:267-270.
- Cerling TE. 2007. Determining biological tissue turnover using stable isotopes: the reaction progress variable. *Oecologia* 151:175-189.
- Coltrain JB and Leavitt SW. 2002. Climate and diet in Fremont prehistory: economic variability and abandonment of maize agriculture in the Great Salt Lake Basin. *Am Antiquity* 67(3):453-485.
- Danforth ME. 1994. Stature change in prehistoric Maya of the Southern Lowlands. *Latin Am Antiquity* 5(3):206-211.
- Doucett RR, Booth RK, Power G, McKinley RS. 1999. Effects of the spawning migration on the nutritional status of anadromous Atlantic salmon (*Salmo salar*): insights from stable-isotope analysis. *Can J Fish Aquat Sci* 56:2172-2180.
- Ehleringer JR, Bowen GJ, Chesson LA, West AG, Podlesak DW, and Cerling TE. 2008. Hydrogen and oxygen isotope ratios in human hair are related to geography. *PNAS* 105(8):2788-2793.
- Focken U. 2001. Stable isotopes in animal ecology: the effect of ration size on the trophic shift of C and N isotopes between feed and carcass. *Isot Environ Healt S* 37:199-211.
- Fry B, Brand W, Mersch FJ, Tholke K, and Garritt R. 1992. Automated analysis system for coupled $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements. *Anal Chem* 64(3):288-291.
- Gaye-Siessegger J, Focken U, Muetzel S, Abel H, and Becker K. 2004. Feeding level and individual metabolic rate $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in carp: implications for food web studies. *Oecologia* 138:175-183.

- Gaye-Siessegger J, Focken U, Abel HJ, and Becker K. 2007. Starvation and low feeding levels result in an enrichment of ^{13}C in lipids and ^{15}N in protein of Nile tilapia *Oreochromis niloticus* L. *J Fish Biol* 71:90-100.
- Gaye-Siessegger J, Focken U, Abel HJ, Becker K. 2003. Feeding level and diet quality influence trophic shift of C and N isotopes in Nile tilapia (*Oreochromis niloticus* L.). *Isot Environ Health S* 39:125-134.
- Gorokhova E and Haansson S. 1999. An experimental study on variations in stable carbon and nitrogen isotope fractionation during growth of *Mysis mixta* and *Neomysis integer* (Crustacea, Mysidacea). *Can J Fish Aquat Sci* 56:2203-2210.
- Gretebeck RJ, Schoeller DA, Socki RA, Davis-Street J, Gibson EK, Schulz LO, and Lane HW. 1997. Adaptation of the doubly labeled water method for subjects consuming isotopically enriched water. *J Appl Physiol* 82:563-570.
- Hatch KA, Sacksteder KA, Treichel IW, Cook ME, and Porter WP. 1995. Early detection of catabolic state via change in $^{13}\text{C}/^{12}\text{C}$ ratios of blood proteins. *Biochem Biophys Res Commun* 212(3):719-726.
- Hatch KA, Crawford MA, Kunz AW, Thomsen SR, Eggett DL, Nelson ST, and Roeder BL. 2006. An objective means of diagnosing anorexia nervosa and bulimia nervosa using $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$ ratios in hair. *Rapid Commun Mass Sp* 20:3367-3373.
- Haubert D, Langel R, Scheu S, and Ruess L. 2005. Effects of food quality, starvation and life stage on stable isotope fractionation in *Collembola*. *Pedobiologica* 49:229-237.
- Hedges REM and Reynard LM. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *J Archaeol Sci* 34:1240-1251.
- Hobson KA, Atwell L, and Wassenaar LI. 1999. Influence of drinking water and diet on the stable-hydrogen isotope ratios of animal tissues. *PNAS* 96:8003-8006.
- Hobson KA and Clark RG. 1992. Assessing avian diets using stable isotopes II: factors influencing diet-tissue fractionation. *Condor* 94(1):189-197.
- Hobson KA, Alisauskas RT, and Clark RG. 1993. Stable-nitrogen isotope enrichment in avian tissues due to fasting and nutritional stress: implications for isotopic analyses of diet. *Condor* 95(2):388-394.
- Ivanhoe F. 1995. Secular decline in cranioskeletal size over two millennia of interior Central California prehistory – relation to calcium deficit in the reconstructed diet and demographic stress. *Int J Osteoarchaeol* 5(3):213-253.
- Katzenberg MA and Lovell NC. 1999. Stable isotope variation in pathological bone. *Int J Osteoarchaeol* 9:316-324.
- Kellner CM, and Schoeninger MJ. 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *Am J Phys Anthropol* 133(4):1112-1127.
- Kelly JF. 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. *Can J Zoolog* 78:1-27.

- Kempster B, Zanette L, Longstaffe FJ, MacDougall-Schakleton SA, Wingfield JC, Clinchy M. 2007. Do stable isotopes reflect nutritional stress? Results from a laboratory experiment on song sparrows. *Oecologia* 151:365-371.
- Koch PL. 1998. Isotopic reconstruction of past continental environments. *Annu Rev Earth Pl Sc* 26:573-613.
- Larsen CS. 1997. *Bioarchaeology: Interpreting Behavior from the Human Skeleton*. London: Cambridge University Press.
- Lee-Thorp J. 2008. On isotopes and old bones. *Archaeometry* 50:925-950.
- Martinez del Rio C and Wolf BO. 2005. Mass-balance models for animal isotopic ecology. In: Stark M, editor. *Physiological and Ecological Adaptations to Feeding in Vertebrates*. Enfield, NH: Science Publishers. p. 141-174.
- McCue MD. 2007. Western diamondback rattlesnakes demonstrate physiological and biochemical strategies for tolerating prolonged starvation. *Physiol Biochem Zool* 80(1):25-34.
- McCue MD. 2008. Endogenous and exogenous factors influence $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ dietary fractionation in hissing cockroaches, *Gromphadorhina portentosa*. *Physiol Biochem Zool* 81(1):14-24.
- McCue MD and Pollock ED. 2008. Stable isotopes may provide evidence for starvation in reptiles. *Rapid Commun Mass Sp* 22:2307-2314.
- McCutchan JH, Lewis WM, Kendall C, and McGrath CC. 2003. Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. *OIKOS* 102:378-390.
- Miller ER and Ullrey DE. 1987. The pig as a model for human nutrition. *Annu Rev Nutr* 7:361-382.
- Miller RF, Orr GL, Fritz P, Downer RGH, and Morgan AV. 1985. Stable carbon isotope ratios in *Periplaneta americana* L., the American cockroach. *Can J Zoolog* 63(3):584-589.
- O'Brien D and Wooller M. 2007. Tracking human travel using stable oxygen and hydrogen isotope analyses of hair and urine. *Rapid Commun Mass Sp* 21:2422-2430.
- Oelbermann K and Scheu S. 2002. Stable isotope enrichment ($\delta^{15}\text{N}$ and $\delta^{13}\text{C}$) in a generalist predator (*Pardosa lugubris*, Araneae: Lycosidae): effects of prey quality. *Oecologia* 130(3):337-344.
- Olive PJ, Pinnegar JK, Polunin NVC, Richards G, Welch R. 2003. Isotope trophic-step fractionation: a dynamic equilibrium model. *J Anim Ecol* 72:608-617.
- Ortner D. 2003. *Identification of Pathological Conditions in Human Skeletal Remains*. San Diego, CA: Academic Press.
- Paul D and Skrzypek G. 2007. Assessment of carbonate-phosphoric acid analytical technique performed using GasBench II in continuous flow isotope ratio mass spectrometry. *Int J Mass Spectrom* 262: 180-186.

- Phillips DL and Koch PL. 2002. Incorporating concentration dependence in stable isotope mixing models. *Oecologia* 130:114-125.
- Podlesak DW, Torregrossa A, Ehleringer JR, Dearing MD, Passey BH and Cerling TE. 2008. Turnover of oxygen and hydrogen isotopes in the body water, CO₂, and enamel of a small mammal. *Geochim Cosmochim Acta* 72:19-35.
- Post D. 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology* 83(3):703-718.
- Prendergast Moore K, Thorp S, Van Gerven DP. 1986. Pattern of dental eruption, skeletal maturation and stress in a Medieval population from Sudanese Nubia. *Hum Evol* 1(4):325-330.
- Quinn RL, Tucker BD and Krigbaum J. Diet and mobility in Middle Archaic Florida: stable isotopic and faunal evidence from the Harris Creek archaeological site (8Vo24), Tick Island. *J Archaeol Sci* 35(8): 2346-2356.
- Reynard LM and Hedges REM. 2008. Stable hydrogen isotopes of bone collagen in palaeodietary and palaeoenvironmental reconstruction. *J Archaeol Sci* 35:1934-1942.
- Robbins CT, Felicetti LA, and Sponheimer M. 2005. The effect of dietary protein quality on nitrogen isotope discrimination in mammals and birds. *Oecologia* 144:534-540.
- Rose F. 2008. Intra-community variation in diet during the adoption of a new staple crop in the Eastern Woodlands. *Am Antiquity* 73(3):413-439.
- Rubenstein DR and Hobson KA. 2004. From birds to butterflies: animal movement patterns and stable isotopes. *Trends Ecol Evol* 19(5):256-263.
- Saul FP. 1977. The paleopathology of anemia in Mexico and Guatemala. In: Cockburn E, editor. Porotic hyperostosis: an enquiry. Monograph 2. Detroit: Paleopathology Association, 10-15, 18.
- Schmidt O, Scrimgeour CM, Curry JP. 1999. Carbon and nitrogen isotope ratios in body tissue and mucus of feeding and fasting earthworms (*Lumbricus festivus*). *Oecologia* 118:9-15.
- Schoeller D. 1999. Isotope Fractionation: Why aren't we what we eat? *J Archaeol Sci* 26:667-673.
- Schook LB. 2007. The porcine genome initiative: implications for digestive physiology. *Livest Sci* 108(1-3):6-12.
- Schurr M. 1992. Isotopic and mortuary variability in a Middle Mississippian population. *Am Antiquity* 57(2):300-320.
- Schwarcz HP. 1991. Some theoretical aspects of isotope paleodiet studies. *J Archaeol Sci* 18:261-275.
- Schwarcz HP and Schoeninger MJ. 1991. Stable isotope analyses in human nutritional ecology. *Yearb Phys Anthropol* 34:283-321.

- Sharp ZD, Atudorei V, and Durakiewicz T. 2001. A rapid method for determination of hydrogen and oxygen isotope ratios from water and hydrous minerals. *Chem Geol* 178:197-210.
- Sobolik K. 2002. Children's health in the Prehistoric Southwest. In: Kamp K, editor. *Children in the Prehistoric Puebloan Southwest*. Salt Lake City: University of Utah Press. p. 1-13.
- Tibbets T, Wheelless LA, and Martínez del Rio C. 2008. Isotopic enrichment without change in diet: an ontogenetic shift in $\delta^{15}\text{N}$ during insect metamorphosis. *Funct Ecol* 22:109-113.
- Tonge CH, and McCance RA. 1973. Normal development of jaws and teeth in pigs, and delay and malocclusion produced by calorie deficiencies. *J Anat* 115(May):1-22.
- Trueman CN, McGill RAR, and Guyard PH. 2005. The effect of growth rate on tissue-diet isotopic spacing in rapidly growing animals: an experimental study with Atlantic salmon (*Salmo salar*). *Rapid Commun Mass Sp* 19:3239-3247.
- Tumbleson M. 1986. *Swine in biomedical research*. New York: Plenum Press.
- Tuross N, Warinner C, Kirsanow K, and Kester C. 2008. Organic oxygen and hydrogen isotopes in a porcine controlled dietary study. *Rapid Commun Mass Sp* 22:1741-1745.
- Ubelaker D. 1994. The biological impact of European contact in Ecuador. In: Larsen CS and Milner GR, editor. *In the Wake of Contact: biological responses to conquest*. New York: Wiley-Liss. p. 147-160.
- Vander Zanden J and Rasmussen JB. 2001. Variation in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ trophic fractionation: implications for aquatic food web studies. *Limnol Oceanogr* 46(8):2061-2066.
- Vanderklift MA and Ponsard S. 2003. Sources of variation in consumer-diet $\delta^{15}\text{N}$ enrichment: a meta-analysis. *Oecologia* 136(2):169-182.
- Warinner C and Tuross N. 2009. Alkaline cooking and stable isotope diet-tissue discrimination in swine: archaeological implications. *J Archaeol Sci* 36(8):1690-1697.
- Webb SC, Hedges REM, Simpson SJ. 1998. Diet quality influences the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of locusts and their biochemical components. *J Exp Biol* 201:2903-2911.
- West JB, Bowen GJ, Cerling TE and Ehleringer JR. 2006. Stable isotopes as one of nature's ecological recorders. *Trends Ecol Evol* 21(7):408-414.
- White C. 1988. The ancient Maya from Lamanai, Belize: Diet and health over 2,000 years. *Can Rev Phys Anth* 6:1-21.
- White C, ed. 1999. *Reconstructing Ancient Maya Diet*. University of Utah Press.
- White CD and Armelagos GJ. 1997. Osteopenia and stable isotope ratios in bone collagen of Nubian female mummies. *Am J Phys Anthropol* 103:185-199.
- Williams CD, Buck CL, Sears J, and Kitaysky AS. 2007. Effects of nutritional restriction on nitrogen and carbon stable isotopes in growing seabirds. *Oecologia* 153:11.

3.8. Appendix

Appendix 3.1. Mathematical models employed in analysis

Dietary, trophic, and geographic reconstruction models tested in this study are detailed below:

SCHWARCZ (1991), two-source linear mixing model (1):

$$f_x = \frac{\delta^{13}C_M - \delta^{13}C_Y - \Delta^{13}C_{\text{tissue-X}}}{\delta^{13}C_X - \delta^{13}C_Y} \quad (1)$$

where f_x is the percentage C4 contribution to the diet, $\delta^{13}C_M$ is the isotopic ratio of the food mixture, $\delta^{13}C_X$ is the isotopic ratio of the C4 component of the diet, $\delta^{13}C_Y$ is the isotopic ratio of the C3 component of the diet. This model is commonly used in archaeology and yields the same result as the simple two-source mixing model that has been employed in ecology (McCutchan et al. 2003).

PHILLIPS AND KOCH (2002), concentration-dependent multiple source mixing model (2-4):

$$\begin{aligned} &(\delta^{13}C_X + \Delta^{13}C_{\text{tissue-X}} - \delta^{13}C_M)[C]_X f_{X,B} + \\ &(\delta^{13}C_Y + \Delta^{13}C_{\text{tissue-Y}} - \delta^{13}C_M)[C]_Y f_{Y,B} = 0 \quad (2) \end{aligned}$$

$$\begin{aligned} &(\delta^{15}N_X + \Delta^{15}N_{\text{tissue-X}} - \delta^{15}N_M)[N]_X f_{X,B} + (\delta^{15}N_Y + \Delta^{15}N_{\text{tissue-Y}} - \\ &\delta^{15}N_M)[N]_Y f_{Y,B} = 0 \quad (3) \end{aligned}$$

$$f_{X,B} + f_{Y,B} = 0 \quad (4)$$

where the subscripts X and Y represent the two food sources, M represents the consumer, f represents the fractional contribution of carbon atomic mass from each food source to the consumer's diet, and $\Delta_{\text{tissue-(X or Y)}}$ is the trophic fractionation between food source X or Y and the consumer tissue. This model, building on the simpler linear mixing model, accounts for differential elemental concentration in each food source. In addition, it also allows each food source to have an independent fractionation value and incorporates data from multiple isotopes.

KELLNER AND SCHOENINGER (2007), empirical model (5, 6):

$$\delta^{13}C_{\text{diet}} = (0.86 \delta^{13}C_{\text{collagen}}) - 6.0 \quad (5)$$

$$\delta^{13}C_{\text{diet}} = (1.04 \delta^{13}C_{\text{apatite}}) - 9.2 \quad (6)$$

This model differs from the above mixing models in that it estimates average dietary $\delta^{13}C$ from a simple linear relationship derived from empirical data collected from controlled feeding experiments in rodents and pigs.

MCCUTCHAN ET AL. (2003), trophic position interpolation model (7):

$$\lambda = \frac{\delta^{15}\text{N}_{\text{consumer}} - \delta^{15}\text{N}_{\text{base}}}{\Delta^{15}\text{N}} + 2 \quad (7)$$

where λ is the trophic position of an organism, $\delta^{15}\text{N}_{\text{base}}$ is the nitrogen isotopic ratio of the base of the food chain (i.e., primary producers), and $\Delta^{15}\text{N}$ is the nitrogen fractionation factor per trophic level. This model is used in ecology to estimate trophic position (λ) in complex ecosystems. Under this model, a primary producer has a λ of 1, an herbivore has a λ of 2, and a first-order carnivore has a λ of 3. Fractional λ indicates feeding at mixed trophic levels, and whole integer increases in λ represent trophic steps.

REYNARD AND HEDGES (2008), $\delta\text{D}_{\text{precipitation}}$ reconstruction from large-bodied mammal collagen (8):

$$\delta\text{D}_{\text{collagen}} = 1.069 \delta\text{D}_{\text{precipitation}} + 71.9 \quad (8)$$

This model estimates $\delta\text{D}_{\text{precipitation}}$ from a simple linear relationship derived from the $\delta\text{D}_{\text{collagen}}$ of large-bodied mammals and $\delta\text{D}_{\text{precipitation}}$ data collected from the IAEA Global Network of Isotopes in Precipitation (IAEA/WMO 2004) and Bowen et al. (2005).

LONGINELLI (1984), $\delta^{18}\text{O}_{\text{drinking water}}$ reconstruction from human bone apatite (9-10)
 $y = 0.64x + 22.37 \quad (9)$

where y is the $\delta^{18}\text{O}$ of human bone apatite phosphate and x is the $\delta^{18}\text{O}$ of meteoric water. The equation was derived from a study of 59 human bone samples dating from 1850-1950 and regional meteoric water data. In the original study, the R value of this line is given as 0.98, with a slope standard deviation of ± 0.03 . This equation was modified in Iacumin et al. (1996) to accommodate human bone apatite carbonate through the following conversion:

$$\delta^{18}\text{O}_{\text{PO}_4} = 0.973\delta^{18}\text{O}_{\text{CO}_3} - 9.02 \quad (10)$$

Iacumin et al. (1996) also assume that x likely reflects drinking water rather than meteoric water. The modified Longinelli (1984) model described by Iacumin et al. (1996) is also used by Quinn et al. 2008.

LONGINELLI (1984), $\delta^{18}\text{O}_{\text{drinking water}}$ reconstruction from swine bone apatite (11-12)
 $y = 0.86x + 22.71 \quad (11)$

where y is the $\delta^{18}\text{O}$ of swine bone apatite phosphate and x is the $\delta^{18}\text{O}$ of meteoric water. The equation was derived from a study of 32 bone samples from domestic pigs and regional meteoric water data. In the original study, the R value of this line is given as 0.98, with a slope standard deviation of ± 0.05 . Following the modifications of Iacumin et al. (1996), equation 10 (see above) was applied, and x was interpreted to represent drinking rather than meteoric water.

**CHAPTER 4: ISOTOPIC DIVERSITY OF THE MIDDLE AMERICAN DIETOME:
REEVALUATING PALEODIETARY INTERPRETATION
WITHIN A REGIONAL FRAMEWORK³**

The results of this study were presented in part at the 2006 and 2008 Society for American Archaeology meetings, as well as in complete form at the 2009 UK Archaeological Sciences conference. A version of this chapter was submitted as a research article to *Current Anthropology* in 2010.

4.1. Chapter summary

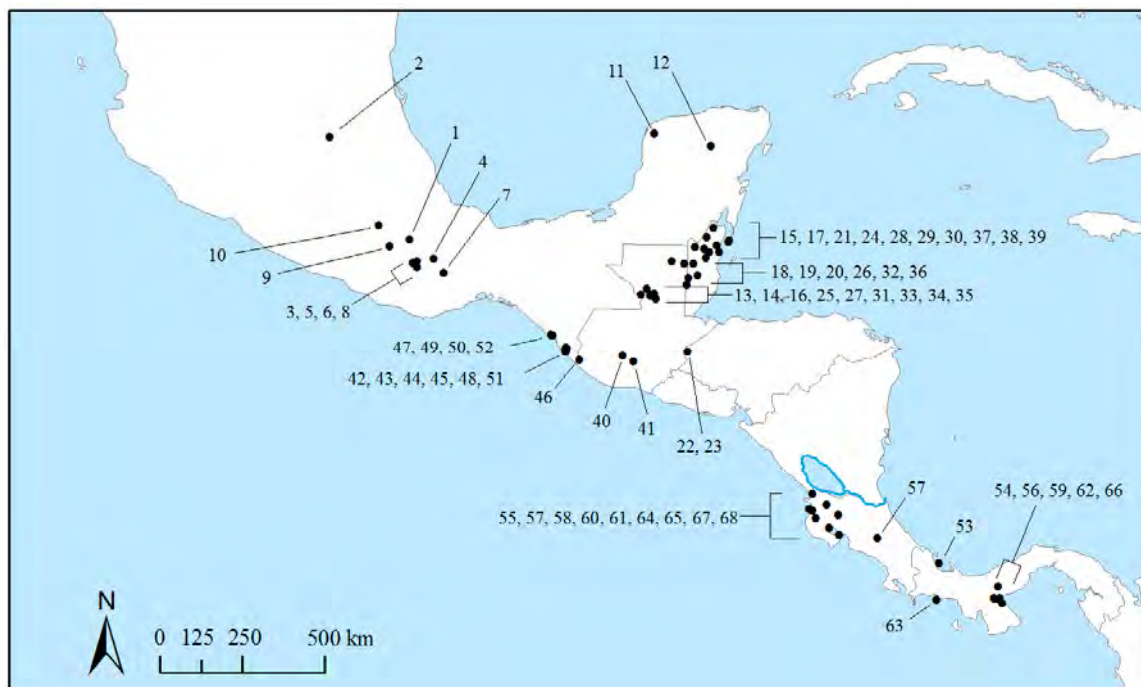
Stable isotope-based paleodiet reconstructions in Middle America have relied on idealized models of plant isotopic diversity drawn from global isotopic averages of plant types. As archaeologists increasingly employ isotopic evidence in high-resolution paleodietary studies, a more detailed understanding of the underlying local food web is required. In this study, I obtained carbon and nitrogen isotopic data for more than 350 plants collected from traditional markets in highland and lowland Mesoamerica, herbarium collections, archaeological deposits, and a field transect in the Valley of Oaxaca. Combined with a meta-analysis of previously published regional isotopic flora and fauna data, I demonstrate a much more diverse and complicated isotopic landscape than has been previously assumed for Middle America. In addition, my data contradict several generalizations that have been made in paleodietary modeling, and suggest that previous analyses of human collagen data may need to be reconsidered in light of a broader understanding of the underlying food base.

³ This research was supported by grants from the David Rockefeller Center for Latin American Studies, the Harvard University Owens Fund, and the Harvard University Graduate Student Council. We'd like to thank Antonio Martínez Tuñón, Cheryl Makarewicz, Josh Wright, and David Diaz for their assistance with field collection, Henry Kesner and Stephanie Zabel for assistance with historical collections, Miriam Belmaker for statistical advice, and Cynthia Kester for technical assistance with the mass spectrometer. We extend our sincere thanks to the staff of Monte Alban, to the Harvard University Herbaria, to Alejandro de Avila at the Jardín Etnobotánico de Oaxaca, and to the many Mexican merchants who allowed us to sample their produce.

4.2. Introduction

Over the last thirty years, light stable isotope analysis has become a standard tool of archaeological inquiry. It has expanded our understanding of global subsistence strategies and has shed new light on previously intractable archaeological problems. Archaeologists have used stable isotopes to analyze the diet breadth of australopithecines, Neanderthals, and early modern humans (Drucker and Bocherens 2004; Hu et al. 2009; Richards and Trinkhaus 2009; Sponheimer et al. 2006; Sponheimer and Lee-Thorp 1999), explore seasonal mobility and resource exploitation among hunter gatherer groups (Nehlich et al. 2009; Pate 1995; Tessone et al. 2009), and study the origins and spread of agriculture (Barton et al. 2009; Lubell et al. 1994; Schoeninger 2009; van der Merwe and Vogel 1978). Increasingly, stable isotope analyses are moving beyond questions of subsistence pattern characterization and are being applied to questions regarding social organization and change. This is especially true in Middle America, where archaeologists have used stable isotope analysis to explore gender and social inequality (Chase and Chase 2000; White 2005; White et al. 2001), agricultural intensification processes (Henderson 2003), long distance trade (Powis et al. 1999), diversification and regionalization of cuisines (van der Merwe et al. 2000; Metcalfe et al. 2009), and potential environmental factors behind the Classic Maya collapse (Wright and White 1996). Human bone and tooth isotopic data are now available for more than 50 sites in Middle America, making it among the most intensively studied regions worldwide (Figure 4.1; Appendix 4.1). Coupled with a long history of archaeological excavation and rich ethnohistorical sources, Middle America represents an excellent testing ground for evaluating social interpretations based on established and emerging methods of isotopic analysis.

Figure 4.1. Stable isotope-based paleodietary studies of Middle American^a human populations



No.	Site	Culture ^b	Time Period	Enamel ($\delta^{13}\text{C}$)	Collagen ($\delta^{13}\text{C}$) ^c	Collagen ($\delta^{15}\text{N}$) ^c	Ref. ^c
<i>Central Mexico</i>							
1	Tehuacan Valley	n.r.	6000 BC-AD 1000	-	11	11	8^f, 9, 10^f
2	Teotihuacan	Zapotec ^g	AD 200-650	-	11(1)	11(1)	33
<i>Oaxaca</i>							
3	El Paragüito	Zapotec	500 BC-AD 750	-	2	2	This study
4	Lambityeco	Zapotec	AD 600-700	-	1	1	This study
5	Monte Alban	Zapotec	200 BC-AD 1000	-	10(27)	10(27)	3
6	Atzompa	Zapotec	AD 550-650	-	1	1	This study
7	S. Miguel Albarradas	Zapotec	AD 1300-1400	-	1	1	This study
8	S. Pedro Ixtlahuaca	Zapotec	AD 1150-1250	-	1	1	This study
9	Teposcolula	Mixtec	AD 1520-1552	19	48	48	This study
10	Xatachio	Zapotec	350-200 BC	-	1	1	This study
<i>Northern Maya Lowlands</i>							
11	Chunchucmil	Maya	AD 400-800	3	(3)	(3)	15
12	Yaxuna	Maya	AD 250-900	17	(3)	(3)	15
<i>Southern Maya Lowlands</i>							
13	Aguateca	Maya	AD 600-800	-	6(3)	6(3)	40, 41^e, 42
14	Altar de Sacrificios	Maya	900 BC-AD 1000	-	52(4)	51(4)	12, 13^e, 40, 41^e, 42
15	Altun Ha	Maya	800 BC-AD 950	-	57	53(1)	32
16	Arroyo de Piedra	Maya	AD 600-900	-	1	1	42
17	Baking Pot	Maya	AD 600-900	-	8(1)	8(1)	12, 13^e
18	Barton Ramie	Maya	AD 1-900	-	32(6)	32(6)	12, 13^e

Figure 4.1 continued

No.	Site	Culture ^b	Time Period	Sample Size (Individuals)			Ref. ^c
				Enamel ($\delta^{13}\text{C}$)	Collagen ($\delta^{13}\text{C}$) ^c	Collagen ($\delta^{15}\text{N}$) ^c	
19	Cahal Pech	Maya	650 BC-AD 300	-	3(9)	3(10)	19^e
20	Caracol	Maya	AD 250-1050	-	(85)	(85)	4^f, 5^f
21	Chau Hiix	Maya	AD 250-1400	31	29	29	16
22	Copan	Maya	AD 400-1250	-	14(92)	14(90)	12ⁱ, 13^e, 20^{ef}, 21, 22, 36
23	Copan area	Maya	AD 1-900	-	16(8)	16(8)	12ⁱ, 13^e
24	Cuello	Maya	1200 BC-AD 1	39	(31)	(26)	25^e, 26^e
25	Dos Pilas	Maya	AD 600-1000	-	31	31	40, 41^e, 42
26	Holmul	Maya	AD 1-900	-	13(1)	13(2)	12, 13^e
27	Itzan	Maya	AD 600-800	-	5	5	40, 41^e, 42
28	K'axob	Maya	800 BC-AD 900	-	6	7	14
29	Lamanai	Maya	1250 BC-AD 1670	5	9(32)	8(30)	7, 27^h, 28^e, 29, 31^e
30	La Milpa	Maya	AD 600-1000	-	(3)	(3)	24^f
31	La Paciencia	Maya	AD 600-900	-	1	1	42
32	Pacbitun	Maya	AD 250-900	3	20	20	7, 28^e, 30
33	Punta de Chimino	Maya	AD 600-900	-	1	1	42
34	Seibal	Maya	900 BC-AD 1000	-	53(9)	53(9)	12, 13^e, 40, 41^e, 42
35	Tamarindito	Maya	AD 600-900	-	4(2)	4(2)	42
36	Uaxactun	Maya	AD 600-900	-	5(1)	5	12, 13^e
<i>Maya Islands</i>							
37	Marco Gonzalez	Maya	100 BC-AD 1350	-	22	22	39
38	Mojo Cay	Maya	AD 400-700	-	8	8	17
39	San Pedro	Maya	AD 1400-1650	-	42	42	39
<i>Maya Highlands</i>							
40	Iximche	Maya	AD 1470-1530	43	(15)	(15)	23^h, 34^{ef}, 35, 37, 38 43^{ij,k}
41	Kaminaljuyu	Maya	AD 400-600	12	10	6	
<i>Pacific Coast</i>							
42	Altamira	n.r.	AD 1200-1524	-	(1)	(1)	6
43	Aquiles Serdan	Mokaya	1150-900 BC	-	(2)	(2)	6
44	Chilo	Mokaya	1350-1250 BC	-	(1)	(1)	6
45	Huanacastal	Mokaya	850-750 BC	-	1	-	2
46	La Blanca	Mokaya	850-750 BC	-	3(1)	2(2)	2, 6
47	Las Morenas	n.r.	AD 600-1000	-	1	1	2, 6
48	Paso de la Amada	Mokaya	1250-750 BC	-	1(3)	(3)	2, 6
49	Rio Arriba	n.r.	AD 300-600	-	1	1	2, 6
50	Tlacuachero	Chantuto, n.r.	2700 BC-AD 100	-	2(1)	2(1)	2, 6
51	Villo	Mokaya	1000-900 BC	-	(1)	(1)	6
52	Zapotillo	n.r.	AD 1200-1524	-	1(1)	1(1)	2, 6
<i>Lower Central America</i>							
53	Cerro Brujo	n.r.	AD 600-900	-	5	5	17
54	Cerro Mangote	n.r.	5000-3000 BC	-	13	12	1ⁱ, 17, 18
55	Duarte-La Guinea	n.r.	AD 1000-1550	-	1	1	1, 17
56	El Cano	n.r.	AD 700-1100	-	4	4	17

Figure 4.1 continued

No.	Site	Culture ^b	Time Period	Sample Size (Individuals)			Ref. ^c
				Enamel ($\delta^{13}\text{C}$)	Collagen ($\delta^{13}\text{C}$) ^c	Collagen ($\delta^{15}\text{N}$) ^c	
57	El Molino	n.r.	AD 700-1200	-	9	9	17
58	El Silencio	n.r.	c. AD 1000	-	(8)	-	11, 17
59	Giron	n.r.	300 BC-AD 500	-	3	3	17
60	Guayabo de Bagaces	n.r.	AD 500-1000	-	1	1	17
61	Herramientas	n.r.	AD 1200-1550	-	3	3	17
62	La Mula-Sarigua	n.r.	1000-200 BC	-	6	6	17, 18
63	La Pitahaya	n.r.	AD 700-1100	-	9	9	17
64	Las Marias	n.r.	AD 1200-1550	-	5	5	17
65	Nacascolo	n.r.	AD 300-1200	-	15	14	1, 17
66	Sitio Sierra	n.r.	300 BC-AD 1100	-	31	31	1, 17, 18
67	Vidor	n.r.	AD 300-800	-	7	7	17
68	Vigilante Alta	n.r.	AD 1200-1550	-	6	6	17
Total				173	663(355)	649(341)	

Notes:

^aThis table excludes data from the West Indies. The complete human isotopic dataset is available in Appendix 4.1.

^bWhen the archaeological culture is not specified, culture is given as n.r. (not reported).

^cOnly individuals with collagen C/N ratios between 2.8-3.6 were tallied because C/N ratios outside of this range have been shown to yield unreliable results (DeNiro 1985). Individuals for which no C/N ratios have been reported are noted in parentheses.

^dPublications containing original data or raw data published for the first time are highlighted in bold. This includes dissertations available in the ProQuest Dissertations and Theses Full Text database. Reference codes are as follows: 1=Amrose and Norr 1992; 2=Blake et al. 1992; 3=Blitz 1995; 4=Chase and Chase 2000; 5=Chase, Chase, and White 2001; 6=Chisholm and Blake 2006; 7=Coyston, White, and Schwarcz 1999; 8=DeNiro and Epstein 1981; 9=DeNiro and Epstein 1986; 10=Farnsworth et al. 1985; 11=Friedman and Gleason 1984; 12=Gerry 1993; 13=Gerry and Krueger 1997; 14=Henderson 2003; 15=Mansell et al. 2006; 16=Metcalfe et al. 2009; 17=Norr 1991; 18=Norr 1995; 19=Powis et al. 1999; 20=Reed 1994; 21=Reed 1998; 22=Reed 1999; 23=Reed and Whittington 1995; 24=Tykot 2002; 25=Tykot et al. 1996; 26=van der Merwe et al. 2000; 27=White 1986; 28=White 1997; 29=White and Schwarcz 1989; 30=White, Healy, and Schwarcz 1993; 31=White, Wright, and Pendergast 1994; 32=White et al. 2001; 33=White et al. 2004; 34=Whittington and Reed 1994; 35=Whittington and Reed 1996; 36=Whittington and Reed 1997; 37=Whittington and Reed 1998; 38=Whittington and Tykot 2000; 39=Williams, White, and Longstaffe 2005; 40=Wright 1994; 41=Wright 1997; 42=Wright 2006; 43=Wright and Schwarcz 1999.

^eIncludes isotopic data presented in summary form only.

^fData reported graphically only.

^gZapotec barrio at Teotihuacan.

^hOriginal data appear in an unpublished government report or in an academic thesis that is not available in the ProQuest Dissertation and Theses Full Text database.

ⁱOne sample was excluded as an extreme outlier and likely represents contamination or instrumental error.

^jIncludes dentine collagen.

^kReplicate measurements for an individual were averaged.

Although human populations have been intensively sampled in Middle America, the isotopic diversity of the underlying food base, or “dietome,” has not received the same level of inquiry. As in other regions, Middle American paleodietary studies have instead relied primarily upon idealized models of global plant isotopic diversity to derive estimates of mean $\delta^{13}\text{C}$ for C3, CAM, and C4 plants (O’Leary 1988; Farquhar, Ehleringer, and Hubick 1989; Smith and Epstein 1971) and mean $\delta^{15}\text{N}$ for N₂-fixing and non-N₂-fixing plants (Delwiche and Steyn 1970; Delwiche et al. 1979; DeNiro 1987; Shearer and Kohl 1988). Modeling of higher trophic levels within Middle American food webs has likewise been based on generalized, global patterns of stepwise nitrogen enrichment from plants to herbivores to carnivores that have been observed in marine and terrestrial ecosystems (Wada, Kadonaga, and Matsuo 1975; Minagawa and Wada 1984; Schoeninger and DeNiro 1984; Schoeninger 1985; Sealy et al. 1987).

Accurate diet modeling at a fine scale, however, necessitates at a minimum a detailed understanding of the underlying local dietome, since the actual $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of plant and animal tissues are known to deviate from idealized models as a result of environmental, physiological, and cultural factors (Ambrose and DeNiro 1986; Ambrose 1991, 1993; Heaton et al. 1986; Hobson and Clark 1992; Keegan and DeNiro 1988; Pinnegar and Polunin 1999; van der Merwe and Medina 1991; Warinner and Tuross 2009a,b). Patterns of trophic enrichment also require local verification since observed trophic level isotopic differences are more variable than often assumed (Vander Zanden and Rasmussen 2001), and few studies have focused on within-ecosystem, as opposed to global, trophic enrichment patterns.

Limited isotopic surveys of indigenous crops conducted in parts of Middle America have produced regional plots of isotopic diversity that differ from global models, suggesting that the use of localized isotopic parameters may lead to more accurate paleodietary interpretations for Middle American populations. However, the cumulative sample size of these surveys is small (94 samples from fewer than 30 taxa), which permits only restricted intra- and interspecies isotopic characterization of the diverse array of flora consumed in prehistory. Although the faunal resources of Middle America have been more extensively surveyed (388 samples from at least 77 taxa), patterns of trophic enrichment cannot be independently evaluated within human food chains without an adequate isotopic understanding of plants at the base of the food web. In this study, I combine new and previously published regional isotopic data from Middle America to explore the isotopic diversity of Middle American human food webs and the impact on human paleodietary interpretation.

4.3. Data Collection

Isotopic data for Middle American flora and fauna have been published from seven principal locations: northern Belize, the Petén, Copan/Quirigua, Lagartero, coastal Soconusco, Costa Rica, and Panama. To complement this data set, I selected the Valley of Oaxaca and coastal Tabasco as regions of isotopic interest, and I additionally obtained plant material from historic collections throughout Middle America and carbonized plant remains from the archaeological site of Monte Alban in the Valley of Oaxaca. Figure 4.2 displays the collection locations of Middle American flora and fauna analyzed in this study. Because Southern Mexico is underrepresented in human isotopic studies of Middle America, I also obtained and analyzed human skeletal material from multiple

archaeological sites in Oaxaca, Mexico. The complete Middle American isotopic dataset is available in Appendices A-G. All new flora, fauna, and human material obtained for this study were analyzed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ at the Harvard University Biogeochemistry Laboratory using established isotopic methods (Warinner and Tuross 2009). Carbon and nitrogen isotopic values are expressed relative to VPDB and AIR, respectively.

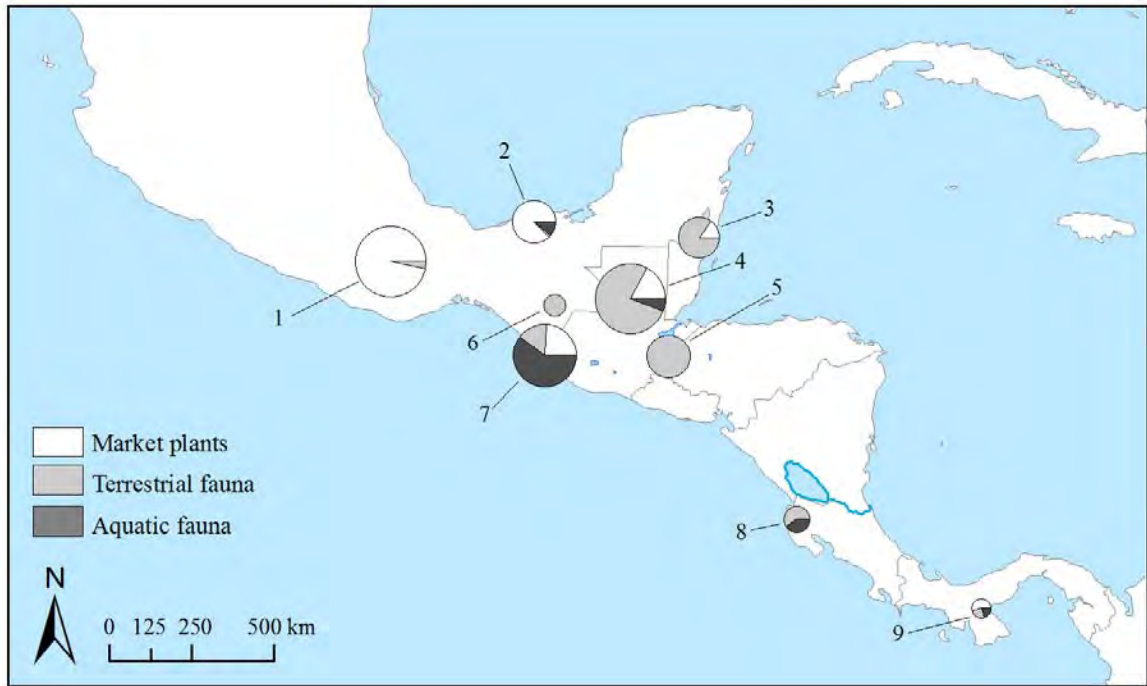
4.3.1. Published data

Published isotopic data were compiled for plants, terrestrial fauna, and aquatic fauna collected from locations within Middle America and surrounding bodies of water. Non-native species introduced after European contact were excluded. Because of taphonomic concerns (DeNiro and Hastorf 1985), compiled plant data were limited to modern specimens only. Faunal data include collagen isotopic values of both modern and archaeological specimens, but archaeological samples were only accepted if reported C/N data fell within the range of 2.8-3.6 for authentic collagen (DeNiro 1985). Modern meat samples were also included in analysis, but other tissues (e.g., shell, chitin) were not.

4.3.2. Valley of Oaxaca

The Valley of Oaxaca is located in southern Mexico at an elevation of over 1550 meters, and it supports a diverse array of highland, arid-adapted vegetation. The earliest human occupation in the valley's Mitla cave system dates to the late Paleoindian period (Flannery 1986), and archaic deposits from Guilá Naquitz rockshelter have yielded the earliest macrobotanical evidence for maize and squash domestication in the Americas (Smith 1986; Piperno and Flannery 2001; Smith 2001). The valley additionally contains important Formative, Classic, and Postclassic Zapotec and Mixtec archaeological sites, and is today home to a diverse range of indigenous ethnic groups.

Figure 2. Middle American^a flora and fauna collection locations for stable isotope analysis



No.	Location	Plants ^b		Terrestrial Fauna ^c		Aquatic Fauna ^c		References ^d
		$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	
MARKET FOODSTUFFS^e								
<i>Central Mexico</i>								
-	Unknown ^f	9 ^g	-	-	-	-	-	5
<i>Oaxaca</i>								
1	Valley of Oaxaca	145	142	5	5	-	-	This study
<i>Gulf Coast</i>								
2	Coastal Tabasco	47	46	2	2	5	5	This study
<i>Southern Maya Lowlands</i>								
3	Northern Belize	9	-	48 ^e	38 ^e	-	-	6, 7
4	Peten	31	10	130	63	11	11	2, 3, 8, 9, 10
5	Copan/Quirigua	-	-	58	56	-	-	3, 8
<i>Maya Highlands</i>								
6	Lagartero	-	-	14	14	-	-	8
<i>Pacific Coast</i>								
7	Soconusco	32	24	19	19	67	61	1
<i>Lower Central America</i>								
8	Costa Rica	-	-	14	14	8	8	4
9	Panama	12	7	2	2	4	4	4
Total		285	229	292	213	95	89	
OTHER COLLECTIONS								
<i>Wild plant transect</i>								
1	Valley of Oaxaca	150	119	-	-	-	-	This study
<i>Herbarium samples</i>								
-	Various locations ^h	38	38	-	-	-	-	This study
<i>Archaeological samples</i>								
1	Valley of Oaxaca	5	5	-	-	-	-	This study
Total		193	162	-	-	-	-	

Figure 4.2 continued

Notes:

^aWest Indies are not included.

^bMarket plants include only taxa native to prehistoric Middle America.

^cIncludes both modern and ancient samples. Ancient samples included only if reported C/N is 2.8-3.6 (DeNiro 1985).

^d1=Chisholm and Blake 2006; 2=Emery, Wright, and Schwarcz 2000; 3=Gerry 1993; 4=Norr 1991; 5=Tieszen and Fagre 1993; 6=van der Merwe et al. 2000; 7=White et al. 2001; 8=White et al. 2004; 9=Wright 1994; 10=Wright 2006

^eRelative regional sample sizes of foodstuffs analyzed in this study are visualized using pie charts in the corresponding map.

^fMaize grown on CIMMYT experimental farms at undisclosed locations in Central Mexico.

^gExcludes samples that are reported in averaged summary form only.

^hAll herbarium samples were collected between 1850 and 1950 from various locations scattered throughout Middle America. Individual collection locations, which range from North Mexico to Panama, are not indicated on the map.

Cultivated plants were purchased from three markets in the Valley of Oaxaca in January and July of 2006 in order to collect both early and late harvest crops. In addition to plants, toasted grasshoppers, maguey worms, and fermented pulque were also acquired. A total of 150 samples were collected from the Valley of Oaxaca markets.

Wild vegetation was sampled along a 185-meter elevational transect in the vicinity of Guilá Naquitz rockshelter in January 2006. Plant collection zones were established at intervals from the rockshelter to the valley floor and consisted of complete sampling of all plants within a 5 meter radius of each collection point. A total of 96 samples were collected from five collection zones, and an additional 54 samples were collected non-systematically between collection zones. Plants were classified into three broad categories: grasses, cacti and succulents, and other plants.

Carbonized plant remains were obtained from archaeological deposits at the Zapotec site Atzompa, a satellite community of Monte Alban. A total of five samples from different contexts were analyzed. Calibrated radiocarbon dates for the plant remains range from the 5th-16th centuries AD.

4.3.3. Coastal Tabasco

Located approximately 30 kilometers from the Gulf Coast at an elevation of 12 meters, the Tabascan city of Villahermosa is situated between the traditional Olmec and Maya heartlands and within 100 kilometers of Formative and Classic period sites of La Venta, Comacalco, and Palenque. Coastal resources are abundant in the city's outdoor market, which also includes a wide variety of lowland tropical produce. Cultivated plants were collected from the Villahermosa outdoor market in July 2006. Shellfish, locally bottled bee honey, and cooked turkey meat were also collected. A total of 54 samples were collected from the Villahermosa market.

4.3.4. Herbarium samples

A total of 38 historic plant samples were obtained for isotopic analysis from the Harvard University Herbaria collections. Samples were originally collected between 1850 and 1950 from locations throughout Mexico, Guatemala, Honduras, and Panama. All samples were dessicated before mounting and exhibit good structural preservation.

4.3.5. Human samples

I obtained and analyzed bone samples from 55 individuals excavated from six Zapotec sites and one Mixtec site in the Southern Mexican state of Oaxaca. Samples were prepared according to the methods described in Chapter 4. C/N for all collagen samples fell within the accepted range of 2.8-3.6 (DeNiro 1985).

4.4. Isotopic characterization of modern Middle American flora

Based on their characteristic isotopic signatures, plants may be classified into three basic categories with respect to $\delta^{13}\text{C}$: C4, CAM, and C3 (Bender 1971; Farquhar, Ehleringer, and Hubick 1989; Griffiths 1992); and two categories with respect to $\delta^{15}\text{N}$:

legumes and non-legumes (Virginia and Delwiche 1982). Understanding the dietary proportions of these plant types within a population and across time can be informative about changing subsistence strategies, agricultural practices, and social status. In Middle America, the relative proportion of C4 plants in the diet, for example, is thought to be a general indicator for dietary reliance on maize, the major C4 staple in Middle American diets. Legumes are also an important dietary category, as they are thought to provide the majority of plant proteins in traditional diets, and their isotopic values may be contrasted with those of animal protein sources. In studies of ancient humans, dietary reconstruction models rely on isotopic estimates for each category in order to determine by interpolation the relative proportion of each food type in the total diet (e.g., Schwarcz 1991).

To date, little isotopic work has been conducted on Middle American plants, and as a result most paleodietary studies base their analyses on isotopic estimates derived from modern, non-local empirical studies. However, there is little agreement in either the empirical or archaeological literature about which estimates are most appropriate for use in Middle American paleodietary models (Table 4.1). The range in the assumed $\delta^{15}\text{N}$ of plants and the $\delta^{13}\text{C}$ of maize are particularly problematic and have resulted in inconsistent archaeological interpretations. To overcome this problem, I determined the average, range, and standard deviation of carbon and nitrogen isotopic values for each plant category among modern native cultivated plants of Middle America.

4.4.1. Carbon

Two hundred eighty-five modern samples from more than 60 cultivated plant taxa were analyzed for $\delta^{13}\text{C}$ (Figure 4.3). As expected, C3 and C4 plants in Middle America

demonstrate good isotopic separation, although carbon isotopic averages differ from common estimates employed in paleodietary studies.

Among C3 plants analyzed in this study, the measured average $\delta^{13}\text{C}$ of -27.4‰ is similar to that reported in other empirical studies (O'Leary 1988; Smith and Epstein 1971; van der Merwe 1989), but differs by approximately 1‰ from the -26.5‰ estimate most commonly cited in paleodietary reviews (e.g., Lee-Thorp 2008; Tykot 2006). A reexamination of the literature reveals that in large-scale studies of C3 plants, an average $\delta^{13}\text{C}$ of -26.5‰ has only been observed among tropical C3 grasses (Vogel, Fuls, and Ellis 1978). Of all the cultivated C3 taxa included in this study, only one medicinal plant, *Equisetum sp.*, is a grass. As a result, grasses are likely to be a poor model for the C3 component of ancient Middle American diets. Van der Merwe (1989) has noted that the average $\delta^{13}\text{C}$ of C3 plants increases from -28‰ to between -26‰ and -27‰ when forest species are eliminated, and averages -26.5‰ if all trees and shrubs are excluded; however, traditional Middle American diets include a large number important tree products and other forest taxa, including cacao (*Theobroma cacao*), avocado (*Persea americana*), zapote (*Diospyros digyna*), mamey (*Pouteria sapota*), coyol (*Acrocomia aculeate*), guajes (*Leucaena spp.*), and piñon pine (*Pinus cembroides*). It therefore does not seem that estimates of average Middle American C3 $\delta^{13}\text{C}$ would be improved by a selective exclusion of forest taxa, and instead a more depleted average $\delta^{13}\text{C}$ for C3 plants should be adopted. Nevertheless, overreliance on a particular isotopic value should be cautioned against in paleodietary interpretations since average C3 $\delta^{13}\text{C}$ is a weighted average of plants measured and not a proportional average of the actual plants consumed. The wide range (>12‰) and large standard deviation ($\pm 2.0\%$) in $\delta^{13}\text{C}$ observed among

Table 4.1. Average plant $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ determined in empirical studies compared to estimates employed in Middle American paleodiet reconstructions

Location	$\delta^{13}\text{C}$		$\delta^{15}\text{N}$		References ^a
	C4	C3	Legume	Non-legume	
<i>Empirical estimates^b</i>					
California, Texas	-14.4	-28.0	-	-	18
South Africa ^c	-12.5	-26.5	-	-	23
Global	-14.0	-28.0	-	-	12
California	-	-	0.8 [‡]	3.5 [‡]	3
California	-	-	0.2	1.3	4
Japan	-	-	0.0 [‡]	1.9	24
California	-	-	0.3	1.0	22
Sonoran Desert	-	-	2.0-6.3	3.0-13.0	17
South Africa, Namibia	-	-	-2 to 8	-4 to 19	9
Iowa, Florida, Mexico	-11 [†]	-	-	-	19
S. Maya Lowlands	-11.1 ^{†‡}	-28.4	3.9 [‡]	5.1	30, 32
Pacific Coast	-10.2 ^{†‡}	-26.6	3.6 [‡]	4.2	1
L. Central America	-9.8 ^{†‡}	-27.2	0.9 [‡]	1.9 [‡]	10
<i>Paleodietary studies^d</i>					
Central Mexico	-9.0	-25.0	0.0	6.2	5
S. Maya Lowlands	-9.0	-26.0	-	-	26
S. Maya Lowlands	-9.5	-26.5	-	-	27
S. Maya Lowlands	-11.0	-25.0	0	2-6	25
S. Maya Lowlands	-11.0	-25.0	0	2-6	28
S. Maya Lowlands	-9.0	-26.5	1	2-4	2
S. Maya Lowlands	-9.6	-26.0	-	-	6
S. Maya Lowlands	-10	-26	-	-	31
S. Maya Lowlands	-12.5	-26.5	0-1	3	7
S. Maya Lowlands	-12.5	-26.5	-	-	8
S. Maya Lowlands	-9.5	-27.0	-	-	13
S. Maya Lowlands	-12.5	-27.0	1	9	14
S. Maya Lowlands	-12.5	-27.0	1	9	29
S. Maya Lowlands	-13.1	-27.1	-	-	15
S. Maya Lowlands	-12.5	-27.0	-	-	16
S. Maya Lowlands	-12	-26	-	-	20
S. Maya Lowlands	-9.6	-26.4	-	-	21
L. Central America	-12.0	-26.0	0	4	11

Notes:

[†]Maize only.

[‡]Average of five or fewer samples.

^a1=Chisholm and Blake; 2=Coyston, White, and Schwarcz 1999; 3=Delwiche and Steyn 1970; 4=Delwiche et al. 1979; 5=DeNiro and Epstein 1981; 6=Emery, Wright, and Schwarcz 2000; 7=Gerry 1993; 8=Gerry and Krueger 1997; 9=Heaton 1987; 10=Norr 1991; 11=Norr 1995; 12=O'Leary 1988; 13=Powis et al. 1999; 14=Reed 1994; 15=Reed 1998; 16=Reed 1999; 17=Shearer et al. 1983; 18=Smith and Epstein 1971; 19=Tieszen and Fagre 1993; 20=Tykot 2002; 21=van der Merwe et al. 2000; 22=Virginia and

Table 4.1. continued

Delwiche 1982; 23=Vogel, Fuls, and Ellis 1978; 24=Wada, Kadonaga, and Matsuo 1975; 25=White 2005; 26=White and Schwarcz 1989; 27=White, Healy, and Schwarcz 1993; 28=White et al. 2001; 29=Whittington and Reed 1997; 30=Wright 1994; 31=Wright 1997; 32=Wright 2006.

^bIsotopic averages determined from empirical measurements of plants. Only studies with a sample size of at least 10 total specimens are included.

^cA study of grasses only.

^dPlant isotopic estimates employed in Middle American paleodiet reconstructions

C3 plants makes establishing mean dietary $\delta^{13}\text{C}$ problematic and contributes to the uncertainty in reconstructing ancient diets.

Cultivated C4 plants ($-10.8 \pm 1.0\text{‰}$), represented in this study by the staple crops maize and amaranth, are isotopically heavier than C4 averages reported elsewhere (O'Leary 1988; Smith and Epstein 1971; Vogel, Fuls, and Ellis 1978), and approximately 2.5‰ enriched over the wild C4 grasses analyzed in this study ($p < 0.01$, ANOVA). This finding is in agreement with previous analyses of maize from other regions (DeNiro and Hastorf 1985; Tieszen and Fagre 1993), and confirms that different estimates of C4 $\delta^{13}\text{C}$ may need to be employed in studies of maize agricultural and non-agricultural populations.

Cultivated CAM plants, with a mean $\delta^{13}\text{C}$ of $-13.2 \pm 1.5\text{‰}$, are on average only slightly more depleted than C4 plants. Importantly, the cultivated CAM plants measured in this study, which include pineapples, piñuela fruit, agave, and two species of cactus, do not vary widely in $\delta^{13}\text{C}$, as has been found among some CAM taxa (Griffiths 1992; Winter and Holtum 2002; O'Leary 1988). Projected isotopic distribution plots for CAM taxa frequently allow for a very large, range of $\delta^{13}\text{C}$ values spanning the entire C3-C4 isotopic spectrum. The results of this study suggest that economically important CAM

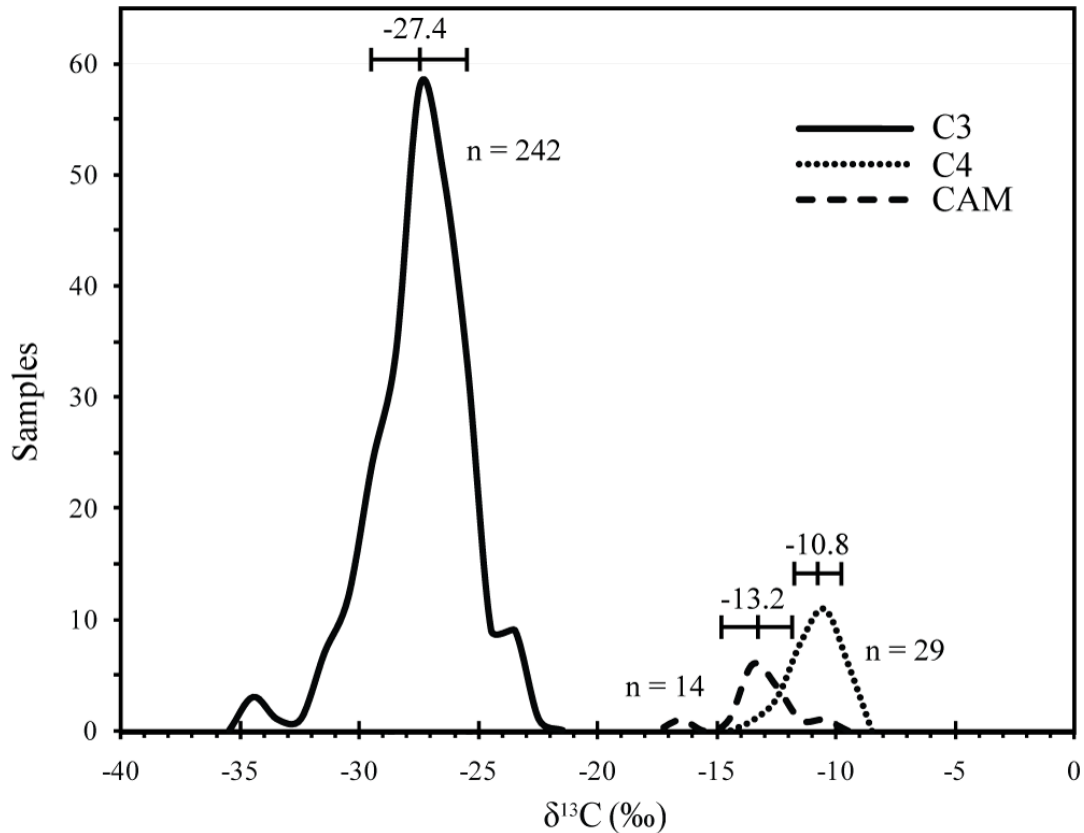


Figure 4.3. Carbon isotopic histogram of modern market plants. Data are binned in 1‰ increments. Error bars represent one standard deviation.

plants in Middle America are disproportionately enriched in $\delta^{13}\text{C}$ and isotopically restricted.

Notably, epazote (*Chenopodium ambrosioides*), an important Mesoamerican domesticated described elsewhere as a C4 plant (Wright and White 1996; Powis et al. 1999; Emery, Wright, and Schwarcz 2000; White et al. 2001), is found in this study to fall within the isotopic range of C3 plants. The misattribution of epazote as a C4 plant may have resulted from the fact that some members of the Chenopodiaceae family display Kranz anatomy (Downton 1975; Smith and Epstein 1971). Although concerns have been raised that dietary chenopods may mimic a maize signal in ancient diets, the epazote specimens collected in this study, as well as specimens of two other

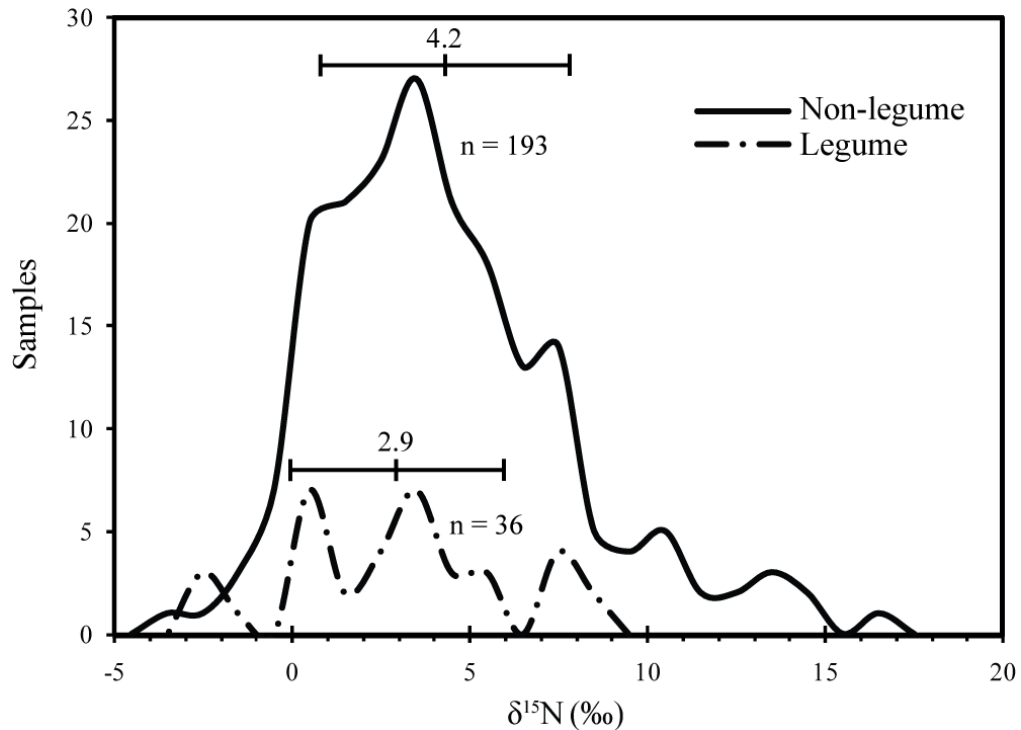


Figure 4.4. Nitrogen isotopic histogram of modern market plants. Data are binned in 1‰ increments. Error bars represent one standard deviation.

economically important Chenopodiaceae species (*C. hybridum* and *C. glaucum*) analyzed by Schwarcz et al. (1985), are all C3 plants.

4.4.2. Nitrogen

With respect to nitrogen, little isotopic discrimination could be found between legumes and non-legumes (Figure 4.4). Although similar results have been found in ecological studies of South Africa and the Sonoran Desert (Heaton 1987; Shearer et al. 1983), much of the archaeological literature assumes that the $\delta^{15}\text{N}$ distribution of the two plant types are distinct and largely non-overlapping, with legumes ranging from 0-1‰ and non-legumes from 2-9‰ (Table 4.1). I obtained $\delta^{15}\text{N}$ values for 36 legumes and 192 non-legumes from Middle American markets and found a wide range of nitrogen isotopic values from -2.7‰ to 16.8‰ with complete isotopic overlap of the two plant types.

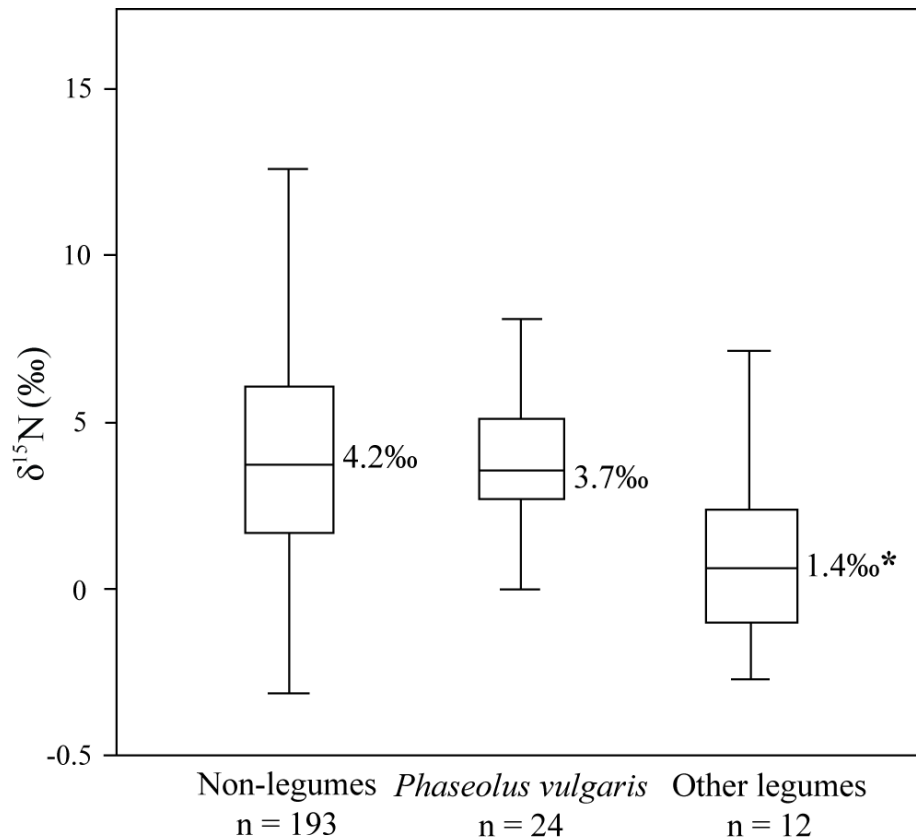


Figure 4.5. Boxplots of legume and non-legume $\delta^{15}\text{N}$. The statistical difference between legumes and non-legumes is primarily driven by the low $\delta^{15}\text{N}$ of leguminous trees. The mean $\delta^{15}\text{N}$ of common beans (*Phaseolus vulgaris*) is not statistically different from that of non-legumes. Statistical difference ($p < 0.05$) from the mean of non-legumes is indicated by a star (*). Error bars represent 95% confidence intervals.

Although the $\delta^{15}\text{N}$ averages of non-legumes ($4.2 \pm 3.5\text{‰}$) and legumes ($2.9 \pm 3.0\text{‰}$) are significantly different ($p \geq 0.05$), this difference is largely driven by the relatively depleted values of leguminous trees, such as mesquite (*Prosopis sp.*) and guaje (*Leucaena spp.*). If non-leguminous plants are compared to the common bean *Phaseolus vulgaris* ($n = 24$), the most commonly consumed legume in Middle America, the isotopic difference between the two groups is no longer significant (Figure 4.5). Thus, in contrast to previous analyses, the $\delta^{15}\text{N}$ of consumer tissues in Middle America is unlikely to be informative about the degree of legume consumption in agricultural populations.

4.4.3. Intra-taxonomic isotopic variation

Although total isotopic variation among plant types is high, previous work by on maize cultivars by Tieszen and Fagre (1993) suggested that intra-taxonomic variation is comparatively low. In a study of 302 maize seeds collected from large farms in Iowa, Florida, and Mexico, Tieszen and Fagre found that bulk $\delta^{13}\text{C}$ fell within a narrow range of less than 2.5‰, from -9.8 to -12.0‰. Nitrogen isotopic data were not reported. I observed similar $\delta^{13}\text{C}$ results for the 18 additional Middle American maize samples analyzed in this study, although the range was slightly larger, from -9.6 to -13.4‰, which may be reflective of a more heterogeneous seed stock or a less controlled growing environment. Nitrogen isotopic variation in my maize samples ($n = 13$) was relatively high, ranging from 0.3-6.2‰, exceeding that commonly modeled for all non-legumes in paleodietary studies.

In order to explore intra-taxonomic isotopic variation within cultivated C3 plants, I measured 55 chile peppers (*Capsicum spp.*) for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. Chile peppers, an important C3 crop, have been cultivated in Middle America since at least 6000 BP (Perry et al. 2007; Smith 1967) and represent an important component of both contemporary and Precolumbian Middle American cuisines. Combined with isotopic data from four previously published Middle American chile peppers, I found a total $\delta^{13}\text{C}$ range of 8.4‰ (from -24.8 to -33.2‰), more than twice that observed for maize. This observation contradicts previous assertions that isotopic discrimination within individual C3 taxa is usually fixed within a narrow, 3-4‰ range (Griffiths 1992; Schwarcz 1991). The range of $\delta^{13}\text{C}$ in chile peppers parallels the more general observation that carbon isotopic variation among C3 plants is larger than that observed among C4 plants (Vogel, Fuls, and Ellis

1978). In nitrogen, chile peppers ($n = 57$) ranged from -3.1 to 9.6‰ , a substantial difference equivalent to more than four trophic levels (Minagawa and Wada 1984; Post 2002). Thus, among chile peppers I find a very high degree of carbon and nitrogen isotopic variation approaching that observed for C3 plants as a whole, suggesting that local environmental factors play a large role in determining the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of individual plants.

4.4.4. Comparison of $\delta^{15}\text{N}$ in cultivated and wild plants

Previous large-scale studies of plant isotopic diversity have focused primarily on natural ecosystems, and archaeologists have relied on these studies to generate parameters for paleodietary interpretation. Recently, however, increased attention has been drawn to the impact of agricultural management practices on the nitrogen isotopic values of crop plants (Bateman, Kelly, and Jickells 2005; Bogaard et al. 2007; Choi et al. 2002; Flores, Fenoll, and Hellín 2007; Nakano, Uehara, and Yamauchi 2003). Crop plants, which may experience altered patterns of water stress or increased nitrogen availability through soil amendments, may differ isotopically from wild plants growing in a similar geographical environment. In Middle America, where evidence for village-based agricultural communities spans more than 4000 years (Pohl et al. 1996; Pope et al. 2001), understanding the role of agriculture in shaping the nitrogen isotopic ratios of crop plants is essential for accurate paleodietary interpretation.

To explore basic isotopic differences between wild and cultivated plants, I compared the $\delta^{15}\text{N}$ of modern wild ($n = 119$) and cultivated ($n = 142$) plants collected in 2006 from the Valley of Oaxaca. I found cultivated plants in Oaxaca to be significantly more enriched in $\delta^{15}\text{N}$ than wild plants ($p < 0.001$, ANOVA) by an average of 2.1‰ , indicating

that agricultural management practices in contemporary Oaxaca result in crop plants measuring nearly one trophic level higher than wild plants. Although today this difference may be partially caused by the amendment of fields with dung from common draft animals, there is a growing body of archaeological evidence for complex Precolumbian agricultural management and soil conservation practices (Atran et al. 1993; Beach et al. 2009; Beach and Dunning 1995; Bloom et al. 1983; Dunning et al. 2002; Jacob 1995; Kunen 2001; Nations and Nigh 1980; Pohl et al. 1996; Pope and Dahlin 1989; Siemens and Puleston 1972; Turner 1974) that may have had similar effects. Raised field agricultural technology, in particular, has been shown to substantially alter local nitrogen cycles, resulting in sustainable, high-yield agriculture (Biesboer, Binford, and Kolata 1999; Erickson 1988).

Determining the mean $\delta^{15}\text{N}$ of ancient crop plants in Middle America is challenging. Plant material often fails to preserve in archaeological deposits, and previous studies have demonstrated that even structurally well-preserved plant tissues undergo isotopic diagenetic alteration in the burial environment (DeNiro and Hastorf 1985). Carbonized plants, however, have been shown to retain endogenous nitrogen isotopic values (Aguilera et al. 2008; Bogaard et al. 2007; DeNiro and Hastorf 1985), and carbonized wheat and barley grains have been used to investigate patterns of cereal cultivation through time in southern Spain (Aguilera et al. 2008). To my knowledge, no $\delta^{15}\text{N}$ values for carbonized crop remains have been reported from Middle America. I obtained a carbonized maize kernel from a hearth deposit at the site of Atzompa in the Valley of Oaxaca (cal. AD 1504 \pm 57 BP) and determined its $\delta^{15}\text{N}$ to be 5.1‰. This isotopic value, which is higher than the mean $\delta^{15}\text{N}$ of Middle American deer, falls within 1 standard

deviation of modern crop plants, but is more than 1 standard deviation higher than the mean $\delta^{15}\text{N}$ of wild plants. The relatively high $\delta^{15}\text{N}$ observed in the archaeological maize kernel is consistent with agricultural crop enrichment, but caution must be exercised in interpreting the results of a single sample, given the large degree of modern $\delta^{15}\text{N}$ variability observed in both cultivated and wild plants. More carbonized plant samples are needed to determine to what degree ancient Middle American crops show evidence for agricultural isotopic enrichment.

4.5. Reconstructing ancient food webs

Ideally, dietary isotopic modeling would involve the direct measurement of plant and animal taxa comprising a food web. Although this is possible in some ecological studies, it is not feasible in studies of the past. Ancient macrobotanical finds are rare, and, if present, may be taphonomically altered (Chalfoun and Tuross 1999; DeNiro and Hastorf 1985), and archaeological faunal remains, although abundantly represented by skeletal material, rarely include animal products that were consumed by humans, such as meat, organs, or fat stores. As a result, ancient food webs must be reconstructed by proxy from modern specimens and ancient skeletal remains. Two isotopic adjustments are generally applied to modern data in order to approximate ancient values: a +1.5‰ carbon offset applied to all samples to account for recent industrial pollution (Suess effect), and a -2‰ carbon offset applied to faunal collagen to approximate meat values. Using historically collected herbarium plants, carbonized archaeological plant remains, and bone collagen/meat sample pairs, I evaluated the utility of both adjustments for paleodietary analysis.

4.5.1. Impact of industrial carbon inputs

In this section, I discuss the Suess effect (Suess 1955), its impact on stable isotope-based paleodietary reconstruction, and the conventional approach for adjusting the $\delta^{13}\text{C}$ of modern data to simulate preindustrial values for use in paleodietary models. I then consider three theoretical reasons for why the current approach of a universal adjustment factor may not be sufficient, and I present data from modern and historically collected Middle American plants to illustrate that different isotopic offsets are observed for different plant types.

In terrestrial ecosystems, the carbon cycle begins with the fixation of atmospheric carbon (CO_2) during plant photosynthesis into carbohydrates (cf. Post et al. 1990). Thus, anthropogenic changes in the isotopic composition of atmospheric carbon or alterations in atmospheric conditions that affect the rate of photosynthesis will have downstream effects on the isotopic values of plant and animal tissues. With the advent of industrial fossil fuel emissions, humans have reintroduced fossilized carbon (e.g., coal, oil) from the geosphere into the atmosphere, thereby increasing the amount of atmospheric CO_2 and altering its isotopic composition to reflect the organic and Paleozoic origin of the fuel. This alteration of global atmospheric carbon pools was first described by Hans Suess (1955) and has subsequently become known as the Suess effect. On a practical level for archaeologists, the Suess effect means that the $\delta^{13}\text{C}$ of contemporary plants are likely to be different from their preindustrial counterparts, and thus must be accounted for in isotopic reconstructions of ancient diets.

Today, most paleodietary reconstructions apply a uniform +1.5‰ adjustment to modern plant data to simulate preindustrial values (e.g., Pechenkina et al. 2005; White et

al. 2001), and was originally based on diachronic observations made by Leavitt and Long (1986) of a decreasing secular trend in the $\delta^{13}\text{C}$ of piñon pine tree rings from 1830-1983, with a net change of 1.5‰ (van der Merwe 1989). Later, Marino and McElroy (1991) measured a decline of approximately 1.5‰ in the $\delta^{13}\text{C}$ of maize grown between 1948 and 1986, which they also correlated with a similar declining trend in the $\delta^{13}\text{C}$ of CO_2 from ice cores (Friedli et al. 1986) and direct atmospheric measurements (Keeling et al. 1989). Finally, direct measurement of ancient maize seeds by Schwarcz et al. (1985) and Tieszen and Fagre (1993) revealed that ancient seeds are 1-3‰ more enriched in $\delta^{13}\text{C}$ than those of modern maize cultivars, confirming that modern plants are more depleted than their archaeological counterparts.

Although a 1.5‰ correction for industrial carbon emissions has now become standard in paleodietary reconstruction modeling, there are a number of theoretical problems with the application of a universal isotopic adjustment of modern data. First, plants growing in closed habitats are buffered from atmospheric CO_2 mixing pools and thus do not always reflect the secular trends in $\delta^{13}\text{C}$ observed in ice core CO_2 or open habitat plant species. For example, in a comparison of open habitat Scots pine and closed habitat Spessart oak over a 500 year period, Freyer and Belacy (1983) found that while Scots pine displayed an expected anthropogenic decline of ~2‰ in $\delta^{13}\text{C}$ after 1840, Spessart oak were characterized by nonsystematic carbon isotopic variation over the same period. In fact, average oak $\delta^{13}\text{C}$ actually increased by 1‰ between 1820 and 1940. Similar results have also been obtained by Anderson, Bernasconi, and McKenzie (1998), Francey (1981), Robertson et al. (1997), Stuiver (1978), Tans and Mook (1980), and Treydte et al. (2001).

Second, because of differences in photosynthetic physiology, C3 plants are more sensitive to changes in CO₂ concentration, temperature, and water availability than C4 plants (Bowes 1991; Monson 2003). As a result, C3 plants exhibit a wider range of $\delta^{13}\text{C}$ under different environmental conditions (Farquhar, Ehleringer, and Hubick 1989; Tieszen 1991) and may require additional corrections for the complex effects of industrial pollution (Treydte et al. 2001; McCarroll and Loader 2004).

Finally, although paleoclimatologists have demonstrated that in most cases recent secular atmospheric declines in $\delta^{13}\text{C}$ can be de-trended from tree ring data (McCarroll and Loader 2004), the stated goal of the 1.5‰ adjustment in isotopic paleodietary studies—the reconstruction of “pre-1800” or “preindustrial” values - is misleading since the $\delta^{13}\text{C}$ of both atmospheric CO₂ and tree ring $\delta^{13}\text{C}$ are known to fluctuate through time as a function of long-term and short-term paleoclimatic cycles (Francey et al. 1999; Kitagawa and Matsumoto 1995). In some cases, preindustrial tree ring $\delta^{13}\text{C}$ from a single tree has been shown to vary by as much as 1.7‰ within a 50 year time period (Kitagawa and Matsumoto 1995). In diachronic studies of human subsistence, variation in human bone collagen must also be distinguished from short-term or localized paleoclimatic variation before being attributed to dietary change.

To explore temporal isotopic trends in C3 and C4 Middle American foodstuffs, I compared the $\delta^{13}\text{C}$ of modern market plants to historic plants collected between 1850 and 1950 and to carbonized archaeological plant remains dating AD 400-1600 (Figure 4.6). Recent experimental work has demonstrated that carbonized plant remains retain authentic carbon isotopic values, and therefore they may be used to understand the isotopic ecology of past ecosystems (Aguilera et al. 2008; Bogaard et al. 2007; DeNiro

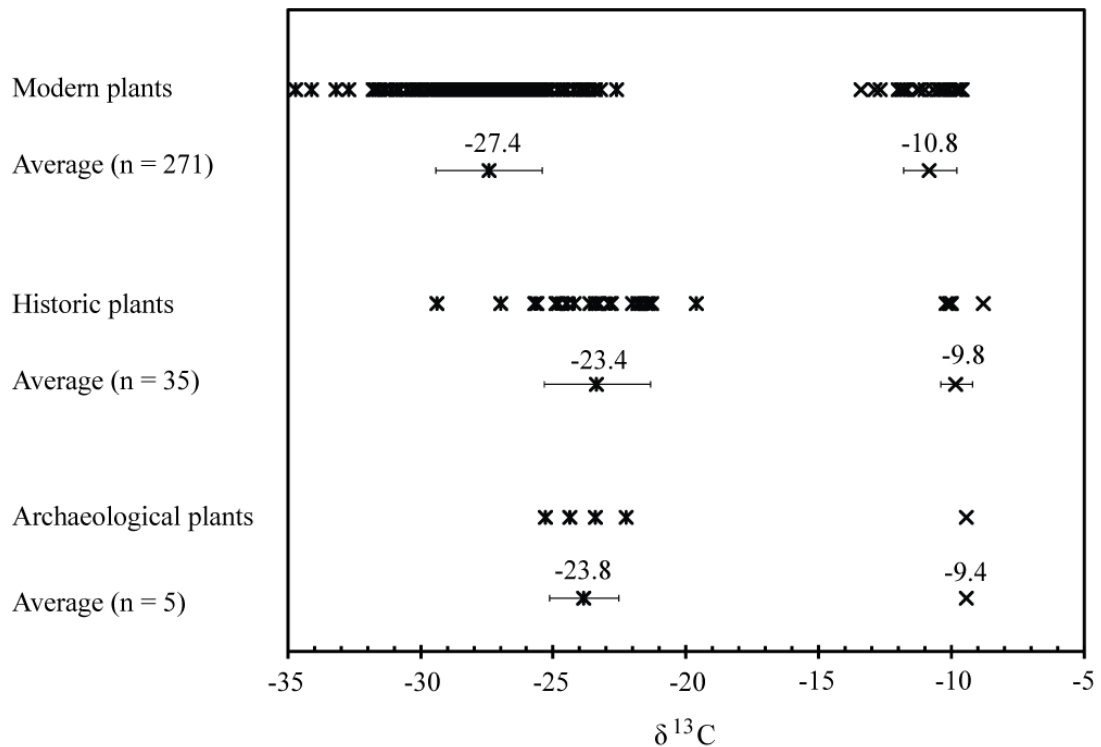


Figure 4.6. Average $\delta^{13}\text{C}$ of modern (AD 1980-2006), historic (AD 1850-1950), and archaeological (AD 400-1600) Middle American C3 (✕) and C4 (✗) plants. Modern and historic samples include only edible taxa. Archaeological samples include only carbonized specimens. Error bars represent one standard deviation.

and Hastorf 1985; Marino and DeNiro 1987). Rather than a simple 1.5‰ offset from modern plants, historic C3 plants were found to be 4‰ more enriched than modern specimens ($p < 0.01$, ANOVA), while historic C4 plants were relatively enriched by approximately 1‰ ($p < 0.01$, ANOVA). The average $\delta^{13}\text{C}$ of carbonized C3 plants, $-23.8 \pm 1.3\text{‰}$ ($n = 4$), compares closely with that of my historic samples, $-23.4 \pm 2.0\text{‰}$, and confirms that modern C3 carbon isotopic values are nearly 4‰ more depleted than those in the past. The $\delta^{13}\text{C}$ of a carbonized 16th century maize kernel, -9.4‰ , also compares well with the average $\delta^{13}\text{C}$ of historic C4 plants, $-9.8 \pm 0.6\text{‰}$, and reinforces the observation that modern C4 plants are less depleted from their ancient counterparts compared to C3 plants. These results illustrate the insufficiency of a simple 1.5‰

adjustment to modern plant data in order to model ancient foods, and point to the need for finer scale testing of temporal trends in the $\delta^{13}\text{C}$ of Middle American food plants.

4.5.2. Estimating isotopic offsets between meat and bone collagen

A number of studies have looked at isotopic offsets between different tissues within a single organism, and within the context of paleodietary modeling, offsets between bone collagen and muscle are most relevant. Based on work by Vogel (1978) and DeNiro and Epstein (1978), $\Delta^{13}\text{C}_{\text{meat-coll}}$ is estimated to be -2‰, while DeNiro and Epstein (1981) and Sealy et al. (1987) have reported no significant difference between collagen and meat $\delta^{15}\text{N}$. These isotopic adjustments have been widely applied in paleodietary models. Additional data for both mammals and fish have become available since the publication of these studies (Appendix 4.8), and I reevaluated these adjustments in light of the new data (Figure 4.7). I found that while mammals broadly conform to the pattern described above, fish show marked differences, including a larger $\Delta^{13}\text{C}_{\text{meat-coll}}$ (-3.5‰) and higher $\Delta^{15}\text{N}_{\text{meat-coll}}$ (+1.5‰) relative to collagen. Isotopic offsets for other taxonomic groups, such as birds and reptiles, have not been studied.

Observed differences in carbon isotopic ratios between meat and collagen are likely driven in part by muscle lipid content. Compared to proteins, lipids are isotopically depleted (DeNiro and Epstein 1977), and Focken and Becker (1998) found a significant correlation between tissue lipid content and total tissue $\delta^{13}\text{C}$ depletion in experimental feeding studies of tilapia. Isotopic differences between mammals and fish may be related to differences in both fat content and storage between the two taxonomic groups, but further research is necessary to delineate specific causes. The reason for differences in

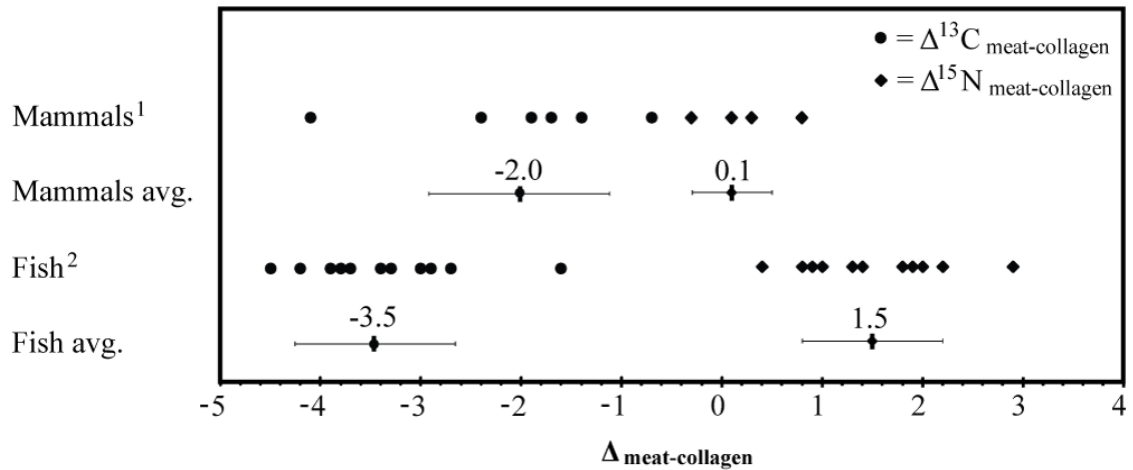


Figure 4.7. Carbon and nitrogen isotopic offsets between paired bone collagen and muscle samples from mammals and fish. Data collected from: DeNiro and Epstein 1978; DeNiro and Epstein 1981; Sealy et al. 1987; Tieszen and Fagre 1993b; Vogel 1978; Warinner and Tuross 2009; Warinner and Tuross 2010; Warinner and Tuross unpublished; Wright 1994. Species information is available in Appendix H. Error bars represent one standard deviation.

$\Delta^{15}\text{N}_{\text{meat-coll}}$ between mammals and fish is less well-understood, and requires further study.

4.6. Reconstructed isotopic distribution of ancient Middle American foods

The distribution of stable carbon and nitrogen isotopes within food webs is conventionally represented by isotopic distribution plots containing idealized, bounded regions corresponding to the isotopic distribution of particular resource types (e.g., Ambrose 1993; Tykot 2004). Isotopic distribution plots are a valuable tool for qualitative dietary analysis because they highlight variation in food web isotopic data, an important issue not currently factored into quantitative paleodietary reconstruction models (e.g., Schwarcz 1991, 2000; Kellner and Schoeninger 2007; Phillips and Koch 2002).

Foodstuff isotopic data collected from modern plants and ancient and modern terrestrial and aquatic fauna in Middle America are presented with human collagen isotopic data in Figure 4.8. Given the uncertainty associated with estimating changes in

plant (and also faunal) $\delta^{13}\text{C}$ through time, carbon isotopic values were not adjusted. Faunal collagen isotopic data were adjusted to estimated meat values using the empirically derived offsets determined in this study. In general, there is considerably more isotopic variation within and overlap between discrete resource types than estimated by previous isotopic distribution plots for Middle America (e.g., Norr 1995; Powis et al. 1999; Tykot 2006; White et al. 2001; Wright 2006) and the Americas as a whole (Tykot 2004). The isotopic distribution of Middle American foodstuffs is also distinct from generalized models of isotopic diversity (e.g., Ambrose 1993).

4.6.1. Regional differences

I examined the issue of regional isotopic differences by comparing the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of plant types within different regions of Middle America. Regional differences in fauna were not analyzed because of species and geographical bias in the data set. Among C3 plants, no significant differences were observed in $\delta^{13}\text{C}$ between highland and lowland contexts or between individual regions. Because of sample size constraints, the $\delta^{13}\text{C}$ of maize could only be compared between highland and lowland locations. On average, lowland maize was found to be more slightly enriched than highland maize by approximately 1‰ ($p < 0.05$, ANOVA). With respect to nitrogen, no difference in $\delta^{15}\text{N}$ is observed between highland and lowland legumes, although lowland non-legumes are on average more enriched than highland non-legumes by approximately 1‰ ($p < 0.05$, ANOVA). This difference seems to be largely driven by the relatively high $\delta^{15}\text{N}$ values of Gulf Coast non-legumes, which average $6.0 \pm 3.0\text{‰}$ ($n = 35$). At present, there is marginal support for regional isotopic differences within Middle America, but more data are necessary to delineate further trends.

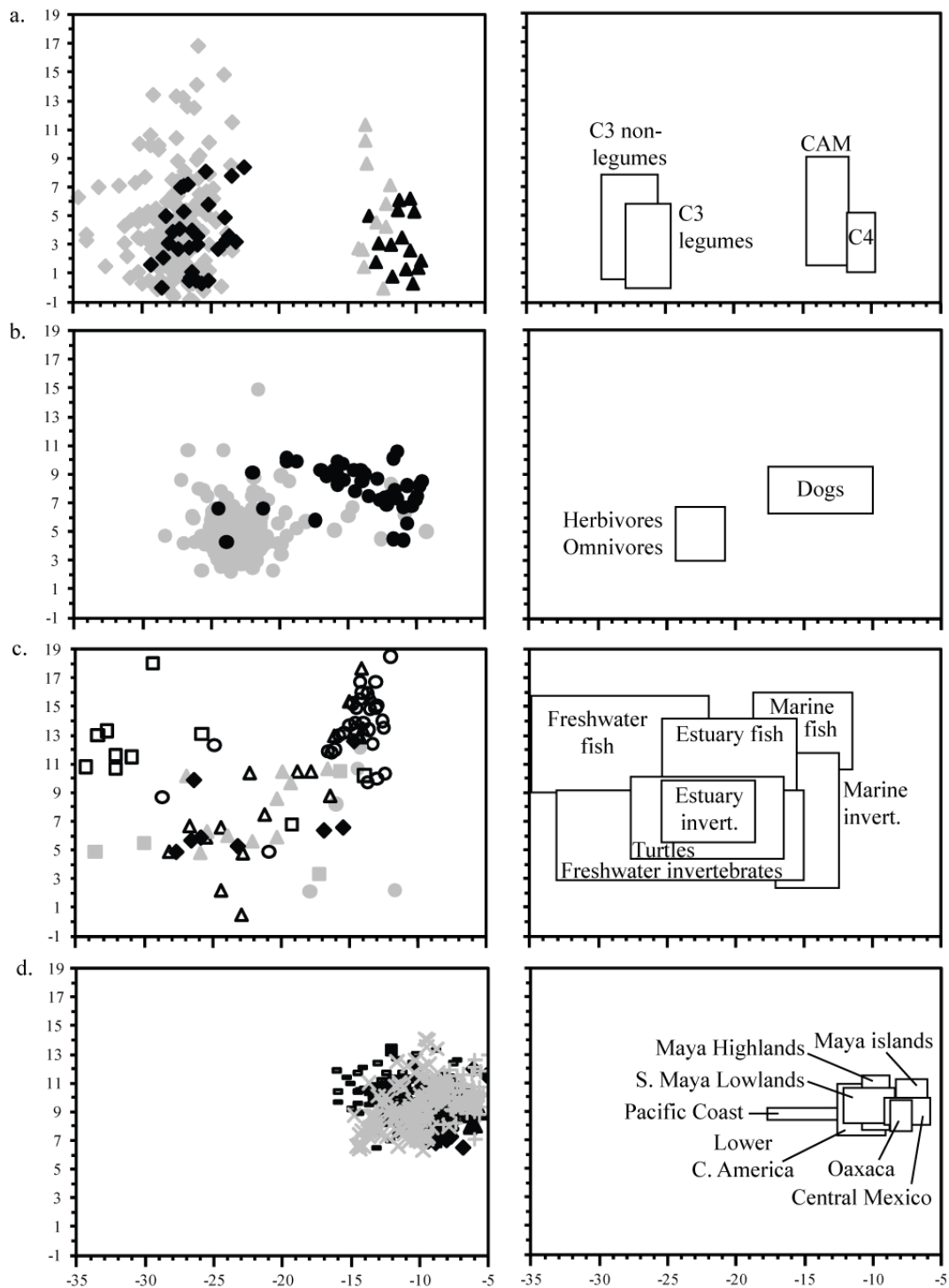


Figure 4.8a-d. Carbon and nitrogen isotopic distributions of Middle American foodstuffs and human populations: a) plants, b) terrestrial fauna, c) aquatic fauna, and d) humans. Individual data points are shown on the left; bounded group regions signifying mean $\pm 1\sigma$ are shown on the right. Faunal collagen values have been corrected to estimated meat values.

4.7. Dietary interpretation of Middle American human populations

Within Middle America, human isotopic data have been primarily employed to investigate three main paleodietary questions: 1) the origin and spread of maize agriculture, 2) the relative proportion of dietary maize consumed by farming populations, and 3) the proportion of plant and animal proteins in human diets (i.e., trophic level). Each of these questions relies on fundamental assumptions about the structure of human food webs that require testing. I examine each of these questions in light of the Middle American food web data described in this study.

4.7.1. Origins and spread of maize agriculture

In recent years, a growing body of microbotanical evidence (phytoliths, pollen, and starch) for Archaic period maize cultivation and processing has pushed back the proposed origins of maize domestication to before 6500 BC (Ranere et al. 2009; Piperno et al. 2009). Archaeological evidence for sedentism and intensive maize agriculture, however, lags several millennia behind and only becomes widespread in the Middle Formative period. To explain this pattern, Hugh Iltis (2000) and others (Smalley and Blake 2003; Webster, Rue, and Traverse 2005) have suggested that maize was originally domesticated by seasonally mobile horticulturalists for the sugary juice of its stalk, and only later under different selective pressures developed the large cob and numerous grains which make it the agricultural dietary staple we are familiar with today. Characterizing the timing and tempo of this transition, from an early minor crop to the dietary staple of subsequent complex societies, has proven both challenging and controversial. Stable isotope analysis, as a measure of past “meals” rather than past “menus,” has great potential for clarifying this transition.

Table 4.2. Stable carbon and nitrogen isotopic ratios for Middle American humans predating 1000 BC

Region	N ^a	Phase dates (BC)	Avg. $\delta^{13}\text{C}$	Avg. $\delta^{15}\text{N}$	Habitat	Ref. ^b
<i>Central Mexico</i>						
Tehuacan caves	1	6800-5000	-13.3	10.4	Inland, thorn-scrub-cactus forest	3, 4
Tehuacan caves	1	5000-3500	-6.1	10.0	Inland, thorn-scrub-cactus forest	3, 4
<i>Pacific Coast</i>						
Tlacuachero	2	2700-1800	-9.8	8.7	Estuary, shell midden	1, 2
Chilo	1	1350-1250	-19.3	13.0	Inland, near estuary	1, 2
Paso de la Amada	2	1250-1150	-18.0	13.9	Inland, near estuary	1, 2
Aquiles Serdan	1	1150-1000	-17.8	13.1	Inland, near estuary	1, 2
<i>Lower Central America</i>						
Cerro Mangote	15	5000-2500	-13.7±0.6	7.4±0.4	Coastal, shell midden	5, 6

Notes:

^aOnly samples with reported C/N between 2.8 and 3.6 were included.

^b1=Blake et al. 1992; 2=Chisholm and Blake 2006; 3=DeNiro and Epstein 1981; 4=DeNiro and Epstein 1986; 5=Norr 1991; 6=Norr 1995; 7=Smalley and Blake 2003

In a discussion of the isotopic evidence for the origins and spread of maize agriculture in Middle and South America, Smalley and Blake (2003) argued that isotopic evidence for maize as a dietary staple is not generally observed in human bone collagen until after 1000 BC, which roughly coincides with the rise of sedentary agricultural communities. Very few skeletons predating 1000 BC have been isotopically analyzed, however, and of those that have, several in the Tehuacan Valley, Soconusco, and Panama have yielded enriched collagen $\delta^{13}\text{C}$ values, which Smalley and Blake identify as consistent with moderate to high levels of maize reliance. I reevaluated the isotopic evidence for early maize reliance in each of these areas (Table 4.2) in light of a broader understanding of Middle American food webs and isotopic ecology.

Tehuacan Valley

The dry rockshelters of the Tehuacan Valley in Puebla, Mexico contain archaeological deposits spanning more than 10,000 years and have been recognized as an important locus for studying the transition from foraging to early agriculture in highland Middle America (Byers 1967; DeNiro and Epstein 1981, 1986; Smith 2005). Human remains recovered from the Tehuacan Valley include one skeleton that predates the earliest directly dated maize cobs in the deposits (c. 6800-5000 BC), a second skeleton contemporaneous with the earliest cobs (skeleton: c. 5000-3500 BC; earliest cob: 3540 BC), and several skeletons that postdate the appearance of maize in the deposits (c. 900 BC-AD 1540).

The use of stable isotope analysis to identify dietary reliance on maize in the highlands assumes that archaic period foragers and horticulturalists consumed a predominantly C3 diet and did not utilize CAM and other C4 resources in sufficient quantity to obscure an isotopic signature announcing the introduction of maize as a dietary staple. Macrobotanical evidence (Smith 1967; Smith 1986), however, indicates that highland Archaic foragers and horticulturalists utilized many CAM and C4 taxa (including *Setaria* grass, amaranth, prickly pear, and agave, among others), and wild CAM and C4 plants would also have been available to local fauna, and therefore indirectly to humans. Unfortunately, no highland Middle American vertebrate fauna, either archaeological or modern, have been isotopically analyzed at present, so it is difficult to estimate what the isotopic values of local wild animal resources may have been for highland populations. For taxa such as the cottontail rabbit (*Sylvilagus* spp.), which consistently makes up a large proportion of the faunal assemblages during the

Paleoindian, Archaic, and Early Formative periods in the Tehuacan Valley, grasses would have made up a majority of the diet. Grasses would have also been an important food resource for jackrabbits (*Lepus* spp.) and extinct species of horse (*Equus* sp.) and antelope (*Antilocapra* sp.), the remains of which characterize Paleoindian deposits in the Tehuacan Valley. I measured 34 wild grass specimens in my Guila Naquitz plant transect, and found that over 90% exhibit carbon isotope values consistent with C4 photosynthesis. If past highland grass assemblages resemble those today, a significant proportion of dietary meat resources may have been characterized by enriched $\delta^{13}\text{C}$ values.

Of the two Tehuacan skeletons that predate 1000 BC, both exhibit elevated bone collagen $\delta^{13}\text{C}$. However, while the $\delta^{13}\text{C}$ of the more recent skeleton (-6‰) closely resembles that of later agricultural periods (-6 to -7‰) and thus likely indicates maize consumption, the earlier skeleton exhibits a more equivocal value (-13.4‰). It is difficult to know how to interpret this value since it could represent either a moderate degree of maize consumption or a diet rich in wild C4 and CAM plants. Because no highland skeletons clearly predating the period of maize domestication have been found, it is not possible to establish the baseline $\delta^{13}\text{C}$ of a non-maize consuming highland forager for comparison. Thus, at present macrobotanical and isotopic evidence support a subsistence change to dietary reliance on maize by 3500 BC, but earlier adoption of maize in the Tehuacan Valley cannot be substantiated without further evidence.

Panama and Soconusco

In Panama, enriched human collagen $\delta^{13}\text{C}$ (-14‰) has been observed at the site of Cerro Mangote during the period 5000-2500 BC, and in Soconusco very enriched (-

9.8‰) and moderately enriched (-18‰) human collagen $\delta^{13}\text{C}$ has been found at several sites spanning the period 2700-1000 BC (Blake et al. 1992; Chisholm and Blake 2006; Norr 1991, 1995). Although Smalley and Blake (2003) argue that these values are evidence for dietary maize reliance, this interpretation is complicated by the fact that all of these individuals were recovered from either coastal or estuarine sites with evidence for aquatic resource consumption (Blake et al. 1992; Chisholm and Blake 2006; Norr 1991; Norr 1995; Voorhies 1976). Because mean $\delta^{13}\text{C}$ of Middle American marine and estuarine fish and shellfish is more enriched than that of terrestrial C3 plants, elevated collagen $\delta^{13}\text{C}$ cannot be assumed *a priori* to result from increased C4 plant consumption. Nitrogen isotopic ratios, which have been used to distinguish exploitation of terrestrial and marine resources in North American and European populations (e.g., Salamon et al. 2008; Schoeninger et al. 1983), are of less use in Middle America, where there is a high degree of scatter in the $\delta^{15}\text{N}$ of fish and shellfish, and coastal and non-coastal populations show little isotopic differentiation (see below).

While some degree of maize consumption at these sites is probable, given archaeobotanical evidence for minor maize processing at contemporaneous sites in Panama (Piperno et al. 2000), Tabasco (Pohl et al. 2007), and northern South America (Zarrillo et al. 2008), determination of maize consumption or status as a dietary staple cannot be made on the basis of current stable isotope evidence. Instead, heavy dietary reliance on aquatic resources with a possibility some maize consumption is a more parsimonious interpretation of the enriched collagen $\delta^{13}\text{C}$ values observed in Archaic and Early Formative coastal communities in Panama and Soconusco. In order to overcome problems of isotopic equifinality and to determine when maize became a dietary staple in

these areas, human remains from inland communities with little or no zooarchaeological evidence for coastal aquatic resource exploitation should be analyzed.

In total, only 23 individuals predating 1000 BC have been analyzed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in Middle America. Of these, 19 have yielded elevated collagen $\delta^{13}\text{C}$ values, but the vast majority were recovered from coastal or estuarine sites where aquatic resource exploitation complicates isotopic interpretation of maize consumption. Isotopic analysis holds great promise for tracking the origin and spread of maize agriculture in terrestrial populations, but the current Middle American isotopic data set for Archaic and Early Formative humans is small and problematic. Until more early human samples become available, stable isotope analysis will be largely limited to confirming the existence of maize consumption in later periods when widespread archaeological and macro- and microbotanical evidence provide strong independent evidence for maize cultivation.

4.7.2. Estimation of maize consumption in agricultural populations

For periods after 1000 BC, when intensive maize agriculture is firmly established throughout most of Middle America, carbon stable isotope analysis is predominantly used to estimate the relative proportion of maize in mixed diets. These estimations are based on an explicit or implicit model of interpolation between theoretical isotopic endpoints (e.g., van der Merwe 1982; White and Schwarcz 1989; Schwarcz 1991; Schwarcz 2000; Phillips and Koch 2002; Kellner and Schoeninger 2007). Whether quantitative or qualitative, estimating the degree of dietary reliance on maize from carbon isotopic values relies on problematic assumptions about the isotopic composition of food webs.

First, isotopic dietary models cannot distinguish maize from other C₄ taxa or CAM plants. Thus, any purported estimate of maize consumption also implicitly includes other

dietary C4 and CAM plants that may have been consumed. Most Middle American paleodietary studies assume that CAM consumption was minor and that consumption of C4 plants other than maize was negligible. Although this may be a reasonable assumption for tropical lowland populations, non-maize C4 and CAM plants make up an important part of traditional Mesoamerican highland diets. Exploitation of *Opuntia* cacti and agave, two important economic CAM crops today, can be traced back to the Archaic period in Central Mexico (Flannery 1968), and amaranth, a high-protein C4 grain and vegetable (Tucker 1986), was a major tribute crop collected by the Aztec Triple Alliance (Berdan and Anawalt 1992). As a result, isotope-based estimates of “maize” consumption among highland populations are likely to be overestimated.

Second, within Middle America, carbon isotopic differences among individuals and between populations are almost always interpreted as evidence for differences in maize consumption. In the highlands, however, changes in consumption patterns of non-maize C4 and CAM also may also be an important driver of change in the $\delta^{13}\text{C}$ of mineralized tissues. Evidence for this can be seen in the Middle American human data set, where among non-coastal, maize-agricultural populations with a sample size greater than five, the sites with the highest average collagen $\delta^{13}\text{C}$ are all located in the highlands:

Tehuacan, Monte Alban, Teposcolula, and Teotihuacan.

Among all populations, small changes in tissue $\delta^{13}\text{C}$ may also be driven in part by differential consumption of C3 plants. The range of isotopic variation among Middle American C3 plants is high and spans more than 12‰ with a standard deviation of $\pm 2\%$. As a result, estimating the weighted average $\delta^{13}\text{C}$ of dietary C3 plants for use in paleodietary models is somewhat arbitrary, and the actual average likely varies among

and within populations as a result of local differences in climate and dietary preferences. The impact of this variation can be observed among preagricultural North American and European forest-dwelling C3 browsers, whose tissue isotopic ratios typically vary by approximately 2‰ despite no evidence for C4 consumption (DeSantis and Wallace 2008; Garcia et al. 2009). To what extent carbon isotopic variation in C3 plants affects paleodietary interpretation of humans is uncertain, but caution should be exercised against interpreting small differences in tissue $\delta^{13}\text{C}$ as unequivocal evidence for differences in maize consumption.

4.7.3. Trophic level estimation

Determination of dietary trophic level is important in both biological and archaeological studies, and among ancient human populations it is often used as an indicator of dietary reliance on animal proteins. Relative trophic level is conventionally calculated (explicitly or implicitly) using the following equation (modified from Post 2002):

$$\lambda_{\text{consumer}} = 1 + \frac{\delta^{15}\text{N}_{\text{consumer}} - \delta^{15}\text{N}_{\text{base}}}{\Delta^{15}\text{N}}$$

where $\lambda_{\text{consumer}}$ is the trophic level of the consumer, $\delta^{15}\text{N}_{\text{consumer}}$ is the measured $\delta^{15}\text{N}$ of the consumer, $\delta^{15}\text{N}_{\text{base}}$ is the measured $\delta^{15}\text{N}$ of the base of the food web, and $\Delta^{15}\text{N}$ is the enrichment in $\delta^{15}\text{N}$ per trophic level (usually assumed to be 3.4‰; Minagawa and Wada 1984; Post 2002). This formula contains two major assumptions that must be met in order to accurately reconstruct trophic level: 1) the $\delta^{15}\text{N}$ at the base of the food web (i.e., plants) must be known and constant; and 2) there must be a stepwise pattern of isotopic enrichment up the food chain (i.e., plants to herbivores to omnivores to carnivores).

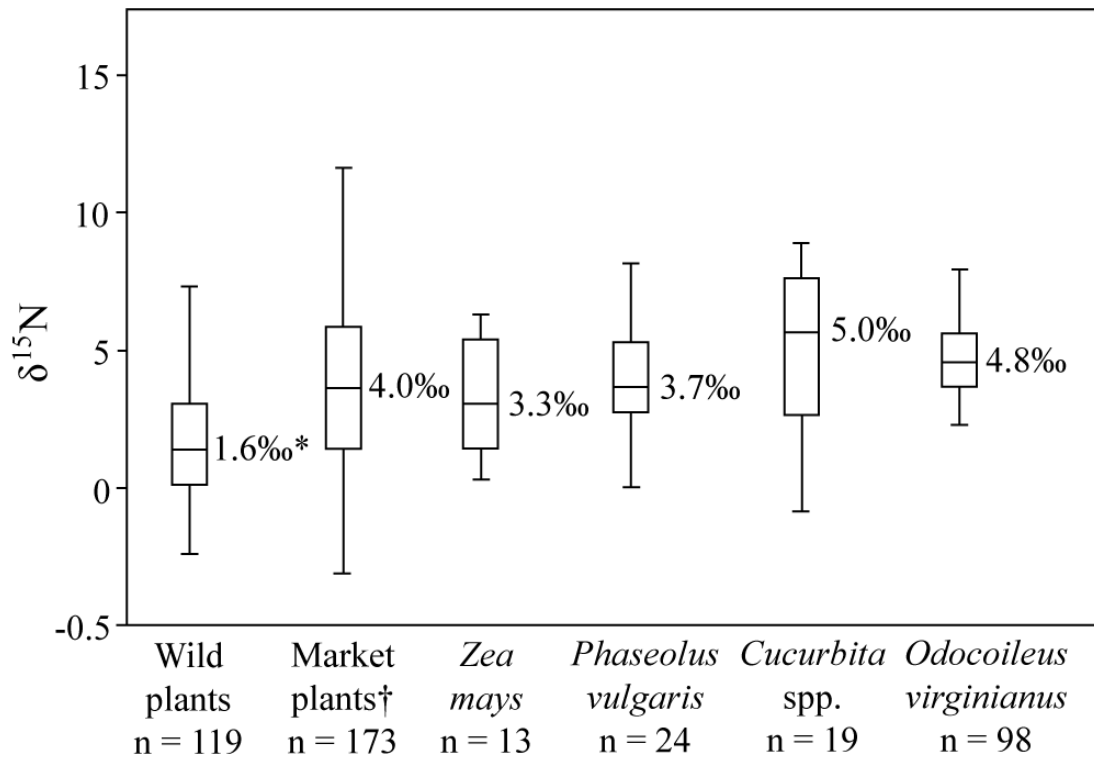


Figure 4.9. Boxplots of flora and deer $\delta^{15}\text{N}$. No statistical difference in $\delta^{15}\text{N}$ is detected between deer and any category of flora except wild plants. The total range of $\delta^{15}\text{N}$ in plants exceeds that of deer, and squashes are on average more enriched than deer. Statistical difference ($p < 0.05$) from the mean of deer is indicated by a star (*). Error bars represent 95% confidence intervals. †Market plants excluding maize, common beans, and squash.

Using my Middle American data, I found that the standard deviation for $\delta^{15}\text{N}_{\text{base}}$ is high ($> 3\text{‰}$), and that there is no stepwise pattern of nitrogen isotopic enrichment in human food webs. For example, although deer are significantly more enriched in $\delta^{15}\text{N}$ than wild plants ($p < 0.01$, ANOVA), deer are not statistically different from cultivated plants (Figure 4.9), a complication that, if generally applicable, would alter trophic level interpretations in agricultural populations. Overall, rather than a stepwise pattern of enrichment, plants, herbivores, and omnivores form a single isotopic cluster, while humans, dogs, and carnivores form another (Figure 4.10). Interestingly, even though Middle American humans are known to have consumed diverse, omnivorous diets,

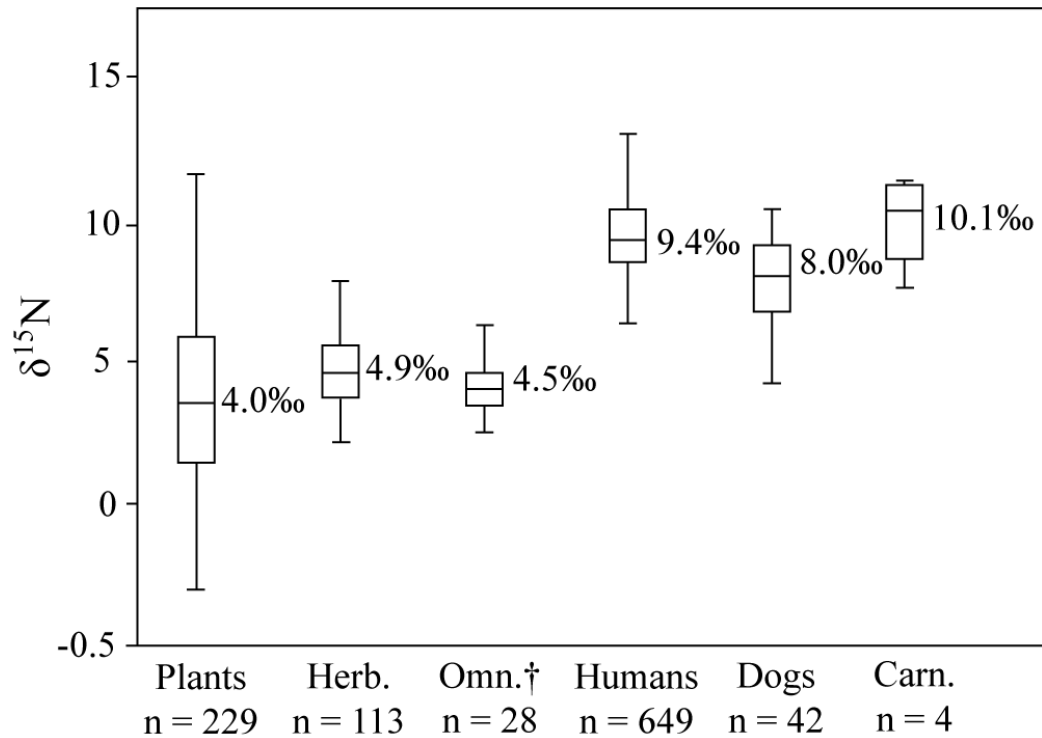


Figure 4.10. Boxplots of trophic group $\delta^{15}\text{N}$. Rather than a step-wise pattern of enrichment at each trophic level, two distinct isotopic groups are discerned: 1) plants, herbivores, and omnivores; and 2) humans, dogs, and carnivores. Error bars represent 95% confidence intervals. Fauna include only mammals. †Omnivores excluding humans and dogs.

variance in human $\delta^{15}\text{N}$ across all regions is not significantly different from that of white-tailed deer ($p > 0.1$, f -test).

Among humans, I find only minor nitrogen isotope differentiation between regional populations, the greatest difference, only 1.5‰, being found between island Maya fisher-agriculturalists off the coast of Belize and Oaxacan maize farmers (Figure 4.11).

Although mean collagen $\delta^{15}\text{N}$ of Oaxacan maize farmers is significantly lower than that of island Maya fisher agriculturalists ($p < 0.01$, ANOVA), no isotopic differentiation could be discerned between Oaxacan maize farmers and other fishing populations, including estuarine populations along the Pacific Coast and coastal populations in lower Central America. Thus, despite strong zooarchaeological evidence for regional dietary

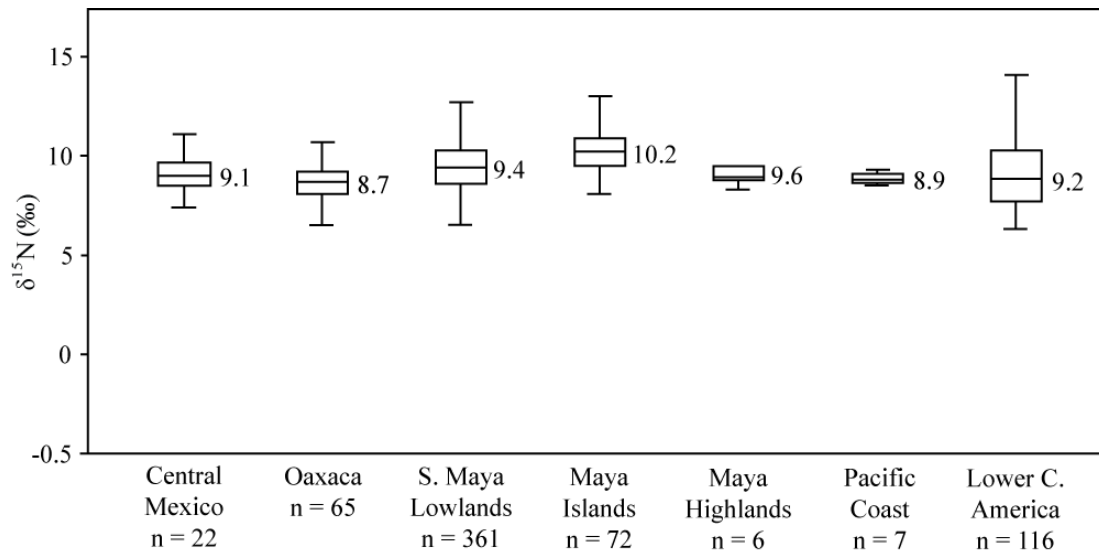


Figure 4.11. Boxplots of human bone collagen $\delta^{15}\text{N}$ among Middle American sub-regions. Error bars represent 95% confidence intervals.

differences (e.g., Chisholm and Blake 2006; Cooke, Norr, and Piperno 1996; Emery 2004; Graham and Pendergast 1989; Middleton et al. 2002), nitrogen isotopic evidence for dietary diversity is highly compressed and terrestrial and coastal populations are generally poorly differentiated. Similar results have also been obtained for nearby Bahamian fisher-agriculturalists (Keegan and DeNiro 1988). These results contrast sharply with studies of North American and European fisher-gatherers, who show strong nitrogen isotope differentiation from terrestrial hunter-gatherers and agriculturalists (Schoeninger et al. 1983), and suggest that collagen $\delta^{15}\text{N}$ may not be a good indicator of marine vs. terrestrial resource consumption in all regions.

4.7.4. Humans as carnivores?

In an attempt to refine trophic level assessment, a number of studies have compared the nitrogen isotopic ratios of humans with those of herbivores and carnivores from the same or nearby sites. In Paleolithic Europe, Neanderthals have been found to consistently cluster with hyenas, wolves, and foxes, which has led to the conclusion that Neanderthals

were top level carnivores (Bocherens et al. 1991, 2001, 2005; Fizet et al. 1995; Richards et al. 2000, 2008; Richards and Trinkhaus 2009; Richards and Schmitz 2008). However, the clustering of humans with carnivores is relatively common, even in populations where additional lines of evidence indicate that plants made up a significant portion of the diet. In Britain, for example, Privat and O'Connell (2002) found that the $\delta^{15}\text{N}$ of Anglo Saxon agriculturalists cluster with that of local foxes, and in Middle America I find $\delta^{15}\text{N}$ overlap between Classic period Maya maize farmers and large wild cats, such as pumas or jaguars (*Felis* spp.; Wright 2006). Why humans tend to cluster with local carnivores is not understood, but similar dietary habits is not the only possible explanation (e.g., see Ambrose 1991).

4.7.5. Role of agriculture

In recent years, conventional isotopic interpretation of bulk tissue $\delta^{15}\text{N}$ as a straightforward indicator of dietary reliance on animal proteins has increasingly come under criticism (Hedges and Reynard 2007). In Europe, widespread evidence for improbably high levels of meat consumption among farming communities (Dürrewächter et al. 2006; Hedges, Saville, and O'Connell 2008; Jay and Richards 2006; Lightfoot et al. 2009) has led archaeologists to seek alternative explanations for the often very enriched collagen $\delta^{15}\text{N}$ observed in prehistoric populations. Dürrewächter et al. (2006) have suggested that isotopically enriched crops or fodder may be responsible for some of the high collagen $\delta^{15}\text{N}$ values observed in Neolithic linear pottery culture (LBK) populations, and subsequent experiments by Bogaard et al. (2007) demonstrated that long-term manuring and crop management can result in trophic-level increases in the $\delta^{15}\text{N}$ of cereals compared to control plots. Systematic differences in the mean $\delta^{15}\text{N}$ of cultivated

and wild plants have important consequences for paleodietary interpretation. In my own data set, I observed elevated $\delta^{15}\text{N}$ in crop plants, including legumes, at a level equivalent to that observed in modern and archaeological Middle American fauna. If ancient crop $\delta^{15}\text{N}$ resembles that of modern crops, nitrogen isotopic analysis of human bone collagen will not be informative about the relative dietary contribution of plant and herbivore proteins. Failure to account for isotopically enriched crops when applying the “standard model” of nitrogen isotopic analysis (Hedges and Reynard 2007) will result in an overestimation of dietary animal protein and poor isotopic differentiation of populations consuming variable amounts of animal protein.

4.8. Conclusions

Stable isotope-based paleodietary interpretation is a powerful tool for reconstructing human subsistence patterns of the distant and recent past. However, stable isotope analysis relies on a number of fundamental assumptions about human food webs that must be verified at a local or regional level before accurate interpretations can be made.

In my study of more than 800 Middle American plants and animals, I demonstrate the power of a large dataset for testing hypotheses about the isotopic structure of human food webs. In contrast to previous studies, I found nitrogen isotopic values to be poor indicators of both nitrogen fixation ability and trophic level. The $\delta^{15}\text{N}$ of Middle American crop plants overlap completely with those of wild herbivores, but was found to be significantly different from that of wild plants. As a result, nitrogen isotopic values of Middle American populations may be more indicative of agricultural management practices than of meat consumption. Nitrogen isotopic values also appear to be poor indicators of marine resource exploitation. Although few fish isotopic data are available

for the region, Caribbean fish (Keegan and DeNiro 1988) do not appear to exhibit the extreme $\delta^{15}\text{N}$ enrichment characteristic of other marine fish (Richards and Hedges 1999), and Middle American fisher-agriculturalists generally show poor differentiation from inland agricultural populations on the basis of collagen $\delta^{15}\text{N}$.

With respect to carbon isotopic values, I found that the widespread assumption that collagen $\delta^{13}\text{C}$ is a direct proxy for maize consumption is complicated by isotopic variation at the base of the food web. Uncertainties about the average $\delta^{13}\text{C}$ of dietary C3 plants, the presence of non-maize C4 and CAM plants in the diet, variation in the $\delta^{13}\text{C}$ of atmospheric CO_2 through time, and difficulties modeling past meat isotopic ratios each contribute to the error associated with accurately interpreting dietary information from human tissue isotopic values. Although maize consumption is likely the primary driver of $\delta^{13}\text{C}$ variation in Middle American agricultural populations, these additional factors likely contribute to low-level variation. As a result, care should be taken to avoid overinterpretation of small isotopic differences.

In general, I find that Middle America is characterized by a much more diverse and complicated isotopic landscape than has been previously assumed. The large dataset employed in this study has yielded significant insights into the structure of Middle American human food webs and provided a new framework for paleodietary isotopic interpretation. As the cost of stable isotope analysis continues to decline, future research in other regions will likely reveal similar isotopic patterns and open up new lines of inquiry in the study of past human diet.

4.9. Bibliography

- Aguilera, M., J. Araus, J. Voltas, M. Rodriguez-Ariza, F. Molina, N. Rovira, R. Buxo, and J. Ferrio. 2008. Stable carbon and nitrogen isotopes and quality traits of fossil cereal grains provide clues on sustainability at the beginnings of Mediterranean agriculture. *Rapid Communications in Mass Spectrometry* 22(11):1653-1663.
- Ambrose, Stanley. 1991. Effects of Diet, Climate and physiology on nitrogen isotope abundances in terrestrial foodwebs. *Journal of Archaeological Science* 18(3):293-317.
- Ambrose, Stanley, and Michael DeNiro. 1986. Reconstruction of African human diet using bone-collagen carbon and nitrogen isotope ratios. *Nature* 319(6051):321-324.
- Ambrose, Stanley, and Lynette Norr. 1992. On stable isotopic data and prehistoric subsistence in the Soconusco region. *Current Anthropology* 33(4):401-404.
- Anderson, W., S. Bernasconi, J. McKenzie, and M. Saurer. 1998. Oxygen and carbon isotopic record of climatic variability in tree ring cellulose (*Picea abies*): An example from central Switzerland (1913-1995). *Journal of Geophysical Research-Atmospheres* 103(D24):31625-31636.
- Atran, S. 1993. Itza Maya Tropical Agroforestry. *Current Anthropology* 34(5):633-700.
- Barton, L., Seth Newsome, F. Chen, H. Wang, T. Guilderson, and R. Bettinger. 2009. Agricultural origins and the isotopic identity of domestication in northern China. *Proceedings of the National Academy of Sciences of the United States of America* 106(14):5523-5528.
- Bateman, A., S. Kelly, and T. Jickells. 2005. Nitrogen isotope relationships between crops and fertilizer: Implications for using nitrogen isotope analysis as an indicator of agricultural regime. *Journal of Agricultural and Food Chemistry* 53(14):5760-5765.
- Beach, Timothy, and Nicholas Dunning. 1995. Ancient Maya Terracing and Modern Conservation. *Journal of Soil and Water Conservation* 50(5):575-575.
- Beach, Timothy, Sheryl Luzzadder-Beach, Nicholas Dunning, J. Jones, J. Lohse, T. Guderjan, S. Bozarth, S. Millspaugh, and T. Bhattacharya. 2009. A review of human and natural changes in Maya Lowland wetlands over the Holocene. *Quaternary Science Reviews* 28(17-18):1710-1724.
- Bender, M. 1971. Variations in $^{13}\text{C}/^{12}\text{C}$ ratios of plants in relation to pathway of photosynthetic carbon dioxide fixation. *Phytochemistry* 10(6):1239-1244.
- Berdan, Frances, and Patricia Rieff Anawalt. 1992. *The Codex Mendoza*. Berkeley: University of California Press.
- Biesboer, D., M. Binford, and A. Kolata. 1999. Nitrogen fixation in soils and canals of rehabilitated raised-fields of the Bolivian altiplano. *Biotropica* 31(2):255-267.

- Blake, Michael, Brian Chisholm, J. Clark, Barbara Voorhies, and M. Love. 1992. Prehistoric subsistence in the Soconusco region. *Current Anthropology* 33(1):83-94.
- Blitz, Jennifer. 1995. Dietary variability and social inequality at Monte Alban, Oaxaca, Mexico. PhD dissertation, University of Wisconsin, Madison.
- Bloom, P. R., Mary Pohl, C. Buttleman, F. Wiseman, A. Covich, C. Miksicek, J. Ball, and J. Stein. 1983. Prehistoric Maya wetland agriculture and the alluvial soils near San-Antonio Rio-Hondo, Belize. *Nature* 301(5899):417-419.
- Bocherens, H., D. Billiou, A. Mariotti, M. Toussaint, M. Patou-Mathis, D. Bonjean, and M. Otte. 2001. New isotopic evidence for dietary habits of Neandertals from Belgium. *Journal of Human Evolution* 40(6):497-505.
- Bocherens, H., D. Drucker, D. Billiou, M. Patou-Mathis, and B. Vandermeersch. 2005. Isotopic evidence for diet and subsistence pattern of the Saint-Cesaire I Neanderthal: review and use of a multi-source mixing model. *Journal of Human Evolution* 49(1):71-87.
- Bocherens, H., M. Fizet, A. Mariotti, B. Langebadre, B. Vandermeersch, J. Borel, and G. Bellon. 1991. Isotopic biogeochemistry (^{13}C , ^{15}N) of fossil vertebrate collagen: application to the study of a past food web including Neanderthal man. *Journal of Human Evolution* 20(6):481-492.
- Bogaard, A., T. Heaton, P. Poulton, and I. Merbach. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34(3):335-343.
- Bowes, G. 1991. Growth at Elevated CO_2 : Photosynthetic responses mediated through Rubisco. *Plant Cell and Environment* 14(8):795-806.
- Chalfoun, David, and Noreen Tuross. 1999. Botanical remains: utility in protein and DNA research. *Ancient Biomolecules* 3:67-79.
- Chase, Arlen, and Diane Chase. 2000. The royal court of Caracol, Belize: Its palaces and people. In *Royal Courts of the Ancient Maya*. Takeshi Inomata and Stephen Houston, eds. Pp. 102-137. Boulder: Westview Press.
- Chase, Arlen, Diane Chase, and Christine White. 2001. El Paisaje Urbano Maya: La integracion de los espacios construidos y la estructura social en Caracol, Belize. In *Reconstruyendo La Ciudad Maya: El Urbanism en las Sociedades Antiguas*. A. Ciudad Ruiz, M. J. Iglesias Ponce de León, and M. d. C. Martínez Martínez, eds. Pp. 95-122. Madrid: Sociedad Española de Estudios Mayas.
- Chisholm, Brian, and Michael Blake. 2006. Diet in prehistoric Soconusco. In *Histories of Maize*. J. Staller, Robert Tykot, and B. Benz, eds. Pp. 161-172. Burlington, MA: Academic Press.
- Choi, W., S. Lee, H. Ro, K. Kim, and S. Yoo. 2002. Natural N-15 abundances of maize and soil amended with urea and composted pig manure. *Plant and Soil* 245(2):223-232.

- Clark, J., Michael Blake, P. Guzzy, M. Cuevas, and T. Salcedo. 1987. El Preclásico temprano en la costa del Pacífico: Informe final. México, D.F.: Instituto Nacional de Antropología e Historia.
- Cooke, R., Lynette Norr, and Dolores Piperno. 1996. Native Americans and the Panamanian landscape. In *Case Studies in Environmental Archaeology*. E. Reitz, L. Newsom, and S. Scudder, eds. Pp. 103-126. New York: Plenum Press.
- Coyston, S., Christine White, and Henry P. Schwarcz. 1999. Dietary carbonate analysis of bone and enamel for two sites in Belize. In *Reconstructing Ancient Maya Diet*. Christine White, ed. Pp. 199-220. Salt Lake City: University of Utah Press.
- Delwiche, C., and P. Steyn. 1970. Nitrogen isotope fractionation in soils and microbial reactions. *Environmental Science & Technology* 4(11):929-&.
- Delwiche, C., P. Zinke, C. Johnson, and R. Virginia. 1979. Nitrogen isotope distribution as a presumptive indicator of nitrogen-fixation. *Botanical Gazette* 140:S65-S69.
- DeNiro, Michael 1985. Postmortem preservation and alteration of *in vivo* bone-collagen isotope ratios in relation to paleodietary reconstruction. *Nature* 317(6040):806-809.
- . 1987. Stable Isotopy and Archaeology. *American Scientist* 75(2):182-191.
- DeNiro, Michael, and Samuel Epstein. 1977. Mechanism of carbon isotope fractionation associated with lipid-synthesis. *Science* 197(4300):261-263.
- . 1978. Influence of diet on distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42(5):495-506.
- . 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45(3):341-351.
- . 1986. Erratum. *Geochimica et Cosmochimica Acta* 50(2):329.
- DeNiro, Michael, and Christine Hastorf. 1985. Alteration of $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$ ratios of plant matter during the initial stages of diagenesis: studies utilizing archaeological specimens from Peru. *Geochimica et Cosmochimica Acta* 49(1):97-115.
- DeSantis, L., and S. Wallace. 2008. Neogene forests from the Appalachians of Tennessee, USA: Geochemical evidence from fossil mammal teeth. *Palaeogeography Palaeoclimatology Palaeoecology* 266(1-2):59-68.
- Downton, W. 1975. Occurrence of C4 Photosynthesis among plants. *Photosynthetica* 9(1):96-105.
- Drucker, D., and H. Bocherens. 2004. Carbon and nitrogen stable isotopes as tracers of change in diet breadth during Middle and Upper Palaeolithic in Europe. *International Journal of Osteoarchaeology* 14(3-4):162-177.
- Dunning, Nicholas, Sheryl Luzzadder-Beach, Timothy Beach, J. G. Jones, V. Scarborough, and T. P. Culbert. 2002. Arising from the bajos: the evolution of a neotropical landscape and the rise of Maya civilization. *Annals of the Association of American Geographers* 92(2):267-283.

- Durrwachter, C., O. Craig, Matthew Collins, J. Burger, and K. Alt. 2006. Beyond the grave: variability in Neolithic diets in Southern Germany? *Journal of Archaeological Science* 33(1):39-48.
- Emery, Kitty, ed. 2004. *Maya zooarchaeology: new directions in method and theory*. Monograph 51. Los Angeles: University of California, Cotsen Institute of Archaeology.
- Emery, Kitty, Lori E. Wright, and Henry P. Schwarcz. 2000. Isotopic analysis of ancient deer done: Biotic stability in collapse Period Maya land-use. *Journal of Archaeological Science* 27(6):537-550.
- Erickson, C. 1988. Raised field agriculture in the Lake Titicaca Basin: Putting ancient agriculture back to work. *Expedition* 30(1):8-16.
- Farnsworth, Paul, J. Brady, Michael DeNiro, and Richard Macneish. 1985. A re-evaluation of the isotopic and archaeological reconstructions of diet in the Tehuacan Valley. *American Antiquity* 50(1):102-116.
- Farquhar, G., J. Ehleringer, and K. Hubick. 1989. Carbon isotope discrimination and photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology* 40:503-537.
- Fizet, M., A. Mariotti, H. Bocherens, B. Langebadre, B. Vandermeersch, J. Borel, and G. Bellon. 1995. Effect of diet, physiology and climate on carbon and nitrogen stable isotopes of collagen in a Late Pleistocene anthropic palaeoecosystem: Marillac, Charente, France. *Journal of Archaeological Science* 22(1):67-79.
- Flores, P., J. Fenoll, and P. Hellin. 2007. The feasibility of using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for discriminating between conventionally and organically fertilized pepper (*Capsicum annuum* L.). *Journal of Agricultural and Food Chemistry* 55(14):5740-5745.
- Focken, Ursula, and K. Becker. 1998. Metabolic fractionation of stable carbon isotopes: implications of different proximate compositions for studies of the aquatic food webs using $\delta^{13}\text{C}$ data. *Oecologia* 115(3):337-343.
- Francey, R. 1981. Tasmanian tree rings belie suggested anthropogenic $^{13}\text{C}/^{12}\text{C}$ trends. *Nature* 290(5803):232-235.
- Francey, R., C. Allison, D. Etheridge, C. Trudinger, I. Enting, M. Leuenberger, R. Langenfelds, E. Michel, and L. P. Steele. 1999. A 1000-year high precision record of $\delta^{13}\text{C}$ in atmospheric CO_2 . *Tellus Series B-Chemical and Physical Meteorology* 51(2):170-193.
- Freyer, H., and N. Belacy. 1983. $^{13}\text{C}/^{12}\text{C}$ records in Northern Hemispheric trees during the past 500 years: anthropogenic impact and climatic super-positions. *Journal of Geophysical Research-Oceans and Atmospheres* 88(Nc11):6844-6852.
- Friedman, I., and J. Gleason. 1984. ^{13}C analyses of bone samples from Site G-150, El Silencio. *Vinculos* 10:113-114.

- Garcia, N., R. Feranec, J. Arsuaga, J. de Castro, and E. Carbonell. 2009. Isotopic analysis of the ecology of herbivores and carnivores from the Middle Pleistocene deposits of the Sierra De Atapuerca, northern Spain. *Journal of Archaeological Science* 36(5):1142-1151.
- Gerry, John. 1993. Diet and status among the Classic Maya: An isotopic perspective. PhD dissertation, Harvard University, Cambridge.
- Gerry, John, and H. Krueger. 1997. Regional diversity in Classic Maya Diets. In *Bones of the Maya: Studies of Ancient Skeletons*. Stephen Whittington and David Reed, eds. Pp. 197-207. Washington, D.C.: Smithsonian Institution Press.
- Graham, Elizabeth, and David Pendergast. 1989. Excavations at the Marco Gonzalez Site, Ambergris Cay, Belize, 1986. *Journal of Field Archaeology* 16(1):1-16.
- Griffiths, H. 1992. Carbon isotope discrimination and the integration of carbon assimilation pathways in terrestrial CAM plants. *Plant Cell and Environment* 15(9):1051-1062.
- Heaton, T. 1987. The $^{15}\text{N}/^{14}\text{N}$ Ratios of plants in South-Africa and Namibia: relationship to climate and coastal saline environments. *Oecologia* 74(2):236-246.
- Heaton, T., J. C. Vogel, G. Vonlachevallerie, and G. Collett. 1986. Climatic influence on the isotopic composition of bone nitrogen. *Nature* 322(6082):822-823.
- Hedges, R., A. Saville, and Tamsin O'Connell. 2008. Characterizing the diet of individuals at the neolithic chambered tomb of Hazleton North, Gloucestershire, England, using stable isotopic analysis. *Archaeometry* 50:114-128.
- Hedges, Richard., and L. M. Reynard. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34(8):1240-1251.
- Henderson, Hope 2003. The organization of staple crop production at K'axob, Belize. *Latin American Antiquity* 14(4):469-496.
- Hobson, K., and R. Clark. 1992. Assessing avian diets using stable isotopes. 2. Factors influencing diet-tissue fractionation. *Condor* 94(1):189-197.
- Hu, Y., H. Shang, H. Tong, O. Nehlich, W. Liu, C. H. Zhao, J. C. Yu, C. S. Wang, E. Trinkaus, and M. P. Richards. 2009. Stable isotope dietary analysis of the Tianyuan 1 early modern human. *Proceedings of the National Academy of Sciences of the United States of America* 106(27):10971-10974.
- Inomata, Takeshi, and Stephen Houston, eds. *Royal courts of the ancient Maya*. Westview Press 2001.
- Jacob, J. 1995. Ancient Maya wetland agricultural fields in Cobweb Swamp, Belize: construction, chronology, and function. *Journal of Field Archaeology* 22(2):175-190.
- Jay, M., and M. Richards. 2006. Diet in the Iron Age cemetery population at Wetwang Slack, East Yorkshire, UK: carbon and nitrogen stable isotope evidence. *Journal of Archaeological Science* 33(5):653-662.

- Keegan, W., and Michael DeNiro. 1988. Stable carbon-isotope and nitrogen-isotope ratios of bone-collagen used to study coral-reef and terrestrial components of prehistoric Bahamian diet. *American Antiquity* 53(2):320-336.
- Keeling, C., R. Bacastow, A. Carter, S. Piper, T. Whorf, M. Heimann, W. Mook, and H. Roeloffzen. 1989. Aspects of climate variability in the Pacific and the western Americas. In *Geophysical Monograph* 55. D. Peterson, ed. Pp. 165-236. Washington, D.C.: American Geophysical Union.
- Kellner, C., and Margaret J. Schoeninger. 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology* 133(4):1112-1127.
- Kitagawa, H., and E. Matsumoto. 1995. Carbon-isotope variation within trunks of Japanese cedars from Yakushima Island, Southern Japan. *Geochemical Journal* 29(2):149-153.
- Kunen, J. 2001. Ancient Maya agricultural installations and the development of intensive agriculture in NW Belize. *Journal of Field Archaeology* 28(3-4):325-346.
- Leavitt, S., and A. Long. 1986. Trends of $^{13}\text{C}/^{12}\text{C}$ ratios in Pinyon tree rings of the American Southwest and the global carbon-cycle. *Radiocarbon* 28(2A):376-382.
- Lee-Thorp, Julia. 2008. On isotopes and old bones. *Archaeometry* 50:925-950.
- Lightfoot, E., Tamsin O'Connell, R. Stevens, J. Hamilton, G. Hey, and Richard Hedges. 2009. An investigation into diet at the site of Yarnton, Oxfordshire, using stable carbon and nitrogen isotopes. *Oxford Journal of Archaeology* 28(3):301-322.
- Love, David. 1989. Early settlements and chronology of the Río Naranjo, Guatemala. PhD dissertation, University of California, Berkeley.
- Lubell, D., M. Jackes, Henry P. Schwarcz, M. Knyf, and C. Meiklejohn. 1994. The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science* 21(2):201-216.
- Mansell, E., Robert Tykot, David Freidel, Bruce Dahlin, and T. Ardent. 2006. Early to Terminal Classic Maya diet in the Northern Lowlands of the Yucatan (Mexico). In *Histories of Maize*. J. Staller and Robert Tykot, eds. Pp. 173-180. Burlington, MA: Academic Press.
- Marino, B., and Michael DeNiro. 1987. Isotopic analysis of archaeobotanicals to reconstruct past climates: effects of activities associated with food preparation on carbon, hydrogen and oxygen isotope ratios of plant cellulose. *Journal of Archaeological Science* 14(5):537-548.
- Marino, B., and M. Mcelroy. 1991. Isotopic composition of atmospheric CO_2 inferred from carbon in C_4 plant cellulose. *Nature* 349(6305):127-131.
- McCarroll, D., and N. Loader. 2004. Stable isotopes in tree rings. *Quaternary Science Reviews* 23(7-8):771-801.

- Metcalfe, J., Christine White, Fred Longstaffe, G. Wrobel, D. Cook, and K. Pyburn. 2009. Isotopic evidence for diet at Chau Hiix, Belize: testing regional models of hierarchy and heterarchy. *Latin American Antiquity* 20(1):15-36.
- Middleton, W., G. Feinman, and L. Nicholas. 2002. Domestic fauna assemblages from the Classic Period Valley of Oaxaca, Mexico: A perspective on the subsistence and craft economies. *Journal of Archaeological Science* 29(3):233-249.
- Minagawa, Masao, and Eitaro Wada. 1984. Stepwise enrichment of ^{15}N along food-chains: further evidence and the relation between $\delta^{15}\text{N}$ and animal age. *Geochimica et Cosmochimica Acta* 48(5):1135-1140.
- Monson, R. 2003. Gene duplication, neofunctionalization, and the evolution of C4 photosynthesis. *International Journal of Plant Sciences* 164(3):S43-S54.
- Nakano, A., Y. Uehara, and A. Yamauchi. 2003. Effect of organic and inorganic fertigation on yields, $\delta^{15}\text{N}$ values, and $\delta^{13}\text{C}$ values of tomato (*Lycopersicon esculentum* Mill. cv. Saturn). *Plant and Soil* 255(1):343-349.
- Nations, James, and Ronald Nigh. 1980. The evolutionary potential of Lacandon Maya sustained-yield tropical forest agriculture. *Journal of Anthropological Research* 36(1):1-30.
- Nehlich, Olaf, J. Montgomery, J. Evans, S. Schade-Lindig, S. Pichler, M. Richards, and K. Alt. 2009. Mobility or migration: a case study from the Neolithic settlement of Nieder-Morlen (Hessen, Germany). *Journal of Archaeological Science* 36(8):1791-1799.
- Norr, Lynette. 1991. Nutritional consequences of prehistoric subsistence strategies in lower Central America. PhD dissertation, University of Illinois, Urbana-Champaign.
- . 1995. Interpreting dietary maize from bone stable isotopes in the American tropics: The state of the art. In *Archaeology in the Lowland American Tropics*. P. Stahl, ed. Pp. 198-223. New York: Cambridge University Press.
- O'Leary, M. H. 1988. Carbon isotopes in photosynthesis. *Bioscience* 38(5):328-336.
- Pate, F. 1995. Stable carbon-isotope assessment of hunter-gatherer mobility in prehistoric South Australia. *Journal of Archaeological Science* 22(1):81-87.
- Pechenkina, E., Stanley Ambrose, X. Ma, and R. Benfer. 2005. Reconstructing northern Chinese Neolithic subsistence practices by isotopic analysis. *Journal of Archaeological Science* 32(8):1176-1189.
- Perry, L., R. Dickau, S. Zarrillo, I. Holst, Deborah Pearsall, Dolores Piperno, M. Berman, R. G. Cooke, K. Rademaker, A. Ranere, et al. 2007. Starch fossils and the domestication and dispersal of chili peppers (*Capsicum* spp. L.) in the Americas. *Science* 315(5814):986-988.
- Phillips, D., and Paul Koch. 2002. Incorporating concentration dependence in stable isotope mixing models. *Oecologia* 130(1):114-125.
- Pinnegar, J., and N. Polunin. 1999. Differential fractionation of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ among fish

- tissues: implications for the study of trophic interactions. *Functional Ecology* 13(2):225-231.
- Piperno, Dolores, and Kent Flannery. 2001. The earliest archaeological maize (*Zea mays* L.) from highland Mexico: New accelerator mass spectrometry dates and their implications. *Proceedings of the National Academy of Sciences of the United States of America* 98(4):2101-2103.
- Piperno, Dolores, A. Ranere, I. Holst, and P. Hansell. 2000. Starch grains reveal early root crop horticulture in the Panamanian tropical forest. *Nature* 407(6806):894-897.
- Pohl, Mary, Kevin Pope, John Jones, John Jacob, Dolores Piperno, Susan deFrance, David Lentz, John Gifford, Marie Danforth, and J. Kathryn Josserand. 1996. Early Agriculture in the Maya Lowlands. *Latin American Antiquity* 7(4):355-372.
- Pohl, Mary, Dolores Piperno, Kevin Pope, and John Jones. 2007. Microfossil evidence for pre-Columbian maize dispersals in the neotropics from San Andres, Tabasco, Mexico. *Proceedings of the National Academy of Sciences of the United States of America* 104(16):6870-6875.
- Pope, Kevin, and Bruce Dahlin. 1989. Ancient Maya Wetland Agriculture: New Insights from Ecological and Remote Sensing Research. *Journal of Field Archaeology* 16(1):87-106.
- Pope, Kevin, Mary Pohl, John Jones, David Lentz, C. von Nagy, F. Vega, and I. Quitmyer. 2001. Origin and environmental setting of ancient agriculture in the lowlands of mesoamerica. *Science* 292(5520):1370-1373.
- Post, David. 2002. Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology* 83(3):703-718.
- Post, W., T. Peng, W. Emanuel, A. King, V. Dale, and D. Deangelis. 1990. The global carbon-cycle. *American Scientist* 78(4):310-326.
- Powis, Terry, Norbert Stanchly, Christine White, Paul Healy, Jaime Awe, and Fred Longstaffe. 1999. A reconstruction of Middle Preclassic Maya subsistence economy at Cahal Pech, Belize. *Antiquity* 73:364-376.
- Privat, K., Tamsin O'Connell, and M. Richards. 2002. Stable isotope analysis of human and faunal remains from the Anglo-Saxon cemetery at Berinsfield, Oxfordshire: Dietary and social implications. *Journal of Archaeological Science* 29(7):779-790.
- Ranere, A., Dolores Piperno, I. Holst, Ruth Dickau, and J. Iriarte. 2009. The cultural and chronological context of early Holocene maize and squash domestication in the Central Balsas River Valley, Mexico. *Proceedings of the National Academy of Sciences of the United States of America* 106(13):5014-5018.
- Reed, David 1994. Ancient Maya diet at Copan, Honduras, as determined through the analysis of stable carbon and nitrogen isotopes. In *Paleonutrition: the diet and health of prehistoric Americans*. Kristin Sobolik. Pp. 210-221. Occasional Paper 22, Carbondale: Southern Illinois University, Center for Archaeological

Investigations.

- . 1998. Ancient Maya diet at Copán, Honduras. PhD dissertation, Pennsylvania State University, University Park.
- . 1999. Cuisine from Hun-Nal-Ye. In *Reconstructing ancient Maya diet*, edited by Christine White. Salt Lake City: University of Utah Press.
- Reed, David, and Stephen Whittington. 1995. El análisis de isótopos estables de carbono y nitrógeno en los huesos de Iximché. Final technical report to the Instituto de Antropología e Historia, Guatemala.
- Richards, M., and Richard Hedges. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science* 26(6):717-722.
- Richards, M., P. Pettitt, Erik Trinkaus, F. Smith, M. Paunovic, and I. Karavanic. 2000. Neanderthal diet at Vindija and Neanderthal predation: The evidence from stable isotopes. *Proceedings of the National Academy of Sciences of the United States of America* 97(13):7663-7666.
- Richards, M., and R. Schmitz. 2008. Isotope evidence for the diet of the Neanderthal type specimen. *Antiquity* 82(317):553-559.
- Richards, M., G. Taylor, T. Steele, S. McPherron, M. Soressi, J. Jaubert, J. Orschiedt, J. Mallye, W. Rendu, and J. Hublin. 2008. Isotopic dietary analysis of a Neanderthal and associated fauna from the site of Jonzac (Charente-Maritime), France. *Journal of Human Evolution* 55(1):179-185.
- Richards, M., and Erik Trinkaus. 2009. Isotopic evidence for the diets of European Neanderthals and early modern humans. *Proceedings of the National Academy of Sciences of the United States of America* 106(38):16034-16039.
- Robertson, I., J. Rolfe, V. Switsur, A. Carter, M. Hall, A. Barker, and J. Waterhouse. 1997. Signal strength and climate relationships in $^{13}\text{C}/^{12}\text{C}$ ratios of tree ring cellulose from oak in southwest Finland. *Geophysical Research Letters* 24(12):1487-1490.
- Salamon, Michal, A. Coppa, Michael McCormick, M. Rubini, R. Vargiu, and Noreen Tuross. 2008. The consilience of historical and isotopic approaches in reconstructing the medieval Mediterranean diet. *Journal of Archaeological Science* 35(6):1667-1672.
- Schoeninger, Margaret 1985. Trophic level effects on $^{15}\text{N}/^{14}\text{N}$ and $^{13}\text{C}/^{12}\text{C}$ ratios in bone-collagen and strontium levels in bone-mineral. *Journal of Human Evolution* 14(5):515-525.
- . 2009. Stable isotope evidence for the adoption of maize agriculture. *Current Anthropology* 50(5):633-640.
- Schoeninger, Margaret, and Michael DeNiro. 1984. Nitrogen and carbon isotopic composition of bone-collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48(4):625-639.

- Schwarcz, Henry 1991. Some theoretical aspects of isotope paleodiet studies. *Journal of Archaeological Science* 18(3):261-275.
- . 2000. Some biochemical aspects of carbon isotopic paleodiet studies. In *Biogeochemical approaches to paleodietary analysis*. Stanley Ambrose and M. Katzenberg, eds. Pp. 189-209. New York: Kluwer Academic.
- Schwarcz, Henry, J. Melbye, M. Katzenberg, and M. Knyf. 1985. Stable isotopes in human skeletons of Southern Ontario: reconstructing paleodiet. *Journal of Archaeological Science* 12(3):187-206.
- Sealy, Judith, Nikolaas van der Merwe, Julia Lee-Thorp, and J. L. Lanham. 1987. Nitrogen isotopic ecology in Southern-Africa: implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta* 51(10):2707-2717.
- Shearer, G., and D. Kohl. 1988. Natural ^{15}N abundance as a method of estimating the contribution of biologically fixed nitrogen to N_2 -fixing systems: potential for non-legumes. *Plant and Soil* 110(2):317-327.
- Shearer, G., D. Kohl, R. Virginia, B. Bryan, J. Skeeters, E. Nilsen, M. Sharifi, and P. Rundel. 1983. Estimates of N_2 -fixation from variation in the natural abundance of ^{15}N in Sonoran Desert ecosystems. *Oecologia* 56(2-3):365-373.
- Siemens, Alfred, and Dennis Puleston. 1972. Ridged fields and associated features in southern Campeche: new perspectives on the Lowland Maya. *American Antiquity* 37(2):228-239.
- Smalley, John, and Michael Blake. 2003. Sweet beginnings: sugar stalk and the domestication of maize. *Current Anthropology* 44(5):675-703
- Smith, B. 1986. Preceramic plant remains from Guilá Naquitz. In *Guilá Naquitz: Archaic foraging and early agriculture in Oaxaca, Mexico*. Kent Flannery. Kent Flannery, ed. Pp. 265-274. Orlando: Academic Press.
- . 2001. Documenting plant domestication: The consilience of biological and archaeological approaches. *Proceedings of the National Academy of Sciences of the United States of America* 98(4):1324-1326.
- Smith, B. N., and S. Epstein. 1971. Two categories of $^{13}\text{C}/^{12}\text{C}$ ratios for higher plants. *Plant Physiology* 47(3):380-&.
- Smith, C. 1967. Plant remains. In *Prehistory of the Tehuacan Valley: Environment and Subsistence*. D. Byers, ed. Pp. 220-255. Austin: Texas University Press.
- Sponheimer, Matthew, and Julia Lee-Thorp. 1999. Isotopic evidence for the diet of an early hominid, *Australopithecus africanus*. *Science* 283(5400):368-370.
- Sponheimer, Matthew, Benjamin Passey, D. de Ruiter, D. Guatelli-Steinberg, T. Cerling, and Julia Lee-Thorp. 2006. Isotopic evidence for dietary variability in the early hominin *Paranthropus robustus*. *Science* 314(5801):980-982.
- Stuiver, M. 1978. Atmospheric carbon dioxide and carbon reservoir changes. *Science* 199(4326):253-258.

- Suess, Hans. 1955. Radiocarbon concentration in modern wood. *Science* 122(3166):415-417.
- Tans, P., and W. Mook. 1980. Past Atmospheric CO₂ levels and the ¹³C/¹²C ratios in tree rings. *Tellus* 32(3):268-283.
- Tessone, A., A. Zangrando, G. Barrientos, R. Goni, H. Panarello, and M. Cagnoni. 2009. Stable isotope studies in the Salitroso Lake Basin (Southern Patagonia, Argentina): assessing diet of late Holocene hunter-gatherers. *International Journal of Osteoarchaeology* 19(2):297-308.
- Tieszen, Larry. 1991. Natural variations in the carbon isotope values of plants: implications for archaeology, ecology, and paleoecology. *Journal of Archaeological Science* 18(3):227-248.
- Tieszen, Larry, and Tim Fagre. 1993. Carbon isotopic variability in modern and archaeological maize. *Journal of Archaeological Science* 20(1):25-40.
- Treydte, K., G. Schleser, F. Schweingruber, and M. Winiger. 2001. The climatic significance of δ¹³C in subalpine spruces (Lotschental, Swiss Alps): A case study with respect to altitude, exposure and soil moisture. *Tellus Series B-Chemical and Physical Meteorology* 53(5):593-611.
- Tucker, Jonathan. 1986. Amaranth: the once and future crop. *BioScience* 36(1):9-13.
- Turner, B. L. 1974. Prehistoric Intensive Agriculture in Mayan Lowlands. *Science* 185(4146):118-124.
- Tykot, Robert. 2002. Contribution of stable isotope analysis to understanding dietary variation among the Maya. In *Archaeological chemistry: materials, methods, and meaning*. K. Jakes, ed. Pp. 214-230. Symposium Series 831. Washington, D.C.: American Chemical Society.
- . 2004. Stable isotopes and diet: you are what you eat. In *Physics methods in archaeometry*. M. Martini, M. Milazzo and M. Piacentini, eds. Pp. 433-444. Proceedings of the International School of Physics "Enrico Fermi." Bologna, Italy: Società Italiana di Fisica.
- . 2006. Stable isotope analysis and human diet. In *Histories of Maize*. J. Staller, Robert Tykot, and Bruce Benz, eds. Burlington, MA: Academic Press.
- Tykot, Robert, Nikolaas van der Merwe, and Norman Hammond. 1996. Stable isotope analysis of bone collagen, bone apatite, and tooth enamel in the reconstruction of human diet: a case study from Cuello, Belize. In *Archaeological Chemistry: organic, inorganic, and biochemical analysis*. M. Orna, ed. Pp. 355-365. Symposium Series 625. Washington, D.C.: American Chemical Society.
- van der Merwe, Nikolaas, Robert Tykot, Norman Hammond, and K. Oakberg. 2000. Diet and animal husbandry of the Preclassic Maya at Cuello, Belize. In *Biogeochemical approaches to paleodietary analysis*. Stanley Ambrose and M. Katzenberg, eds. New York: Kluwer Academic.
- van der Merwe, Nikolaas. 1982. Carbon isotopes, photosynthesis, and archaeology. *American Scientist* 70(6):596-606.

- van der Merwe, Nikolaas, and E. Medina. 1991. The canopy effect, carbon isotope ratios and foodwebs in Amazonia. *Journal of Archaeological Science* 18(3):249-259.
- van der Merwe, Nikolaas, and J. C. Vogel. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North-America. *Nature* 276(5690):815-816.
- Vander Zanden, M., and J. Rasmussen. 2001. Variation in $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ trophic fractionation: Implications for aquatic food web studies. *Limnology and Oceanography* 46(8):2061-2066.
- Virginia, R., and C. Delwiche. 1982. Natural ^{15}N abundance of presumed N_2 -fixing and non- N_2 -fixing plants from selected ecosystems. *Oecologia* 54(3):317-325.
- Vogel, J. C. 1978. Isotopic assessment of dietary habits of ungulates. *South African Journal of Science* 74(8):298-301.
- Vogel, J. C., A. Fuls, and R. Ellis. 1978. Geographical distribution of Kranz grasses in South-Africa. *South African Journal of Science* 74(6):209-215.
- Voorhies, Barbara. 1976. The Cantuto people: an Archaic period society of the Chiapas Littoral, Mexico. *Papers of the New World Archaeological Foundation* 41. Provo, UT: Brigham Young University, New World Archaeological Foundation.
- . n.d. Preliminary report on human burial remains from excavations in the Acapetahua region. MS thesis, University of California, Santa Barbara.
- Wada, Eitaro, T. Kadonaga, and S. Matsuo. 1975. ^{15}N abundance in nitrogen of naturally occurring substances and global assessment of denitrification from isotopic viewpoint. *Geochemical Journal* 9:139-148.
- Warinner, Christina, and Noreen Tuross. 2009. Alkaline cooking and stable isotope tissue-diet spacing in swine: archaeological implications. *Journal of Archaeological Science* 36(8):1690-1697.
- Warinner, Christina, and Noreen Tuross. 2010. Tissue isotopic enrichment associated with growth depression in a pig: implications for archaeology and ecology. *American Journal of Physical Anthropology*. Forthcoming.
- Webster, David, David Rue, and Alfred Traverse. 2005. Early *Zea* cultivation in Honduras: implications for the Ilitis hypothesis. *Economic Botany* 59(2):101-111.
- White, Christine. 1986. Paleodiet and nutrition of the ancient Maya at Lamanai, Belize: a study of trace elements, stable isotopes, nutritional and dental pathology, MA thesis, Trent University, Peterborough.
- . 1997. Ancient diet at Lamanai and Pacbitun: implications for the ecological model of collapse. In *Bones of the Maya: studies of ancient skeletons*. Stephen Whittington and David Reed, eds. Pp. 171-180. Washington, D.C.: Smithsonian Institution Press.
- . 2005. Gendered food behaviour among the Maya: time, place, status, and ritual. *Journal of Social Archaeology* 5(3):356-382.

- White, Christine, Paul Healy, and Henry Schwarcz. 1993. Intensive agriculture, social-status, and Maya diet at Pacbitun, Belize. *Journal of Anthropological Research* 49(4):347-375.
- White, Christine D., David M. Pendergast, Fred J. Longstaffe, and Kimberley R. Law. 2001. Social complexity and food systems at Altun Ha, Belize: the isotopic evidence. *Latin American Antiquity* 12(4):371-393.
- White, Christine, Mary Pohl, Henry Schwarcz, and Fred Longstaffe. 2004. Feast, field, and forest. In *Maya Zooarchaeology*. Kitty Emery, ed. Los Angeles: Cotsen Institute of Archaeology, University of California.
- White, Christine, Mary Pohl, Henry Schwarcz, and Fred Longstaffe. 2001. Isotopic evidence for Maya patterns of deer and dog use at Preclassic Colha (Belize). *Journal of Archaeological Science* 28(1):89-107.
- White, Christine, and Henry Schwarcz. 1989. Ancient Maya diet: as inferred from isotopic and elemental analysis of human bone. *Journal of Archaeological Science* 16(5):451-474.
- White, Christine, Lori Wright, and David Pendergast. 1994. Biological disruption in the early colonial period at Lamanai. In *In the wake of contact: biological responses to conquest*. C. Larsen and G. Milner, eds. Pp. 135-145. New York: Wiley-Liss.
- Whittington, Stephen, and David Reed. 1994. Los esqueletos de Iximche. In *VII Simposio de Investigaciones Arqueológicas en Guatemala 1993*. Juan Pedro Laporte and Héctor Escobedo, eds. Pp. 23-28. Guatemala: Ministerio de Cultura y Deportes, Instituto de Antropología e Historia, Asociación Tikal.
- . 1996. Evidence of diet and health in the skeletons of Iximche. In *Estudios Kaqchiqueles: in memory of William R. Swezey*. E. Robinson, ed. Antigua, Guatemala: CIRMA.
- . 1997. Commoner diet at Copan: insights from stable isotopes and porotic hyperostosis. In *Bones of the Maya: studies of ancient skeletons*. Stephen Whittington and David Reed, eds. Pp. 157-170. Washington, D.C.: Smithsonian Institution Press.
- . 1998. Evidencia de dieta y salud en los esqueletos de Iximché. *Mesoamérica* 35:73-82.
- Whittington, Stephen, and Robert Tykot. 2000. Analysis of Kaqchikel skeletons: Iximche, Guatemala. Foundation for the Advancement of Mesoamerican Studies, Inc. (FAMSI). <http://www.famsi.org/reports/99002.index.html> (accessed September 28, 2009).
- Williams, Jocelyn, Christine White, and Fred Longstaffe. 2005. Trophic level and macronutrient shift effects associated with the weaning process in the Postclassic Maya. *American Journal of Physical Anthropology* 128(4):781-790.
- Winter, K., and J. Holtum. 2002. How closely do the $\delta^{13}\text{C}$ values of Crassulacean Acid Metabolism plants reflect the proportion of CO_2 fixed during day and night? *Plant Physiology* 129(4):1843-1851.

- Wright, Lori. 1994. The sacrifice of the earth? Diet, health and inequality in the Pasion Maya lowlands. PhD dissertation, University of Chicago, Chicago.
- . 1997. Ecology or Society? Paleodiet and the collapse of the Pasion Maya Lowlands. In *Bones of the Maya: studies of ancient skeletons*. Stephen Whittington and David Reed, ed. Pp. 181-195. Washington, D.C.: Smithsonian Institution Press.
- . 2006. *Diet, health, and status among the Pasion Maya: a reappraisal of the collapse*. Nashville, TN: Vanderbilt University Press.
- Wright, Lori, and Henry Schwarcz. 1999. Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: infant diets at Kaminaljuyu. *Journal of Archaeological Science* 26(9):1159-1170.
- Wright, Lori, and Christine White. 1996. Human biology in the Classic Maya collapse: Evidence from paleopathology and paleodiet. *Journal of World Prehistory* 10(2):147-198.
- Zarrillo, S., Deborah Pearsall, J. Raymond, M. Tisdale, and D. Quon. 2008. Directly dated starch residues document early formative maize (*Zea mays* L.) in tropical Ecuador. *Proceedings of the National Academy of Sciences of the United States of America* 105(13):5006-5011.

4.10. Appendices

Appendix 4.1. Bone collagen isotopic ratios of Middle American^a humans

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
<i>Central Mexico</i>					
Tehuacan Valley	n.r.	-13.3	10.4	3.4	9, 10, 11
Tehuacan Valley	n.r.	-6.1	10.0	3.6	9, 10, 11
Tehuacan Valley	n.r.	-6.3	9.5	3.5	9, 10, 11
Tehuacan Valley	n.r.	-5.5	8.9	†	9, 10, 11
Tehuacan Valley	n.r.	-5.9	8.0	†	9, 10, 11
Tehuacan Valley	n.r.	-6.3	8.0	†	9, 10, 11
Tehuacan Valley	n.r.	-6.3	7.9	†	9, 10, 11
Tehuacan Valley	n.r.	-6.5	9.2	†	9, 10, 11
Tehuacan Valley	n.r.	-6.5	8.9	†	9, 10, 11
Tehuacan Valley	n.r.	-6.5	8.7	†	9, 10, 11
Tehuacan Valley	n.r.	-6.6	9.1	†	9, 10, 11
Teotihuacan	Zapotec ^d	-9.7	7.4	3.4	37
Teotihuacan	Zapotec ^d	-8.9	8.5	3.4	37
Teotihuacan	Zapotec ^d	-8.6	10.4	3.4	37
Teotihuacan	Zapotec ^d	-9.1	-	3.4	37
Teotihuacan	Zapotec ^d	-	9.2	3.4	37
Teotihuacan	Zapotec ^d	-7.6	9.0	3.3	37
Teotihuacan	Zapotec ^d	-8.0	11.1	3.3	37
Teotihuacan	Zapotec ^d	-7.9	9.0	3.3	37
Teotihuacan	Zapotec ^d	-8.3	9.7	3.4	37
Teotihuacan	Zapotec ^d	-7.9	9.8	3.5	37
Teotihuacan	Zapotec ^d	-7.8	9.0	3.5	37
Teotihuacan	Zapotec ^d	-7.9	8.5	3.4	37
<i>Oaxaca</i>					
El Paragüito	Zapotec	-7.5	8.8	3.5	This study
El Paragüito	Zapotec	-7.8	8.5	3.4	This study
Lambityeco	Zapotec	-7.9	8.9	3.3	This study
Monte Alban	Zapotec	-6.4	9.2	3.4	This study
Monte Alban	Zapotec	-7.4	10.0	3.3	3
Monte Alban	Zapotec	-7.2	9.7	3.3	3
Monte Alban	Zapotec	-9.1	10.5	3.3	3
Monte Alban	Zapotec	-8.1	10.5	3.6	3
Monte Alban	Zapotec	-8.4	9.0	3.2	3
Monte Alban	Zapotec	-10.1	7.2	2.8	3
Monte Alban	Zapotec	-8.3	9.3	3.0	3
Monte Alban	Zapotec	-7.7	10.3	3.4	3
Monte Alban	Zapotec	-9.0	9.3	3.4	3
Monte Alban	Zapotec	-7.4	9.8	3.4	3
San Miguel Albarradas	Zapotec	-6.9	6.5	3.4	This study
San Pedro Ixtlahuaca	Zapotec	-7.7	8.5	3.4	This study
Teposcolulua	Mixtec	-7.6	8.3	3.3	This study
Teposcolulua	Mixtec	-9.4	6.9	3.4	This study
Teposcolulua	Mixtec	-8.9	9.5	3.3	This study
Teposcolulua	Mixtec	-9.9	7.6	3.4	This study
Teposcolulua	Mixtec	-8.3	8.1	3.3	This study
Teposcolulua	Mixtec	-7.8	8.7	3.4	This study

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Teposcolulua	Mixtec	-8.1	8.6	3.4	This study
Teposcolulua	Mixtec	-8.0	8.2	3.3	This study
Teposcolulua	Mixtec	-7.8	7.8	3.3	This study
Teposcolulua	Mixtec	-7.9	9.3	3.4	This study
Teposcolulua	Mixtec	-7.8	7.3	3.4	This study
Teposcolulua	Mixtec	-7.5	9.0	3.4	This study
Teposcolulua	Mixtec	-7.8	8.1	3.3	This study
Teposcolulua	Mixtec	-8.9	6.8	3.4	This study
Teposcolulua	Mixtec	-9.4	8.6	3.3	This study
Teposcolulua	Mixtec	-7.5	8.8	3.4	This study
Teposcolulua	Mixtec	-8.1	9.2	3.3	This study
Teposcolulua	Mixtec	-8.7	8.2	3.3	This study
Teposcolulua	Mixtec	-8.7	8.7	3.4	This study
Teposcolulua	Mixtec	-8.5	7.7	3.3	This study
Teposcolulua	Mixtec	-7.7	8.9	3.3	This study
Teposcolulua	Mixtec	-7.7	8.7	3.4	This study
Teposcolulua	Mixtec	-8.5	8.9	3.4	This study
Teposcolulua	Mixtec	-7.8	8.3	3.4	This study
Teposcolulua	Mixtec	-8.4	9.1	3.3	This study
Teposcolulua	Mixtec	-8.4	9.1	3.4	This study
Teposcolulua	Mixtec	-8.8	9.4	3.5	This study
Teposcolulua	Mixtec	-5.2	11.5	3.4	This study
Teposcolulua	Mixtec	-6.1	12.0	3.2	This study
Teposcolulua	Mixtec	-8.1	9.1	3.1	This study
Teposcolulua	Mixtec	-8.8	9.7	3.3	This study
Teposcolulua	Mixtec	-8.6	8.5	3.5	This study
Teposcolulua	Mixtec	-7.7	7.8	3.3	This study
Teposcolulua	Mixtec	-8.6	7.5	3.5	This study
Teposcolulua	Mixtec	-8.6	8.3	3.3	This study
Teposcolulua	Mixtec	-8.2	8.0	3.4	This study
Teposcolulua	Mixtec	-8.4	8.7	3.4	This study
Teposcolulua	Mixtec	-8.1	9.2	3.2	This study
Teposcolulua	Mixtec	-8.1	8.3	3.3	This study
Teposcolulua	Mixtec	-7.8	8.5	3.4	This study
Teposcolulua	Mixtec	-8.6	7.8	3.3	This study
Teposcolulua	Mixtec	-6.6	10.3	3.5	This study
Teposcolulua	Mixtec	-8.2	8.4	3.1	This study
Teposcolulua	Mixtec	-8.0	7.6	3.5	This study
Teposcolulua	Mixtec	-8.2	7.3	3.5	This study
Teposcolulua	Mixtec	-8.4	8.6	3.6	This study
Teposcolulua	Mixtec	-8.1	7.0	3.5	This study
Teposcolulua	Mixtec	-8.3	8.3	3.5	This study
Xatachio	Zapotec	-8.0	10.7	3.4	This study
<i>Southern Maya Lowlands</i>					
Aguateca	Maya	-9.9	9.1	3.2	44, 45, 46
Aguateca	Maya	-8.8	8.0	3.1	44, 45, 46
Aguateca	Maya	-9.3	9.1	3.2	44, 45, 46
Aguateca	Maya	-9.2	10.6	3.0	44, 45, 46

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Aguateca	Maya	-9.2	10.7	3.1	44, 45, 46
Aguateca	Maya	-9.1	10.2	2.9	45, 46
Altar de Sacrificios	Maya	-9.9	7.7	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.6	8.2	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.6	7.6	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.7	9.3	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.2	7.9	3.2	44, 45, 46
Altar de Sacrificios	Maya	-11.2	9.4	3.3	44, 45, 46
Altar de Sacrificios	Maya	-9.4	8.7	3.1	44, 45, 46
Altar de Sacrificios	Maya	-7.7	8.3	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.3	7.6	3.1	44, 45, 46
Altar de Sacrificios	Maya	-13	9.1	3.0	44, 45, 46
Altar de Sacrificios	Maya	-9.4	7.4	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.2	8.9	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.8	9.2	3.2	44, 45, 46
Altar de Sacrificios	Maya	-10.4	11.4	3.1	44, 45, 46
Altar de Sacrificios	Maya	-10.7	8.7	3.3	44, 45, 46
Altar de Sacrificios	Maya	-11.1	8.5	3.1	44, 45, 46
Altar de Sacrificios	Maya	-10.3	9.2	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.5	10.3	3.2	44, 45, 46
Altar de Sacrificios	Maya	-9.3	7.0	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.4	8.7	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.8	10.2	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.8	8.2	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.1	8.1	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.5	10.5	3.1	44, 45, 46
Altar de Sacrificios	Maya	-6.5	8.5	3.3	44, 45, 46
Altar de Sacrificios	Maya	-8.3	9.0	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.5	8.2	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.1	7.9	3.1	44, 45, 46
Altar de Sacrificios	Maya	-10.6	9.6	3.1	44, 45, 46
Altar de Sacrificios	Maya	-9.1	8.7	3.3	44, 45, 46
Altar de Sacrificios	Maya	-9.2	7.9	3.0	44, 45, 46
Altar de Sacrificios	Maya	-9.3	7.7	3.2	44, 45, 46
Altar de Sacrificios	Maya	-8.3	7.7	3.2	44, 45, 46
Altar de Sacrificios	Maya	-9.5	8.8	3.1	44, 45, 46
Altar de Sacrificios	Maya	-10.4	7.8	3.1	44, 45, 46
Altar de Sacrificios	Maya	-8.9	10.2	3.2	44, 45, 46
Altar de Sacrificios	Maya	-10.5	8.4	3.6	44, 45, 46
Altar de Sacrificios	Maya	-13.4	6.5	3.4	44, 45, 46
Altar de Sacrificios	Maya	-8.9	-	3.5	13, 14
Altar de Sacrificios	Maya	-9.1	9.4	3.3	13, 14
Altar de Sacrificios	Maya	-8.8	8.0	3.4	13, 14
Altar de Sacrificios	Maya	-9.5	8.3	3.4	13, 14
Altar de Sacrificios	Maya	-8.7	8.0	3.4	13, 14
Altar de Sacrificios	Maya	-8.5	9.4	3.3	13, 14
Altar de Sacrificios	Maya	-10.3	8.7	3.4	13, 14
Altar de Sacrificios	Maya	-8.8	9.8	3.4	13, 14

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Altar de Sacrificios	Maya	-8.9	10.4	3.4	13, 14
Altar de Sacrificios	Maya	-8.9	8.9	3.4	13, 14
Altar de Sacrificios	Maya	-8.7	9.1	3.3	13, 14
Altar de Sacrificios	Maya	-9.9	8.2	3.5	13, 14
Altar de Sacrificios	Maya	-8.7	8.6	3.3	13, 14
Altar de Sacrificios	Maya	-9.6	8.4	3.3	13, 14
Altun Ha	Maya	-8.3	9.9	3.3	36
Altun Ha	Maya	-8.5	9.5	3.3	36
Altun Ha	Maya	-11.4	10.9	3.4	36
Altun Ha	Maya	-14.8	10.4	3.3	36
Altun Ha	Maya	-14.3	10.6	3.3	36
Altun Ha	Maya	-9.0	10.3	3.2	36
Altun Ha	Maya	-16.3	11.9	3.4	36
Altun Ha	Maya	-10.5	12.0	3.4	36
Altun Ha	Maya	-9.5	9.2	3.4	36
Altun Ha	Maya	-13.3	10.2	3.3	36
Altun Ha	Maya	-10.2	9.0	3.3	36
Altun Ha	Maya	-14.3	-	3.6	36
Altun Ha	Maya	-9.1	13.3	3.4	36
Altun Ha	Maya	-13.7	10.9	3.4	36
Altun Ha	Maya	-12.3	11.4	3.3	36
Altun Ha	Maya	-12.2	-	3.4	36
Altun Ha	Maya	-16.2	10.4	3.3	36
Altun Ha	Maya	-13.5	10.7	3.3	36
Altun Ha	Maya	-10.8	12.4	3.4	36
Altun Ha	Maya	-11.9	10.8	3.3	36
Altun Ha	Maya	-14.1	10.6	3.3	36
Altun Ha	Maya	-15.3	11.0	3.4	36
Altun Ha	Maya	-12.3	10.6	3.3	36
Altun Ha	Maya	-8.6	10.9	3.3	36
Altun Ha	Maya	-12.1	10.4	3.3	36
Altun Ha	Maya	-9.8	11.3	3.3	36
Altun Ha	Maya	-13.5	9.8	3.4	36
Altun Ha	Maya	-12.7	10.3	3.4	36
Altun Ha	Maya	-10.1	10.6	3.4	36
Altun Ha	Maya	-11.9	9.6	3.3	36
Altun Ha	Maya	-12.8	10.9	3.4	36
Altun Ha	Maya	-14.0	10.3	3.5	36
Altun Ha	Maya	-8.5	11.1	3.4	36
Altun Ha	Maya	-10.5	13.0	3.3	36
Altun Ha	Maya	-9.3	10.4	3.4	36
Altun Ha	Maya	-10.9	10.4	3.4	36
Altun Ha	Maya	-10.8	10.5	3.4	36
Altun Ha	Maya	-10.1	10.8	3.4	36
Altun Ha	Maya	-11.1	-	3.6	36
Altun Ha	Maya	-13.2	10.1	3.4	36
Altun Ha	Maya	-8.9	10.5	3.3	36
Altun Ha	Maya	-14.6	10.5	3.4	36

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Altun Ha	Maya	-12.4	10.8	3.3	36
Altun Ha	Maya	-7.6	12.6	3.3	36
Altun Ha	Maya	-11.2	11.3	3.4	36
Altun Ha	Maya	-12.7	10.0	3.6	36
Altun Ha	Maya	-11.8	10.8	3.3	36
Altun Ha	Maya	-11.9	11.2	3.4	36
Altun Ha	Maya	-13.7	9.7	3.3	36
Altun Ha	Maya	-12.7	11.7	3.4	36
Altun Ha	Maya	-15.0	-	3.2	36
Altun Ha	Maya	-12.8	9.9	3.2	36
Altun Ha	Maya	-12.0	9.9	3.2	36
Altun Ha	Maya	-13.1	10.0	3.1	36
Altun Ha	Maya	-11.3	10.2	3.3	36
Altun Ha	Maya	-12.9	9.5	3.3	36
Altun Ha	Maya	-10.0	10.1	3.4	36
Arroyo de Piedra	Maya	-9.7	2.3	3.2	46
Baking Pot	Maya	-11.4	9.4	3.4	13, 14
Baking Pot	Maya	-11.5	9.4	3.4	13, 14
Baking Pot	Maya	-12.4	7.0	3.6	13, 14
Baking Pot	Maya	-9.5	10.0	3.4	13, 14
Baking Pot	Maya	-11.6	9.0	3.4	13, 14
Baking Pot	Maya	-8.9	8.5	3.3	13, 14
Baking Pot	Maya	-11.7	11.3	3.4	13, 14
Baking Pot	Maya	-11.2	7.6	3.4	13, 14
Barton Ramie	Maya	-12.4	8.5	3.4	13, 14
Barton Ramie	Maya	-8.5	9.0	3.3	13, 14
Barton Ramie	Maya	-10.0	8.8	3.3	13, 14
Barton Ramie	Maya	-12.0	8.3	3.3	13, 14
Barton Ramie	Maya	-10.4	9.5	3.3	13, 14
Barton Ramie	Maya	-12.3	8.6	3.2	13, 14
Barton Ramie	Maya	-7.9	8.4	3.4	13, 14
Barton Ramie	Maya	-9.1	8.9	3.3	13, 14
Barton Ramie	Maya	-10.9	8.7	3.2	13, 14
Barton Ramie	Maya	-11.8	8.9	3.3	13, 14
Barton Ramie	Maya	-12.8	9.0	3.4	13, 14
Barton Ramie	Maya	-13.3	8.9	3.4	13, 14
Barton Ramie	Maya	-13.3	8.8	3.4	13, 14
Barton Ramie	Maya	-13.0	8.1	3.4	13, 14
Barton Ramie	Maya	-8.8	8.7	3.3	13, 14
Barton Ramie	Maya	-11.1	8.2	3.2	13, 14
Barton Ramie	Maya	-13.1	8.5	3.3	13, 14
Barton Ramie	Maya	-10.6	9.2	3.4	13, 14
Barton Ramie	Maya	-10.8	9.4	3.3	13, 14
Barton Ramie	Maya	-12	8.8	3.3	13, 14
Barton Ramie	Maya	-10.8	8.3	3.4	13, 14
Barton Ramie	Maya	-11.3	9.1	3.4	13, 14
Barton Ramie	Maya	-11.1	8.9	3.3	13, 14
Barton Ramie	Maya	-10.9	8.4	3.4	13, 14

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Barton Ramie	Maya	-11.1	8.7	3.3	13, 14
Barton Ramie	Maya	-11.4	9.5	3.4	13, 14
Barton Ramie	Maya	-12.2	9.4	3.2	13, 14
Barton Ramie	Maya	-11.2	8.5	3.4	13, 14
Barton Ramie	Maya	-8.4	8.9	3.4	13, 14
Barton Ramie	Maya	-11.2	8.7	3.4	13, 14
Barton Ramie	Maya	-9.7	9.5	3.4	13, 14
Barton Ramie	Maya	-10.4	9.8	3.3	13, 14
Cahal Pech	Maya	-13.0	8.4	3.6	21
Cahal Pech	Maya	-11.3	7.7	3.3	21
Cahal Pech	Maya	-13.8	8.4	3.3	21
Chau Hiix	Maya	-7.6	11.0	3.4	18
Chau Hiix	Maya	-13.8	10.3	3.4	18
Chau Hiix	Maya	-13.3	12.4	3.5	18
Chau Hiix	Maya	-12.0	11.4	3.4	18
Chau Hiix	Maya	-12.8	11.2	3.4	18
Chau Hiix	Maya	-14.4	12.1	3.4	18
Chau Hiix	Maya	-9.2	9.5	3.3	18
Chau Hiix	Maya	-14.8	11.7	3.3	18
Chau Hiix	Maya	-12.1	10.6	3.4	18
Chau Hiix	Maya	-11.1	11.2	3.4	18
Chau Hiix	Maya	-15.6	11.4	3.4	18
Chau Hiix	Maya	-13.3	10.8	3.4	18
Chau Hiix	Maya	-13.1	11.2	3.4	18
Chau Hiix	Maya	-11.7	10.1	3.4	18
Chau Hiix	Maya	-10.3	11.1	3.4	18
Chau Hiix	Maya	-11.5	11.7	3.4	18
Chau Hiix	Maya	-10.1	10.3	3.4	18
Chau Hiix	Maya	-10.8	11.4	3.4	18
Chau Hiix	Maya	-8.5	9.0	3.4	18
Chau Hiix	Maya	-10.8	11.3	3.4	18
Chau Hiix	Maya	-9.6	10.3	3.4	18
Chau Hiix	Maya	-8.3	11.0	3.4	18
Chau Hiix	Maya	-8.7	9.7	3.4	18
Chau Hiix	Maya	-7.9	9.7	3.4	18
Chau Hiix	Maya	-8.8	9.1	3.4	18
Chau Hiix	Maya	-8.0	8.4	3.4	18
Chau Hiix	Maya	-8.3	10.2	3.4	18
Chau Hiix	Maya	-9.8	10.6	3.4	18
Chau Hiix	Maya	-8.9	10.4	3.4	18
Copan	Maya	-10.1	7.6	3.3	13, 14
Copan	Maya	-9.7	7.7	3.3	13, 14
Copan	Maya	-9.1	6.9	3.3	13, 14
Copan	Maya	-10.6	7.2	3.3	13, 14
Copan	Maya	-9.5	7.5	3.3	13, 14
Copan	Maya	-10.2	8.0	3.4	13, 14
Copan	Maya	-12.4	9.9	3.3	13, 14
Copan	Maya	-9.5	7.7	3.4	13, 14

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Copan	Maya	-10.3	7.9	3.3	13, 14
Copan	Maya	-10.9	7.2	3.3	13, 14
Copan	Maya	-9.0	6.7	3.2	13, 14
Copan	Maya	-11.9	7.4	3.5	13, 14
Copan	Maya	-9.0	7.1	3.3	13, 14
Copan	Maya	-9.1	7.7	3.3	13, 14
Copan area	Maya	-10.6	7.6	3.4	13, 14
Copan area	Maya	-10.9	9.1	3.4	13, 14
Copan area	Maya	-9.7	8.1	3.3	13, 14
Copan area	Maya	-10.7	7.9	3.3	13, 14
Copan area	Maya	-10.0	8.1	3.2	13, 14
Copan area	Maya	-11.1	7.2	3.3	13, 14
Copan area	Maya	-10.3	8.7	3.3	13, 14
Copan area	Maya	-8.8	9.8	3.5	13, 14
Copan area	Maya	-8.9	10.4	3.3	13, 14
Copan area	Maya	-8.9	8.9	3.3	13, 14
Copan area	Maya	-8.7	9.1	3.3	13, 14
Copan area	Maya	-9.9	8.2	3.4	13, 14
Copan area	Maya	-8.7	8.6	3.4	13, 14
Copan area	Maya	-10.3	7.4	3.4	13, 14
Copan area	Maya	-11.0	7.6	3.3	13, 14
Copan area	Maya	-10.0	7.8	3.4	13, 14
Dos Pilas	Maya	-7.0	9.3	3.1	44, 45, 46
Dos Pilas	Maya	-8.2	8.2	3.2	44, 45, 46
Dos Pilas	Maya	-9.1	9.7	3.2	44, 45, 46
Dos Pilas	Maya	-8.6	7.7	3.3	44, 45, 46
Dos Pilas	Maya	-9.8	9.1	3.2	44, 45, 46
Dos Pilas	Maya	-9.7	7.5	3.2	44, 45, 46
Dos Pilas	Maya	-9.7	10.3	3.2	44, 45, 46
Dos Pilas	Maya	-9.6	11.0	3.1	44, 45, 46
Dos Pilas	Maya	-7.7	10.6	3.1	44, 45, 46
Dos Pilas	Maya	-9.2	9.9	3.4	44, 45, 46
Dos Pilas	Maya	-9.7	10.2	3.2	44, 45, 46
Dos Pilas	Maya	-8.5	8.9	3.2	44, 45, 46
Dos Pilas	Maya	-9.5	8.3	3.3	44, 45, 46
Dos Pilas	Maya	-8.6	10.1	3.3	44, 45, 46
Dos Pilas	Maya	-11.3	10.2	3.1	44, 45, 46
Dos Pilas	Maya	-8.2	10.3	3.1	44, 45, 46
Dos Pilas	Maya	-8.3	11.1	3.2	44, 45, 46
Dos Pilas	Maya	-10.1	9.9	3.0	44, 45, 46
Dos Pilas	Maya	-9.1	9.7	3.2	44, 45, 46
Dos Pilas	Maya	-8.9	8.7	3.2	46
Dos Pilas	Maya	-9.6	9.5	3.1	46
Dos Pilas	Maya	-8.6	11.6	3.2	46
Dos Pilas	Maya	-9.0	9.1	3.1	46
Dos Pilas	Maya	-7.8	12.4	3.1	46
Dos Pilas	Maya	-8.6	10.5	3.1	46
Dos Pilas	Maya	-8.6	10.1	3.2	46

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Dos Pilas	Maya	-8.4	11.6	3.3	46
Dos Pilas	Maya	-12.0	12.7	2.8	46
Dos Pilas	Maya	-11.2	9.7	3.3	46
Dos Pilas	Maya	-8.6	9.1	3.1	46
Dos Pilas	Maya	-8.8	10.4	3.1	46
Holmul	Maya	-8.7	8.7	3.4	13, 14
Holmul	Maya	-7.8	10.2	3.4	13, 14
Holmul	Maya	-9.2	9.3	3.4	13, 14
Holmul	Maya	-10.8	8.6	3.3	13, 14
Holmul	Maya	-8.2	9.1	3.4	13, 14
Holmul	Maya	-8.3	9.7	3.4	13, 14
Holmul	Maya	-10.9	8.5	3.4	13, 14
Holmul	Maya	-9.4	9.4	3.3	13, 14
Holmul	Maya	-11.3	10.9	3.4	13, 14
Holmul	Maya	-11.6	7.6	3.3	13, 14
Holmul	Maya	-7.9	10.0	3.4	13, 14
Holmul	Maya	-8.9	9.3	3.4	13, 14
Holmul	Maya	-9.0	8.8	3.4	13, 14
Itzan	Maya	-9.1	7.1	3.1	44, 45, 46
Itzan	Maya	-8.7	8.9	3.3	44, 45, 46
Itzan	Maya	-9.5	9.1	3.2	44, 45, 46
Itzan	Maya	-9.2	7.3	3.2	44, 45, 46
Itzan	Maya	-9.4	7.4	3.2	44, 45, 46
K'axob	Maya	-16.2	9.7	3.2	15
K'axob	Maya	-14.8	9.0	3.3	15
K'axob	Maya	-	9.2	3	15
K'axob	Maya	-14.0	9.5	3	15
K'axob	Maya	-15.2	9.2	3.3	15
K'axob	Maya	-14.7	8.9	2.8	15
K'axob	Maya	-14.8	9.6	2.9	15
Lamanai	Maya	-14.5	10.5	3.6	33, 35
Lamanai	Maya	-9	10.1	3.5	8, 33, 35
Lamanai	Maya	-8.0	9.5	3.6	8, 33, 35
Lamanai	Maya	-9.8	11.4	3.2	8, 33, 35
Lamanai	Maya	-8.1	11.5	3.3	33, 35
Lamanai	Maya	-8.9	9.7	3.1	33, 35
Lamanai	Maya	-9.2	-	3.6	33, 35
Lamanai	Maya	-9.1	9.9	3.5	8, 33, 35
Lamanai	Maya	-10.2	9.6	3.3	8, 33, 35
La Paciencia	Maya	-10.3	9.6	3.2	46
Pacbitun	Maya	-9.2	8.1	3.3	8, 32, 34
Pacbitun	Maya	-7.3	9.1	3.3	8, 32, 34
Pacbitun	Maya	-8.3	8.9	3.3	8, 32, 34
Pacbitun	Maya	-9.1	10.1	3.3	8, 34
Pacbitun	Maya	-9.3	9.6	3.3	8, 34
Pacbitun	Maya	-7.9	9.8	3.3	8, 34
Pacbitun	Maya	-9.6	8.4	3.5	8, 34
Pacbitun	Maya	-9.9	8.7	3.4	34

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Pacbitun	Maya	-9.6	8.8	3.3	8, 32(?), 34
Pacbitun	Maya	-12.1	8.8	3.4	8, 32(?), 34
Pacbitun	Maya	-11.1	9.7	3.4	8, 32(?), 34
Pacbitun	Maya	-12.7	10.6	3.4	8, 32(?), 34
Pacbitun	Maya	-10.4	9.3	3.3	8, 32(?), 34
Pacbitun	Maya	-10.3	9.6	3.3	8, 32(?), 34
Pacbitun	Maya	-10.9	9.2	3.3	8, 32(?), 34
Pacbitun	Maya	-10.4	9.8	3.4	8, 32(?), 34
Pacbitun	Maya	-13.5	7.6	3.3	8, 32(?), 34
Pacbitun	Maya	-13.7	10.0	3.5	8, 34
Pacbitun	Maya	-11.5	8.4	3.6	8, 34
Pacbitun	Maya	-11.8	8.0	3.5	8, 34
Punta de Chimino	Maya	-8.4	10.5	3.1	46
Seibal	Maya	-11.2	8.8	3.3	44, 45, 46
Seibal	Maya	-8.5	7.4	3	44, 45, 46
Seibal	Maya	-8.7	7.2	3.1	44, 45, 46
Seibal	Maya	-9.3	9.9	3.2	44, 45, 46
Seibal	Maya	-10.3	10.8	3.2	44, 45, 46
Seibal	Maya	-7.4	10.0	3.2	44, 45, 46
Seibal	Maya	-10.1	10.3	3.2	44, 45, 46
Seibal	Maya	-9.2	9.9	3	44, 45, 46
Seibal	Maya	-10.6	10.5	3.1	44, 45, 46
Seibal	Maya	-9.0	8.9	3.1	44, 45, 46
Seibal	Maya	-8.6	9.3	3	44, 45, 46
Seibal	Maya	-8.2	9.3	3.1	44, 45, 46
Seibal	Maya	-10.8	8.3	3.1	44, 45, 46
Seibal	Maya	-8.1	9.9	3.1	44, 45, 46
Seibal	Maya	-8.5	9.1	3.2	44, 45, 46
Seibal	Maya	-9.4	11.0	3.3	44, 45, 46
Seibal	Maya	-8.0	8.55	3.1	44, 45, 46
Seibal	Maya	-10.4	8.9	3.5	44, 45, 46
Seibal	Maya	-8.7	9.5	3.1	44, 45, 46
Seibal	Maya	-9.3	9.3	3.1	44, 45, 46
Seibal	Maya	-9.3	9.0	3.1	44, 45, 46
Seibal	Maya	-10	8.4	3.2	44, 45, 46
Seibal	Maya	-8.3	9.7	3.1	44, 45, 46
Seibal	Maya	-10	9.9	3.4	44, 45, 46
Seibal	Maya	-8.6	8.7	3.3	44, 45, 46
Seibal	Maya	-9.2	8.3	3.3	44, 45, 46
Seibal	Maya	-11.1	9.6	3.4	44, 45, 46
Seibal	Maya	-7.9	11.3	3.2	44, 45, 46
Seibal	Maya	-8.8	9.5	3.3	44, 45, 46
Seibal	Maya	-10.3	8.8	3.6	44, 45, 46
Seibal	Maya	-11.8	9.6	3.2	44, 45, 46
Seibal	Maya	-8.0	11.4	3.1	44, 45, 46
Seibal	Maya	-10.7	8.7	3.4	44, 45, 46
Seibal	Maya	-11.4	9.7	3.2	44, 45, 46
Seibal	Maya	-8.7	9.0	3.3	13, 14

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Seibal	Maya	-10.0	10.6	3.3	13, 14
Seibal	Maya	-11.6	9.6	3.4	13, 14
Seibal	Maya	-9.7	7.9	3.4	13, 14
Seibal	Maya	-9.6	9.1	3.3	13, 14
Seibal	Maya	-11.1	8.6	3.4	13, 14
Seibal	Maya	-10.0	11.0	3.3	13, 14
Seibal	Maya	-10.9	8.9	3.5	13, 14
Seibal	Maya	-8.8	9.9	3.5	13, 14
Seibal	Maya	-8.3	9.8	3.6	13, 14
Seibal	Maya	-9.3	10.4	3.3	13, 14
Seibal	Maya	-9.4	9.7	3.3	13, 14
Seibal	Maya	-8.1	10.1	3.3	13, 14
Seibal	Maya	-9.7	10	3.4	13, 14
Seibal	Maya	-11.2	9.9	3.5	13, 14
Seibal	Maya	-9.2	8.8	3.4	13, 14
Seibal	Maya	-8.4	10.1	3.3	13, 14
Seibal	Maya	-8.5	10.5	3.1	13, 14
Seibal	Maya	-10.3	9.4	3	13, 14
Tamarindito	Maya	-9.1	9.8	3.2	46
Tamarindito	Maya	-8.9	10.2	3.3	46
Tamarindito	Maya	-12.6	8.8	3.2	46
Tamarindito	Maya	-9.7	10.9	3.3	46
Uaxactun	Maya	-9.7	8.6	3.4	13, 14
Uaxactun	Maya	-9.6	8.9	3.4	13, 14
Uaxactun	Maya	-9.8	8.9	3.5	13, 14
Uaxactun	Maya	-11.3	9.7	3.5	13, 14
Uaxactun	Maya	-11.3	11.0	3.4	13, 14
<i>Maya Islands</i>					
Marco Gonzalez	Maya	-6.0	10.4	3.4	43
Marco Gonzalez	Maya	-7.8	11.9	3.3	43
Marco Gonzalez	Maya	-6.1	10.7	3.2	43
Marco Gonzalez	Maya	-6.0	12.1	3.2	43
Marco Gonzalez	Maya	-5.6	11.8	3.2	43
Marco Gonzalez	Maya	-6.2	11.6	3.2	43
Marco Gonzalez	Maya	-6.8	11.6	3.3	43
Marco Gonzalez	Maya	-6.0	7.1	3.3	43
Marco Gonzalez	Maya	-7.0	11.0	3.3	43
Marco Gonzalez	Maya	-7.7	9.2	3.6	43
Marco Gonzalez	Maya	-7.1	10.0	3.3	43
Marco Gonzalez	Maya	-9.2	11.0	3.2	43
Marco Gonzalez	Maya	-6.7	10.4	3.4	43
Marco Gonzalez	Maya	-9.9	9.7	3.5	43
Marco Gonzalez	Maya	-8.2	10.9	3.4	43
Marco Gonzalez	Maya	-7.3	11.5	3.3	43
Marco Gonzalez	Maya	-8.4	10.0	3.2	43
Marco Gonzalez	Maya	-6.9	10.8	3.3	43
Marco Gonzalez	Maya	-9.1	11.2	3.2	43
Marco Gonzalez	Maya	-7.7	10.9	3.2	43

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Marco Gonzalez	Maya	-7.9	10.4	3.5	43
Marco Gonzalez	Maya	-7.4	8.2	3.4	43
Mojo Cay	Maya	-8.8	10.3	3.3	19
Mojo Cay	Maya	-8.9	10.4	3.2	19
Mojo Cay	Maya	-8.7	9.7	3.3	19
Mojo Cay	Maya	-8.0	11.1	3.3	19
Mojo Cay	Maya	-8.0	10.4	3.3	19
Mojo Cay	Maya	-8.8	10.2	3.3	19
Mojo Cay	Maya	-8.2	10.8	3.3	19
Mojo Cay	Maya	-8.3	8.1	3.3	19
San Pedro	Maya	-6.0	12.6	3.3	43
San Pedro	Maya	-7.3	10.9	3.2	43
San Pedro	Maya	-8.2	10.0	3.6	43
San Pedro	Maya	-6.5	9.8	3.3	43
San Pedro	Maya	-7.6	9.1	3.2	43
San Pedro	Maya	-6.6	8.9	3.6	43
San Pedro	Maya	-6.1	9.4	3.3	43
San Pedro	Maya	-6.3	9.7	3.3	43
San Pedro	Maya	-6.6	9.2	3.2	43
San Pedro	Maya	-7.6	10.5	3.3	43
San Pedro	Maya	-6.7	10.9	3.3	43
San Pedro	Maya	-5.7	10.7	3.3	43
San Pedro	Maya	-8.8	11.0	3.4	43
San Pedro	Maya	-8.2	11.3	3.4	43
San Pedro	Maya	-8.8	11.2	3.3	43
San Pedro	Maya	-6.7	9.8	3.2	43
San Pedro	Maya	-9.5	11.5	3.3	43
San Pedro	Maya	-9.8	11.5	3.3	43
San Pedro	Maya	-9.2	10.2	3.2	43
San Pedro	Maya	-8.5	10.3	3.5	43
San Pedro	Maya	-5.0	13.0	3.3	43
San Pedro	Maya	-5.7	10.3	3.2	43
San Pedro	Maya	-6.8	9.3	3.4	43
San Pedro	Maya	-6.2	10.2	3.3	43
San Pedro	Maya	-5.7	8.8	3.2	43
San Pedro	Maya	-6.0	9.0	3.3	43
San Pedro	Maya	-5.6	9.3	3.3	43
San Pedro	Maya	-5.4	10.1	3.2	43
San Pedro	Maya	-5.8	10.0	3.3	43
San Pedro	Maya	-5.8	9.3	3.3	43
San Pedro	Maya	-8.8	9.4	3.4	43
San Pedro	Maya	-5.9	9.7	3.2	43
San Pedro	Maya	-7.0	9.3	3.4	43
San Pedro	Maya	-6.0	9.7	3.3	43
San Pedro	Maya	-5.8	9.8	3.4	43
San Pedro	Maya	-8.6	9.5	3.3	43
San Pedro	Maya	-6.0	9.5	3.4	43
San Pedro	Maya	-6.2	10.5	3.3	43

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
San Pedro	Maya	-7.4	9.4	3.3	43
San Pedro	Maya	-7.0	9.5	3.3	43
San Pedro	Maya	-7.6	10.0	3.4	43
San Pedro	Maya	-6.3	9.9	3.3	43
San Pedro	Maya	-6.0	12.6	3.3	43
San Pedro	Maya	-7.3	10.9	3.2	43
<i>Maya Highlands</i>					
Kaminaljuyu	Maya	-9.8 ^e	-	3.4	47
Kaminaljuyu	Maya	-9.9 ^{e,f}	8.9 ^{e,f}	2.9	47
Kaminaljuyu	Maya	-8.6 ^e	-	3.2	47
Kaminaljuyu	Maya	-9.1 ^{e,f}	-	3.2	47
Kaminaljuyu	Maya	-9.8 ^e	-	2.8	47
Kaminaljuyu	Maya	-9.8 ^{e,f}	9.5 ^{e,f}	3.0	47
Kaminaljuyu	Maya	-10.9 ^{e,f}	8.3 ^{e,f}	2.9	47
Kaminaljuyu	Maya	-9.3 ^{e,f}	8.8 ^{e,f}	3.0	47
Kaminaljuyu	Maya	-12.1 ^{e,f}	13.4 ^{e,f}	3.2	47
Kaminaljuyu	Maya	-9.5 ^e	8.9 ^e	2.9	47
<i>Pacific Coast</i>					
Huanacastal	Mokaya	-21.2	-	3.6	2, 7
La Blanca	Mokaya	-13.3	-	3.3	2, 6, 16
La Blanca	Mokaya	-13.3	8.8	3.2	2, 6, 16
La Blanca	Mokaya	-10.8	9.3	3.2	2, 6, 16
Las Morenas	n.r.	-11.3	8.5	2.8	2, 6, 30
Paso de la Amada	Mokaya	-21.5	-	3.3	2
Rio Arriba	n.r.	-9.5	9.1	2.8	2, 6, 30
Tlacuachero	Chantuto	-11.8	9.1	2.9	2, 6, 30
Tlacuachero	n.r.	-9.3	8.6	3.0	2, 6, 29
Zapotillo	n.r.	-9.4	8.7	2.9	2, 6, 29
<i>Lower Central America</i>					
Cerro Brujo	n.r.	-13.2	8.3	3.2	19
Cerro Brujo	n.r.	-13.4	8.7	3.3	19
Cerro Brujo	n.r.	-14.8	8.8	3.3	19
Cerro Brujo	n.r.	-12.8	9.6	3.3	19
Cerro Brujo	n.r.	-12.1	9.2	3.3	19
Cerro Mangote	n.r.	-14.4	7.4	3.4	19, 20
Cerro Mangote	n.r.	-14.1	6.6	3.4	1, 19, 20
Cerro Mangote	n.r.	-14.6	6.6	3.5	19, 20
Cerro Mangote	n.r.	-13.7	7.6	3.4	19, 20
Cerro Mangote	n.r.	-12.9	7.8	3.4	19, 20
Cerro Mangote	n.r.	-12.8	7.4	3.4	19, 20
Cerro Mangote	n.r.	-13.7	7.7	3.4	19, 20
Cerro Mangote	n.r.	-13.8	7.7	3.6	19, 20
Cerro Mangote	n.r.	-13.8	7.8	3.4	19, 20
Cerro Mangote	n.r.	-13.5	7.7	3.3	19, 20
Cerro Mangote	n.r.	-14.2	7.7	3.2	19, 20
Cerro Mangote	n.r.	-12.5	-	3.1	19, 20
Cerro Mangote	n.r.	-13.7	7.3	3.4	1, 19, 20
Duarte-La Guinea	n.r.	-10.2	9.0	3.3	1, 19

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
El Cano	n.r.	-9.9	7.3	3.3	19
El Cano	n.r.	-11.3	7.7	3.3	19
El Cano	n.r.	-10.3	8.8	3.2	19
El Cano	n.r.	-10.8	8.8	3.2	19
El Molino	n.r.	-10.7	7.0	3.3	19
El Molino	n.r.	-10.0	6.9	3.2	19
El Molino	n.r.	-10.3	7.8	3.2	19
El Molino	n.r.	-10.1	7.6	3.3	19
El Molino	n.r.	-10.2	7.0	3.2	19
El Molino	n.r.	-9.8	6.3	3.3	19
El Molino	n.r.	-10.0	7.3	3.2	19
El Molino	n.r.	-10.8	6.9	3.2	19
El Molino	n.r.	-10.1	7.7	3.2	19
Giron	n.r.	-9.5	7.1	3.2	19
Giron	n.r.	-10.7	9.4	3.2	19
Giron	n.r.	-12.0	8.7	3.2	19
Guayabo de Bagaces	n.r.	-10.0	10.2	3.5	19
Herramientas	n.r.	-7.9	8.0	3.3	19
Herramientas	n.r.	-8.0	9.7	3.4	19
Herramientas	n.r.	-9.1	9.7	3.5	19
La Mula-Sarigua	n.r.	-10.4	11.7	3.5	19, 20
La Mula-Sarigua	n.r.	-10.3	12.6	3.2	19, 20
La Mula-Sarigua	n.r.	-10.9	12.2	3.3	19, 20
La Mula-Sarigua	n.r.	-13.7	11.0	3.3	19, 20
La Mula-Sarigua	n.r.	-13.0	10.1	3.3	19, 20
La Mula-Sarigua	n.r.	-11.7	12.5	3.5	19, 20
La Pitahaya	n.r.	-9.9	9.8	3.2	19
La Pitahaya	n.r.	-11.5	11.0	3.2	19
La Pitahaya	n.r.	-11.2	10.7	3.3	19
La Pitahaya	n.r.	-11.5	10.9	3.3	19
La Pitahaya	n.r.	-12.3	9.8	3.2	19
La Pitahaya	n.r.	-11.8	10.8	3.2	19
La Pitahaya	n.r.	-9.4	10.3	3.3	19
La Pitahaya	n.r.	-14.4	6.7	3.2	19
La Pitahaya	n.r.	-14.4	6.4	3.2	19
Las Marias	n.r.	-8.8	13.4	3.3	19
Las Marias	n.r.	-9.5	13.5	3.3	19
Las Marias	n.r.	-9.6	14.1	3.2	19
Las Marias	n.r.	-9.4	14.0	3.2	19
Las Marias	n.r.	-9.6	10.1	3.2	19
Nacascolo	n.r.	-8.1	11	3.3	19
Nacascolo	n.r.	-8.3	10.9	3.2	19
Nacascolo	n.r.	-9.8	12.2	3.2	19
Nacascolo	n.r.	-8.9	11.5	3.2	19
Nacascolo	n.r.	-9.9	11.4	3.4	19
Nacascolo	n.r.	-9.1	10.9	3.2	1, 19
Nacascolo	n.r.	-11.4	10.9	3.6	1, 19
Nacascolo	n.r.	-9.3	12.3	3.2	19

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Nacasclo	n.r.	-10.5	9.7	3.6	19
Nacasclo	n.r.	-7.3	9.6	3.2	19
Nacasclo	n.r.	-8.7	10.3	3.3	19
Nacasclo	n.r.	-9.2	10.8	3.3	19
Nacasclo	n.r.	-8.9	10.5	3.2	19
Nacasclo	n.r.	-12.0	-	3.4	19
Nacasclo	n.r.	-11.6	6.6	3.3	19
Sitio Sierra	n.r.	-11.6	8.9	3.4	19
Sitio Sierra	n.r.	-10.8	7.4	3.4	19
Sitio Sierra	n.r.	-10.7	8.2	3.2	19, 20
Sitio Sierra	n.r.	-10.3	7.9	3.3	19, 20
Sitio Sierra	n.r.	-10.8	9.1	3.2	1, 19, 20
Sitio Sierra	n.r.	-9.9	8.4	3.3	19, 20
Sitio Sierra	n.r.	-11.6	7.6	3	19, 20
Sitio Sierra	n.r.	-11.0	9.0	3.2	19
Sitio Sierra	n.r.	-11.1	7.5	3.3	19
Sitio Sierra	n.r.	-10.6	7.8	3.2	19
Sitio Sierra	n.r.	-10.5	8.1	3.2	19
Sitio Sierra	n.r.	-9.9	9.5	3.3	19
Sitio Sierra	n.r.	-11.2	8.9	3.5	19
Sitio Sierra	n.r.	-11.3	7.8	3.3	19
Sitio Sierra	n.r.	-9.5	9.0	3.3	19, 20
Sitio Sierra	n.r.	-9.7	8.7	3.3	19
Sitio Sierra	n.r.	-10.4	8.6	3.4	19, 20
Sitio Sierra	n.r.	-10.5	7.8	3.4	19
Sitio Sierra	n.r.	-12.4	7.3	3.3	19, 20
Sitio Sierra	n.r.	-13.6	8.7	3.2	19, 20
Sitio Sierra	n.r.	-13.2	8.6	3.2	19
Sitio Sierra	n.r.	-13.3	8.1	3.2	19
Sitio Sierra	n.r.	-13.6	7.9	3.2	19
Sitio Sierra	n.r.	-11.8	8.4	3.2	19
Sitio Sierra	n.r.	-11.8	8.6	3.3	19, 20
Sitio Sierra	n.r.	-11.6	9.0	3.3	19, 20
Sitio Sierra	n.r.	-12.5	10.1	3.2	19, 20
Sitio Sierra	n.r.	-9.6	7.4	3.2	19
Sitio Sierra	n.r.	-12.8	9.7	3.3	1, 19
Sitio Sierra	n.r.	-10.6	9.3	3.6	19
Sitio Sierra	n.r.	-12.3	8.8	3.4	19
Vidor	n.r.	-9.8	11.5	3.3	19
Vidor	n.r.	-8.7	10.1	3.2	19
Vidor	n.r.	-8.2	10.9	3.2	19
Vidor	n.r.	-8.9	11.1	3.2	19
Vidor	n.r.	-8.0	10.8	3.2	19
Vidor	n.r.	-8.7	11.7	3.2	19
Vidor	n.r.	-9.4	7.3	3.2	19
Vigilante Alta	n.r.	-7.7	10.0	3.2	19
Vigilante Alta	n.r.	-9.7	9.3	3.3	19
Vigilante Alta	n.r.	-10.4	7.6	3.3	19

Appendix 4.1. continued

Site	Culture	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^b	Reference ^c
Vigilante Alta	n.r.	-7.2	9.7	3.1	19
Vigilante Alta	n.r.	-9.1	7.9	3.2	19
Vigilante Alta	n.r.	-8.9	9.9	3.2	19

Notes:

^aWest Indies are not included.

^bReported C/N for all human collagen samples in this table fall between 2.8 and 3.6.

^cReference codes correspond to those in Figure 1: 1 = Amrose and Norr 1992; 2 = Blake et al. 1992; 3 = Blitz 1995; 4 = Chase and Chase 2000; 5 = Chase, Chase, and White 2001; 6 = Chisholm and Blake 2006; 7 = Clark et al. 1987; 8 = Coyston, White, and Schwarcz 1999; 9 = DeNiro and Epstein 1981; 10 = DeNiro and Epstein 1986; 11 = Farnsworth et al. 1985; 12 = Friedman and Gleason 1984; 13 = Gerry 1993; 14 = Gerry and Krueger 1997; 15 = Henderson 2003; 16 = Love 1989; 17 = Mansell et al. 2006; 18 = Metcalfe et al. 2009; 19 = Norr 1991; 20 = Norr 1995; 21 = Powis et al. 1999; 22 = Reed 1994; 23 = Reed 1998; 24 = Reed 1999; 25 = Reed and Whittington 1995; 26 = Tykot 2002; 27 = Tykot et al. 1996; 28 = van der Merwe et al. 2000; 29 = Voorhies 1976; 30 = Voorhies n.d.; 31 = White 1986; 32 = White 1997; 33 = White and Schwarcz 1989; 34 = White, Healy, and Schwarcz 1993; 35 = White, Wright, and Pendergast 1994; 36 = White et al. 2001; 37 = White et al. 2004; 38 = Whittington and Reed 1994; 39 = Whittington and Reed 1996; 40 = Whittington and Reed 1997; 41 = Whittington and Reed 1998; 42 = Whittington and Tykot 2000; 43 = Williams, White, and Longstaffe 2005; 44 = Wright 1994; 45 = Wright 1997; 46 = Wright 2006; 47 = Wright and Schwarcz 1999.

^dZapotec barrio at Teotihuacan

^eDentine collagen

^fReplicate measurements for an individual were averaged.

[†]C/N for these samples are: 3.5, 3.5, 3.4, 3.4, 3.5, 3.6, 3.6, 3.5 (DeNiro and Epstein 1986). It is not clear which C/N corresponds to each sample.

Appendix 4.2. Isotopic ratios of modern native Middle American^a economic plant resources

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
C4 taxa							
<i>Amaranthus spp.</i>	Amaranth	Oaxaca	Seed cake	-12.7	3.1	2.4	This study, WO89
<i>Amaranthus spp.</i>	Amaranth	Oaxaca	Seed cake	-12.9	1.8	1.7	This study, WO84
<i>Zea mays</i>	Maize	Gulf Lowlands	Seed	-10.4	6.2	1.9	This study, SV31
<i>Zea mays</i>	Maize (blanco)	Gulf Lowlands	Seed	-10.4	2.6	1.5	This study, SV38
<i>Zea mays</i>	Maize	L. Central America	-	-9.7	-	3	
<i>Zea mays</i>	Maize	L. Central America	-	-9.6	1.9	3	
<i>Zea mays</i>	Maize	L. Central America	-	-10.1	-	3	
<i>Zea mays</i>	Maize	L. Central America	-	-9.8	1.4	3	
<i>Zea mays</i>	Dent maize	Central Mexico	Seed	-9.8	-	4 ^f	
<i>Zea mays</i>	Dent maize	Central Mexico	Seed	-12.0	-	4 ^f	
<i>Zea mays</i>	Flint maize	Central Mexico	Seed	-10.5	-	4 ^f	
<i>Zea mays</i>	Flint maize	Central Mexico	Seed	-11.9	-	4 ^f	
<i>Zea mays</i>	Flour maize	Central Mexico	Seed	-10.2	-	4 ^f	
<i>Zea mays</i>	Flour maize	Central Mexico	Seed	-11.2	-	4 ^f	
<i>Zea mays</i>	Sugar maize	Central Mexico	Seed	-10.4	-	4 ^f	
<i>Zea mays</i>	Maize	Central Mexico	Seed	-9.8	-	4 ^f	
<i>Zea mays</i>	Maize	Central Mexico	Seed	-9.9	-	4 ^f	
<i>Zea mays</i>	Maize	Oaxaca	Seed	-11.3	5.4	2.3	This study, WO27
<i>Zea mays</i>	Maize (negro)	Oaxaca	Seed	-11.8	3.0	1.0	This study, WO69
<i>Zea mays</i>	Maize (blanco)	Oaxaca	Seed	-13.4	5.0	1.9	This study, WO68
<i>Zea mays</i>	Maize (blanco)	Oaxaca	Seed	-10.7	1.3	0.9	This study, WO70
<i>Zea mays</i>	Maize (amarillo)	Oaxaca	Seed	-11.7	0.8	1.8	This study, WO71
<i>Zea mays</i>	Maize	Pacific Coast	-	-10.1		1	
<i>Zea mays</i>	Maize	Pacific Coast	-	-10.1	5.3	1	
<i>Zea mays</i>	Maize	Pacific Coast	-	-10.2	0.3	1	
<i>Zea mays</i>	Maize	Pacific Coast	-	-10.3		1	
<i>Zea mays</i>	Maize	S. Maya Lowlands	Seed	-11.2	6.1	6	
<i>Zea mays</i>	Maize	S. Maya Lowlands	Seed	-11.0	3.5	6	
<i>Zea mays</i>	Maize	S. Maya Lowlands	-	-11.2	-	5	

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
CAM taxa							
<i>Agave spp.</i>	Pulque	Oaxaca	Alcohol	-12.2	4.2	1.4	This study, WO83
<i>Ananas cosmosus</i>	Pineapple	Gulf Lowlands	Fruit	-14.2	2.7	0.8	This study, SV32
<i>Ananas cosmosus</i>	Pineapple	L. Cent America	-	-13.2	-		3
<i>Bromelia karatas</i>	Pinuela	S. Maya Lowlands	-	-16.7	-		6
<i>Hylocereus undatus</i>	Pitaya	Gulf Lowlands	Fruit	-13.9	2.6	0.5	This study, SV14
<i>Opuntia ficus-indica</i>	Green prickly pear	Gulf Lowlands	Fruit	-12.4	-0.1	1.5	This study, SV25
<i>Opuntia ficus-indica</i>	Red prickly pear	Oaxaca	Fruit	-12.2	5.8	1.0	This study, SO38
<i>Opuntia ficus-indica</i>	Green prickly pear	Oaxaca	Fruit	-12.9	4.5	0.9	This study, SO39
<i>Opuntia ficus-indica</i>	Green prickly pear	Oaxaca	Fruit	-13.8	1.4	0.7	This study, SO44
<i>Opuntia ficus-indica</i>	Prickly pear	Pacific Coast	Fruit	-11.9	7.1		1
<i>Opuntia ficus-indica</i>	Nopal cactus	Gulf Lowlands	Stem	-13.7	11.3	2.8	This study, SV18
<i>Opuntia ficus-indica</i>	Nopal cactus	Oaxaca	Stem	-13.7	10.2	1.7	This study, WO13
<i>Opuntia ficus-indica</i>	Nopal cactus	Oaxaca	Stem	-13.6	8.6	2.8	This study, SO36
<i>Opuntia ficus-indica</i>	Nopal cactus	S. Maya Lowlands	Stem	-10.0	-	-	6
C3 taxa							
Legumes ^g							
<i>Phaseolus vulgaris</i>	Bean (negro)	Gulf Lowlands	Seed	-25.4	8.1	5.4	This study, SV57
<i>Phaseolus vulgaris</i>	Bean (bayo)	Gulf Lowlands	Seed	-28.1	3.1	5.4	This study, SV39
<i>Phaseolus vulgaris</i>	Bean (blanco)	Gulf Lowlands	Seed	-26.6	2.8	3.1	This study, SV58
<i>Phaseolus vulgaris</i>	Bean (flor de mayo)	Gulf Lowlands	Seed	-27.3	4.1	4.0	This study, SV40
<i>Phaseolus vulgaris</i>	Bean	L. Cent America	Seed	-28.3	5.0		3
<i>Phaseolus vulgaris</i>	Bean	L. Cent America	Seed	-28.6	0.0		3
<i>Phaseolus vulgaris</i>	Bean (negro)	Oaxaca	Seed	-26.4	4.0	4.4	This study, WO53
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-24.0	4.9	4.4	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-23.9	3.3	5.6	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-26.4	1.1	3.8	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-24.5	2.7	4.5	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-23.2	3.2	4.2	This study, W063

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-23.7	3.6	3.5	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (mixed)	Oaxaca	Seed	-23.5	7.8	4.3	This study, WO63
<i>Phaseolus vulgaris</i>	Bean (rojo)	Oaxaca	Seed	-26.2	-1.7	3.5	This study, WO66
<i>Phaseolus vulgaris</i>	Bean (uallo)	Oaxaca	Seed	-27.0	5.3	3.0	This study, WO51
<i>Phaseolus vulgaris</i>	Bean (blanco)	Oaxaca	Seed	-26.0	3.6	2.8	This study, WO52
<i>Phaseolus vulgaris</i>	Bean (flor de mayo)	Oaxaca	Seed	-27.2	7.0	3.3	This study, WO50
<i>Phaseolus vulgaris</i>	Bean (flor de mayo)	Oaxaca	Seed	-27.0	7.1	3.4	This study, WO50
<i>Phaseolus vulgaris</i>	Bean (blanco)	Pacific Coast	Seed	-26.6	0.5		1
<i>Phaseolus vulgaris</i>	Bean (negro)	Pacific Coast	Seed	-25.2	5.8		1
<i>Phaseolus vulgaris</i>	Bean	Pacific Coast	Seed	-25.5			1
<i>Phaseolus vulgaris</i>	Bean	Pacific Coast	Seed	-25.2	0.5		1
<i>Phaseolus vulgaris</i>	Bean (negro)	Pacific Coast	Seed	-26.0	3.0		1
<i>Phaseolus vulgaris</i>	Bean	S. Maya Lowlands	Seed	-27.1	-		6
<i>Phaseolus vulgaris</i>	Bean	S. Maya Lowlands	Seed	-27.8	3.9		6
<i>Inga preussii</i>	Caspirol	Pacific Coast	Pod	-22.6	8.4		1
<i>Leucaena esculenta</i>	Guaje	Oaxaca	Seed	-25.7	0.3	8.7	This study, WO12
<i>Leucaena sp.</i>	Tepeguaje	Oaxaca	Seed	-28.6	-2.7	6.9	This study, WO93
<i>Leucaena sp.</i>	Tepeguaje	Oaxaca	Leaf	-27.7	-2.5	4.1	This study, WO93
<i>Pachyrhizus erosus</i>	Jicama	Gulf Lowlands	Tuber	-26.7	7.2	1.9	This study, SV19
<i>Pachyrhizus erosus</i>	Jicama	Oaxaca	Tuber	-26.1	0.5	1.1	This study, WO40
<i>Pachyrhizus erosus</i>	Jicama	Oaxaca	Tuber	-26.1	0.5	1.7	This study, WO40
<i>Phaseolus lunatus</i>	Lima bean	L. Cent America	Seed	-26.0	-2.2		3
<i>Prosopis sp.</i>	Mesquite	Gulf Coast	Seed	-26.5	0.7	2.5	This study, SO35
<i>Prosopis sp.</i>	Mesquite	Oaxaca	Pod	-29.4	1.6	1.7	This study, WO98
<i>Prosopis sp.</i>	Mesquite	Oaxaca	Seed	-27.4	2.7	4.7	This study, WO98
<i>Prosopis sp.</i>	Mesquite	Oaxaca	Pod	-28.5	2.1	4.0	This study, WO98
Non-legumes							
<i>Acrocomia aculeata</i>	Coyol palm	Pacific Coast	Nut	-27.3	7.4		1
<i>Acrocomia aculeata</i>	Coyol palm	Pacific Coast	Nut	-27.4	6.4		1
<i>Acrocomia aculeata</i>	Coyol palm	Pacific Coast	Nut	-27.3	7.4		1
<i>Agastache mexicana</i>	Toronjil	Gulf Lowlands	Leaf	-29.0	5.5	4.1	This study, SV56

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Annona muricata</i>	Guanabana	Oaxaca	Fruit	-28.4	2.6	1.8	This study, WO43
<i>Annona muricata</i>	Guanabana	S. Maya Lowlands	-	-27.2	5.2		6
<i>Annona sp.</i>	Anonna	S. Maya Lowlands	Fruit	-29.0	-		6
<i>Annona scleroderma</i>	Bandesopa, poshte	Gulf Lowlands	Fruit	-25.9	7.6	0.6	This study, SV70
<i>Arctosaphylos pungens</i>	Pinguica	Gulf Lowlands	Fruit	-25.7	-	-	This study, SV55
<i>Arctostaphylos pungens</i>	Pinguica	Oaxaca	Leaf	-29.6	-1.2	-	This study, WO10
<i>Asclepias curassavica</i>	Cancerillo	Gulf Lowlands	Leaf	-34.7	6.3	4.3	This study, SV37
<i>Astrocaryum mexicanum</i>	Chapay	S. Maya Lowlands	Nut	-31.4	-		6
<i>Astrocaryum mexicanum</i>	Chapay	S. Maya Lowlands	Nut	-31.6	-		6
<i>Bactris gasipaes</i>	Peach Palm	L. Cent America	-	-27.1	2.4		3
<i>Bactris sp.</i>	Chiquijul	Gulf Coast	Fruit	-27.3	1.0	1.3	This study, SV30
<i>Bixa orellana</i>	Achiote	Oaxaca	Seed	-28.0	4.3	1.9	This study, WO94
<i>Bixa orellana</i>	Achiote	S. Maya Lowlands	Seed	-29.7	-		6
<i>Brosimum alicastrum</i>	Ramon	S. Maya Lowlands	-	-27.7	-		6
<i>Brosimum alicastrum</i>	Ramon	S. Maya Lowlands	Tortilla	-25.2	-		6
<i>Brosimum alicastrum</i>	Ramon	S. Maya Lowlands	-	-27	-		6
<i>Brosimum alicastrum</i>	Ramon	S. Maya Lowlands	-	-29.2	-		5
<i>Byrsonima crassifolia</i>	Nance	Gulf Lowlands	Fruit	-28.8	5.1	0.6	This study, SV1
<i>Byrsonima crassifolia</i>	Nance	L. Cent America	-	-28.3	-		3
<i>Byrsonima crassifolia</i>	Nance	Oaxaca	Fruit	-27.5	7.4	0.6	This study, WO42
<i>Byrsonima crassifolia</i>	Nance	S. Maya Lowlands	-	-27.1	-		6
<i>Capsicum annum</i>	Chile	Gulf Lowlands	Fruit	-26.3	3.5	1.8	This study, SV26
<i>Capsicum annum</i>	Chile anachito	Gulf Lowlands	Fruit	-33.2	7.0	2.4	This study, SV62
<i>Capsicum annum</i>	Chile dulce	Gulf Lowlands	Fruit	-24.8	6.2	2.7	This study, SV8
<i>Capsicum annum</i>	Chile picante	Gulf Lowlands	Fruit	-27.2	2.4	2.2	This study, SV7
<i>Capsicum annum</i>	Chile	Oaxaca	Fruit	-28.6	4.4	3.1	This study, WO109
<i>Capsicum annum</i>	Chile	Oaxaca	Fruit	-25.8	0.2	1.5	This study, WO103
<i>Capsicum annum</i>	Chile	Oaxaca	Fruit	-27.1	2.8	2.1	This study, WO106
<i>Capsicum annum</i>	Chile	Oaxaca	Fruit	-29.7	3.4	1.4	This study, WO109
<i>Capsicum annum</i>	Chile	Oaxaca	Fruit	-27.3	2.9	1.7	This study, WO106

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Capsicum annuum</i>	Chile	Oaxaca	Seed	-26.0	0.8	2.0	This study, WO103
<i>Capsicum annuum</i>	Chile	Oaxaca	Seed	-26.6	1.0	2.8	This study, WO103
<i>Capsicum annuum</i>	Chile	Oaxaca	Seed	-27.7	3.2	2.7	This study, WO106
<i>Capsicum annuum</i>	Chile	Oaxaca	Seed	-27.1	-1.5	2.6	This study, WO107
<i>Capsicum annuum</i>	Chile	Oaxaca	Fruit	-27.5	-3.1	1.8	This study, WO107
<i>Capsicum annuum</i>	Chile de agua	Oaxaca	Fruit	-28.6	3.3	1.8	This study, SO21
<i>Capsicum annuum</i>	Chile ancho rojo	Oaxaca	Fruit	-26.1	2.9	2.1	This study, SO13
<i>Capsicum annuum</i>	Chile ancho negro	Oaxaca	Fruit	-27.6	4.6	1.3	This study, SO18
<i>Capsicum annuum</i>	Chile ancho	Oaxaca	Fruit	-25.2	0.4	1.8	This study, WO105
<i>Capsicum annuum</i>	Chile ancho	Oaxaca	Fruit	-26.0	3.1	2.3	This study, WO104
<i>Capsicum annuum</i>	Chile ancho	Oaxaca	Seed	-25.1	3.0	2.5	This study, WO104
<i>Capsicum annuum</i>	Chile ancho	Oaxaca	Seed	-25.5	-0.2	3.1	This study, WO105
<i>Capsicum annuum</i>	Chile de arbol	Oaxaca	Fruit	-28.9	-0.1	2.4	This study, WO108
<i>Capsicum annuum</i>	Chile de arbol	Oaxaca	Fruit	-30.3	1.1	2.3	This study, SO7
<i>Capsicum annuum</i>	Chile de arbol	Oaxaca	Seed	-26.9	0.6	3.8	This study, WO108
<i>Capsicum annuum</i>	Chile de arbol	Oaxaca	Fruit	-28.2	0.2	2.6	This study, WO108
<i>Capsicum annuum</i>	Chile de arbol	Oaxaca	Seed	-26.6	0.2	2.6	This study, WO108
<i>Capsicum annuum</i>	Chile cascabe	Oaxaca	Fruit	-28.4	5.1	3.1	This study, SO9
<i>Capsicum annuum</i>	Chile chilhuacle rojo	Oaxaca	Fruit	-27.0	4.1	3.3	This study, SO24
<i>Capsicum annuum</i>	Chile chiltepec	Oaxaca	Fruit	-28.9	3.8	1.5	This study, SO6
<i>Capsicum annuum</i>	Chile chintepe	Oaxaca	Fruit	-29.8	4.8	1.8	This study, SO16
<i>Capsicum annuum</i>	Chipote rojo	Oaxaca	Fruit	-27.9	4.5	1.7	This study, SO11
<i>Capsicum annuum</i>	Chile costeno	Oaxaca	Fruit	-27.2	5.5	1.8	This study, SO5
<i>Capsicum annuum</i>	Chile costeno amarillo	Oaxaca	Fruit	-31.1	2.2	2.1	This study, SO4
<i>Capsicum annuum</i>	Chile costeno amarillo	Oaxaca	Fruit	-27.8	3.2	2.0	This study, SO26
<i>Capsicum annuum</i>	Chile guajillo	Oaxaca	Fruit	-26.5	5.0	1.9	This study, WO102
<i>Capsicum annuum</i>	Chile guajillo	Oaxaca	Seed	-25.3	5.1	3.1	This study, WO102
<i>Capsicum annuum</i>	Chile guajillo	Oaxaca	Fruit	-27.8	7.5	1.5	This study, SO12
<i>Capsicum annuum</i>	Chipotle meco	Oaxaca	Fruit	-28.2	6.0	1.2	This study, SO8
<i>Capsicum annuum</i>	Chile morita	Oaxaca	Fruit	-26.7	2.6	3.2	This study, SO3
<i>Capsicum annuum</i>	Chile mulato	Oaxaca	Fruit	-25.8	6.5	2.2	This study, SO17

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Capsicum annum</i>	Chile mulato	Oaxaca	Fruit	-25.5	1.4	1.7	This study, SO10
<i>Capsicum annum</i>	Chile de onza	Oaxaca	Fruit	-28.6	2.3	1.9	This study, SO2
<i>Capsicum annum</i>	Chile de onza amarillo	Oaxaca	Fruit	-29.1	4.8	2.7	This study, SO25
<i>Capsicum annum</i>	Chile de onza	Oaxaca	Fruit	-28.7	0.6	1.8	This study, SO20
<i>Capsicum annum</i>	Chile pico de gallo	Oaxaca	Fruit	-32.7	1.5	2.6	This study, SO23
<i>Capsicum annum</i>	Chile pulla	Oaxaca	Fruit	-30.5	7.3	1.5	This study, SO1
<i>Capsicum annum</i>	Chile tuxtla	Oaxaca	Fruit	-30.9	0.7	2.6	This study, SO15
<i>Capsicum annum</i>	Chiuacle	Oaxaca	Fruit	-27.8	-0.4	2.5	This study, SO22
<i>Capsicum annum</i>	Jalapeno	Oaxaca	Fruit	-28.7	1.3	1.6	This study, WO18
<i>Capsicum annum</i>	Jalapeno	Oaxaca	Fruit	-30.2	5.1	1.9	This study, WO20
<i>Capsicum annum</i>	Jalapeno	Oaxaca	Fruit	-29.6	5.3	1.8	This study, WO20
<i>Capsicum annum</i>	Pasilla mexicana	Oaxaca	Fruit	-26.7	3.1	2.5	This study, SO14
<i>Capsicum annum</i>	Pasilla oaxaqueno	Oaxaca	Fruit	-26.9	4.0	1.5	This study, SO19
<i>Capsicum annum</i>	Pimento	Oaxaca	Fruit	-28.9	3.8	0.9	This study, WO89
<i>Capsicum annum</i>	Serrano pepper	Oaxaca	Fruit	-29.3	2.7	2.4	This study, WO19
<i>Capsicum annum</i>	Chile	Pacific Coast	-	-26.6	4.8		1
<i>Capsicum annum</i>	Chile	Pacific Coast	-	-28.8	9.6		1
<i>Capsicum chinense</i>	Chile habañero	Gulf Lowlands	Fruit	-29.4	9.9	2.1	This study, SV9
<i>Capsicum chinense</i>	Habanjero	Oaxaca	Fruit	-28.3	4.2	-	This study, WO17
<i>Capsicum sp.</i>	Chile	S. Maya Lowlands	-	-30.1	-		6
<i>Capsicum sp.</i>	Chile	S. Maya Lowlands	-	-27.8	-		6
<i>Carica papaya</i>	Papaya	Gulf Lowlands	Fruit	-25.1	10.1	1.4	This study, SV2
<i>Carica papaya</i>	Papaya	S. Maya Lowlands	-	-29.3	-		5
<i>Carica sp.</i>	Wild papaya	S. Maya Lowlands	-	-26.4	5.5		6
<i>Chenopodium ambrosioides</i>	Epazote	Gulf Coast	Leaf	-29.2	13.4	5.0	This study, SV67
<i>Chenopodium ambrosioides</i>	Epazote	Oaxaca	Leaf	-26.0	8.9	6.2	This study, WO110
<i>Chrysobalanus icaco</i>	Jicaco	S. Maya Lowlands	Fruit	-27.3	-		5
<i>Cnidoscolus chayamansa</i>	Chaya	Gulf Lowlands	Leaf	-28.6	4.6	4.3	This study, SV61
<i>Crotalaria sp.</i>	Chipil	Gulf Lowlands	Leaf	-27.5	0.7	7.1	This study, SV65
<i>Crotalaria sp.</i>	Chipil	Oaxaca	Leaf	-26.3	0.3	5.3	This study, WO86
<i>Crotalaria sp.</i>	Chipil	Oaxaca	Leaf	-26.5	-0.8	5.2	This study, WO26

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Cucurbita mixta</i>	Pipian squash	Gulf Lowlands	Seed	-27.5	5.6	7.8	This study, SV42
<i>Cucurbita moschata</i>	White squash	Oaxaca	Fruit	-26.3	2.8	0.7	This study, WO74
<i>Cucurbita moschata</i>	Pepitoria squash	S. Maya Lowlands	-	-27.4	8.8		6
<i>Cucurbita moschata</i>	Pepitoria squash	S. Maya Lowlands	-	-27.1	7.5		6
<i>Cucurbita moschata</i>	White squash	Oaxaca	Seed	-26.8	2.3	3.6	This study, WO74
<i>Cucurbita pepo</i>	Huiche squash	Oaxaca	Flower	-26.5	7.5	5.0	This study, WO25
<i>Cucurbita pepo</i>	Huiche squash	Oaxaca	Fruit	-23.5	8.5	2.9	This study, WO24
<i>Cucurbita pepo</i>	Huiche squash	Oaxaca	Leaves	-24.0	2.7	3.7	This study, WO25
<i>Cucurbita pepo</i>	Zucchini	Oaxaca	Fruit	-23.4	2.6	5.9	This study, WO31
<i>Cucurbita pepo</i>	Squash	Pacific Coast	-	-25.3	6.7		1
<i>Cucurbita pepo</i>	Squash	Pacific Coast	-	-25.4	1.9		1
<i>Cucurbita pepo</i>	Tambulo squash	Oaxaca	Seed	-27.7	6.5	6.4	This study, WO23
<i>Cucurbita pepo</i>	Huiche squash	Oaxaca	Seed	-28.0	3.4	4.6	This study, WO22
<i>Cucurbita pepo</i>	Squash	Oaxaca	Seed (roasted)	-23.8	3.8	-	This study, SO45
<i>Cucurbita sp.</i>	Squash	Gulf Lowlands	Fruit	-27.5	7.3	1.2	This study, SV13
<i>Cucurbita sp.</i>	Squash	Gulf Lowlands	Fruit	-25.1	7.9	2.4	This study, SV17
<i>Cucurbita sp.</i>	Yellow squash	Oaxaca	Fruit	-26.3	-0.9	1.5	This study, WO73
<i>Cucurbita sp.</i>	Squash	Gulf Lowlands	Seed	-29.8	7.7	6.6	This study, SV59
<i>Cucurbita sp.</i>	Yellow squash	Oaxaca	Seed	-26.8	1.7	6.4	This study, WO73
<i>Diospyros digyna</i>	Zapote negro	Oaxaca	Fruit	-26.9	4.2	0.3	This study, WO47
<i>Diospyros digyna</i>	Zapote negro (ripe)	Oaxaca	Fruit	-30.1	3.4	0.4	This study, WO48
<i>Diospyros digyna</i>	Zapote	S. Maya Lowlands	Fruit	-27.1	-		6
<i>Diospyros digyna</i>	Zapote	S. Maya Lowlands	Seed	-27.8	0.6		6
<i>Diospyros digyna</i>	Zapote	S. Maya Lowlands	Fruit	-28.1	-		6
<i>Diospyros digyna</i>	Zapote	S. Maya Lowlands	Seed	-30.0	-		6
<i>Equisetum spp.</i>	Cola de caballo	Oaxaca	Stem	-25.8	9.2	1.8	This study, WO2
<i>Euphorbia spp.</i>	Golondrina	S. Maya Lowlands		-28.7	-		5
<i>Eysenhardtia polystachya</i>	Cascara de pallo dulce	Oaxaca	Wood	-25.4	1.3	0.4	This study, WO8
<i>Gnaphalium spp.</i>	Gordolobo	Oaxaca	Flower	-29.1	-1.8	0.3	This study, WO3
<i>Helianthus annuus</i>	Sunflower	Gulf Lowlands	Seed	-28.8	9.9	3.1	This study, SV45
<i>Helianthus annuus</i>	Sunflower	Oaxaca	Seed	-29.0	3.1	4.4	This study, WO60
<i>Ipomaea batatas</i>	Sweet potato	Gulf Lowlands	Tuber	-27.6	6.2	0.4	This study, SV73

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Ipomaea batatas</i>	Sweet potato	Oaxaca	Tuber	-26.0	14.1	0.5	This study, WO14
<i>Ipomaea batatas</i>	Camote	Oaxaca	Tuber	-25.9	16.8	0.6	This study, WO88
<i>Ipomaea batatas</i>	Camote	Pacific Coast	-	-25.5	-		1
<i>Ipomaea batatas</i>	Tecamote	Pacific Coast	-	-27.3	-		1
<i>Ipomaea batatas</i>	Camote morado	Pacific Coast	-	-26.8	-		1
<i>Ipomaea batatas</i>	Camote	S. Maya Lowlands	-	-26.4	-		6
<i>Ipomaea batatas</i>	Camote cacas	S. Maya Lowlands	-	-29.4	-		5
<i>Ipomaea batatas</i>	Camote	S. Maya Lowlands	-	-27.2	-		5
<i>Juglans sp.</i>	Black walnut	Oaxaca	Seed	-26.3	0.8	1.6	This study, WO49
<i>Juglans sp.</i>	Black walnut	Oaxaca	Seed	-29.0	1.9	2.1	This study, WO49
<i>Licania platypus</i>	Sunzapote	S. Maya Lowlands	-	-29.3	-		6
<i>Lippia graveolens</i>	Mexican oregano	Oaxaca	Leaf	-27.7	-0.6	1.7	This study, WO91
<i>Lycopersicon esculentum</i>	Jitomate rojo	Gulf Lowlands	Fruit	-28.7	4.6	5.2	This study, SV23
<i>Lycopersicon esculentum</i>	Jitomate verde	Gulf Lowlands	Fruit	-24.6	4.8	2.6	This study, SV24
<i>Lycopersicon esculentum</i>	Jitomate	Oaxaca	Fruit	-28.3	3.1	5.0	This study, WO35
<i>Lycopersicon esculentum</i>	Jitomate rojo	Oaxaca	Fruit	-29.5	0.5	2.3	This study, WO34
<i>Lycopersicon esculentum</i>	Jitomate verde	Oaxaca	Fruit	-28.4	2.5	2.8	This study, WO35
<i>Lycopersicon esculentum</i>	Guatomate	Oaxaca	Fruit	-26.7	12.6	2.2	This study, WO29
<i>Lycopersicon esculentum</i>	Guatomate	Oaxaca	Seed	-27.0	13.2	4.0	This study, WO29
<i>Manihot esculenta</i>	Yuca	Gulf Lowlands	Tuber	-27.5	2.2	0.3	This study, SV10
<i>Manihot esculenta</i>	Manioc	L. Cent America	-	-26.1	-		3
<i>Manihot esculenta</i>	Manioc	L. Cent America	-	-26.1	-		3
<i>Manihot esculenta</i>	Yuca	Oaxaca	Tuber	-25.7	-	-	This study, WO90
<i>Manihot esculenta</i>	Manioc	Pacific Coast	-	-26.8	-		1
<i>Manihot esculenta</i>	Manioc	S. Maya Lowlands	-	-27.6	2.4		2
<i>Manihot esculenta</i>	Cassava	S. Maya Lowlands	-	-27	-		5
<i>Manilkara zapotilla</i>	Chicozapote	Gulf Lowlands	Fruit	-27.3	6.7	0.8	This study, SV77
<i>Manilkara zapotilla</i>	Chicozapote	Oaxaca	Fruit	-27.7	1.4	0.3	This study, WO46
<i>Manilkara zapotilla</i>	Chicozapote	Oaxaca	Fruit	-26.3	-	-	This study, WO101
<i>Manilkara zapotilla</i>	Sapodilla	Pacific Coast	-	-23.9	-2.8		1
<i>Manilkara zapotilla</i>	Sapodilla	Pacific Coast	-	-24.2	0.1		1

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Manilkara zapotilla</i>	Sapodilla	Pacific Coast	-	-24.8	6.9		1
<i>Manilkara zapotilla</i>	Sapodilla	Pacific Coast	-	-30.0	0.3		1
<i>Nasturtium officinale</i>	Berro	Oaxaca	Leaf	-27.5	13.3	6.9	This study, WO28
<i>Orbignya cohune</i>	Palma corozo	Pacific Coast	Nut	-24.6	4.6		1
<i>Orbignya cohune</i>	Corozo	S. Maya Lowlands	Nut	-29.7	-		6
<i>Orbignya cohune</i>	Corozo	S. Maya Lowlands	Nut	-28.3	-		6
<i>Parmentiera edulis</i>	Guajilote	Gulf Lowlands	Fruit	-26.8	5.4	1.0	This study, SV15
<i>Passiflora edulis</i>	Maracuya	Gulf Lowlands	Fruit	-28.3	2.6	1.8	This study, SV74
<i>Passiflora edulis</i>	Maracuya	Oaxaca	Fruit	-26.2	12.5	1.3	This study, SO29
<i>Persea americana</i>	Avocado	Gulf Lowlands	Fruit	-27.5	10.4	1.2	This study, SV6
<i>Persea americana</i>	Avocado	Oaxaca	Fruit	-25.9	6.0	1.1	This study, SO37
<i>Persea americana</i>	Aguacate criollo	Oaxaca	Fruit	-31.7	7.1	1.3	This study, WO41
<i>Persea americana</i>	Aguacate criollo	Oaxaca	Fruit	-28.1	0.1	0.7	This study, SO31
<i>Persea americana</i>	Aguacate criollo	Oaxaca	Fruit	-30.8	4.7	0.9	This study, SO34
<i>Persea americana</i>	Avocado	Pacific Coast	-	-29.4	3.6		1
<i>Persea americana</i>	Avocado	Pacific Coast	-	-25.9	1.4		1
<i>Physalis philadelphica</i>	Tomatillo	Oaxaca	Fruit	-25.7	0.7	3.4	This study, WO16
<i>Pouteria sapota</i>	Mamey	Gulf Lowlands	Fruit	-27.4	0.9	0.4	This study, SV76
<i>Pouteria sapota</i>	Mamey	Oaxaca	Fruit	-27.7	2.5	0.9	This study, WO44
<i>Psidium guajava</i>	Guava	Gulf Lowlands	Fruit	-29.4	10.6	0.3	This study, SV75
<i>Psidium guajava</i>	Guava	Gulf Lowlands	Fruit	-27.8	1.1	0.8	This study, SV3
<i>Psidium guajava</i>	Guava	Oaxaca	Fruit	-30.2	10.0	0.5	This study, WO36
<i>Psidium guajava</i>	Guava	Oaxaca	Fruit	-26.8	2.5	0.3	This study, SO30
<i>Psidium guajava</i>	Guava	S. Maya Lowlands	-	-27.3	-		6
<i>Quercus rubra</i>	Cascara de encino rojo	Oaxaca	Wood	-25.4	-		This study, WO4
<i>Salvia hispanica</i>	Chia	Oaxaca	Seeds	-30.3	3.5	3.4	This study, WO72
<i>Salvia hispanica</i>	Chia	Oaxaca	Seeds	-31.3	3.1	3.0	This study, WO72
<i>Sechium edulis</i>	Chayote	Gulf Lowlands	Fruit	-26.9	8.1	1.4	This study, SV11
<i>Sechium edulis</i>	Chayote (smooth)	Oaxaca	Fruit	-25.7	3.9	3.4	This study, WO15
<i>Sechium edulis</i>	Chayote (smooth)	Oaxaca	Fruit	-25.6	3.9	2.8	This study, WO15
<i>Sechium edulis</i>	Chayote (spiny)	Oaxaca	Fruit	-25.4	5.6	1.0	This study, WO100

Appendix 4.2. continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Sechium edulis</i>	Chayote grande	Oaxaca	Fruit	-24.0	14.8	1.8	This study, SO32
<i>Sechium edulis</i>	Chayote	Oaxaca	Fruit	-23.4	11.5	1.9	This study, SO33
<i>Sicana odorifera</i>	Melocoton, cassabanana	Gulf Lowlands	Fruit	-25.8	5.5	1.1	This study, SV68
<i>Spondias sp.</i>	Ciruela	Oaxaca	Fruit	-28.1	1.6	0.6	This study, WO45
<i>Spondias sp.</i>	Ciruela	Oaxaca	Fruit	-25.1	1.2	0.5	This study, SO28
<i>Theobroma cacao</i>	Cacao	Oaxaca	Seed	-34.1	3.3	2.3	This study, WO37
<i>Theobroma cacao</i>	Cacao	Oaxaca	Seed	-31.3	4.3	2.4	This study, WO54
<i>Theobroma cacao</i>	Cacao	Pacific Coast	-	-30.3	4.6	1	
<i>Theobroma cacao</i>	Cacao	Pacific Coast	-	-26.6	3.9	1	
<i>Theobroma cacao</i>	Cacao	Pacific Coast	-	-31.8	-	1	
<i>Theobroma cacao</i>	Cacao	S. Maya Lowlands	-	-34.1	3.7	6	
<i>Xanthosoma sagittifolium</i>	Macal/Cocoyam	Gulf Lowlands	Tuber	-27.1	3.7	0.6	This study, SV71
<i>Xanthosoma sagittifolium</i>	Macal/Cocoyam	S. Maya Lowlands	-	-26.1	4.3	2	
<i>Xanthosoma sagittifolium</i>	Macal/Cocoyam	S. Maya Lowlands	-	-26.8	-	5	

Notes

^aWest Indies are not included.

^bOnly plants native to prehistoric Middle America are included. Botanical names were verified in the International Plant Names Index (IPNI) internet database (www.ipni.org).

^cPlants commonly known in the United States are reported with their English names. Other plants are reported with either their common Spanish or regional names.

^dWhen known, the botanical part sampled for isotopic analysis is provided.

^eSamples reported in this study are followed by their sample identification number. For small items (e.g., beans) repeated references to the same sample identification number refers to multiple measurements from different items within a grouped sample (e.g., different beans from within a bin). For large items (e.g., huiche squash), multiple samples were collected from the same item (e.g., samples from the leaf, seed, and fruit of the same plant). References to previously published samples are as follows: 1 = Chisholm and Blake 2006; 2 = Keegan and DeNiro 1988; 3 = Norr 1991; 4 = Tieszen and Fagre 1993; 5 = White et al. 2001; 6 = Wright 1994.

^f59 Mexican maize seeds were measured in Tieszen and Fagre 1993, but individual values for only 9 are reported.

^gLegume classification verified in the International Legume Database and Information Service (ILDIS) internet database (www.ildis.org).

Appendix 4.3. Isotopic ratios of Middle American wild vegetation collected in a transect survey near the Guila Naquitz rockshelter in the Valley of Oaxaca

Classification ^a	Elevation ^b (m)	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference
C4 TAXA					
Grass	1,915	-13.0	-0.1	1.1	This study
Grass	1,915	-13.5	1.1	0.5	This study
Grass	1,915	-12.9	-	-	This study
Grass	1,915 ^c	-13.7	5.7	0.9	This study
Grass	1,915 ^c	-12.9	-	-	This study
Grass	1,915 ^c	-13.5	5.8	1.6	This study
Grass	1,915 ^c	-14.3	-	-	This study
Grass	1,915 ^c	-13.2	-	-	This study
Grass	1,915 ^c	-13.5	-	-	This study
Grass	1,915 ^c	-13.1	-	-	This study
Grass	1,915 ^c	-13.0	-	-	This study
Grass	1,915 ^c	-14.2	2.7	1.6	This study
Grass	1,915 ^c	-13.6	2.8	2.0	This study
Grass	1,915 ^c	-12.6	-	-	This study
Grass	1,865	-12.1	1.6	0.5	This study
Grass	1,865	-12.7	-	-	This study
Grass	1,865	-12.6	1.2	1.3	This study
Grass	1,805	-13.0	-	-	This study
Grass	1,805	-13.1	-	-	This study
Grass	1,805	-12.8	3.5	1.3	This study
Grass	1,755	-13.3	2.0	0.4	This study
Grass	1,755	-13.8	0.4	0.3	This study
Grass	1,755	-14.0	0.5	0.3	This study
Grass	1,755	-14.2	0.3	0.3	This study
Grass	1,755	-13.2	-1.1	0.6	This study
Grass	1,730	-12.4	3.0	-	This study
Grass	1,730	-13.4	-	-	This study
Grass	1,730	-13.1	3.9	1.4	This study
Grass	1,730	-12.6	-	-	This study
Grass	1,730	-13.6	3.8	1.9	This study
Grass	1,730	-13.4	-	-	This study
Grass	Not recorded ^c	-13.8	-0.6	1.3	This study
CAM TAXA					
Cactus/succulent	1,915	-13.4	1.0	1.3	This study
Cactus/succulent	1,915	-13.5	1.7	1.5	This study
Cactus/succulent	1,915 ^c	-12.9	3.1	5.1	This study
Cactus/succulent	1,915 ^c	-13.2	2.8	1.1	This study
Cactus/succulent	1,915 ^c	-13.9	-	-	This study
Cactus/succulent	1,915 ^c	-14.2	2.5	1.1	This study
Cactus/succulent	1,915 ^c	-14.4	-	-	This study
Cactus/succulent	1,915 ^c	-15.1	3.7	1.2	This study

Appendix 4.3. continued

Classification ^a	Elevation ^b (m)	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference
Cactus/succulent	1,915 ^c	-15.2	-	-	This study
Cactus/succulent	1,915 ^c	-24.6	3.2	2.3	This study
Cactus/succulent	1,865	-12.9	-	-	This study
Cactus/succulent	1,865	-14.3	2.3	0.6	This study
Cactus/succulent	1,805	-11.6	0.4	0.3	This study
Cactus/succulent	1,805	-12.7	1.0	1.9	This study
Cactus/succulent	1,755	-13.0	4.2	0.5	This study
Cactus/succulent	1,755	-13.5	-	-	This study
Cactus/succulent	1,755	-13.6	2.0	0.6	This study
Cactus/succulent	1,730	-12.9	1.5	-	This study
Cactus/succulent	1,730	-13.5	0.4	0.4	This study
Cactus/succulent	1,730	-14.9	1.6	0.5	This study
Cactus/succulent	1,730	-17.1	3.7	0.3	This study
Cactus/succulent	Not recorded ^c	-11.3	1.0	2.3	This study
Cactus/succulent	Not recorded ^c	-11.6	-0.1	0.5	This study
Cactus/succulent	Not recorded ^c	-12.1	3.9	2.4	This study
Cactus/succulent	Not recorded ^c	-12.3	-0.6	0.6	This study
Cactus/succulent	Not recorded ^c	-12.4	4.1	1.6	This study
Cactus/succulent	Not recorded ^c	-12.9	3.1	0.8	This study
Cactus/succulent	Not recorded ^c	-13.8	2.5	1.0	This study
Cactus/succulent	Not recorded ^c	-14.6	2.0	1.5	This study
Cactus/succulent	Not recorded ^c	-27.2	1.4	2.4	This study
C3 TAXA					
Grass	1,915	-30.7	0.8	0.6	This study
Grass	1,915	-32.9	2.2	0.6	This study
Other	1,915	-21.5	-7.9	1.0	This study
Other	1,915	-25.2	1.7	0.6	This study
Other	1,915	-26.0	2.2	0.6	This study
Other	1,915	-27.4	3.2	0.5	This study
Other	1,915	-27.8	0.8	1.3	This study
Other	1,915	-29.2	2.6	1.8	This study
Other	1,915	-29.9	-0.9	2.4	This study
Other	1,915	-30.7	-1.3	1.3	This study
Other	1,915	-31.3	3.2	1.8	This study
Other	1,915	-32.3	1.3	1.4	This study
Other	1,915	-32.4	0.7	1.6	This study
Other	1,915	-32.8	-1.1	1.7	This study
Other	1,915 ^c	-31.3	-	-	This study
Other	1,915 ^c	-27.1	-	-	This study
Other	1,915 ^c	-25.2	7.3	3.6	This study
Other	1,915 ^c	-25.6	2.6	1.5	This study
Other	1,915 ^c	-27.6	-	-	This study
Other	1,915 ^c	-28.4	2.9	1.0	This study
Other	1,915 ^c	-28.6	4.9	2.0	This study

Appendix 4.3. continued

Classification ^a	Elevation ^b (m)	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference
Other	1,915 ^c	-28.7	-	-	This study
Other	1,915 ^c	-30.0	3.0	1.2	This study
Other	1,915 ^c	-31.5	1.1	0.9	This study
Other	1,915 ^c	-32.0	-	-	This study
Other	1,865	-24.6	3.8	1.0	This study
Other	1,865	-26.7	0.7	1.0	This study
Other	1,865	-27.1	-2.3	1.5	This study
Other	1,865	-27.1	1.6	1.8	This study
Other	1,865	-27.3	1.3	2.4	This study
Other	1,865	-28.5	1.3	1.1	This study
Other	1,865	-28.5	-1.5	0.6	This study
Other	1,865	-29.1	-2.4	1.5	This study
Other	1,865	-29.4	-1.5	2.2	This study
Other	1,865	-29.4	-0.1	0.7	This study
Other	1,865	-29.4	0.0	0.3	This study
Other	1,865	-29.6	-	-	This study
Other	1,865	-29.6	2.1	2.3	This study
Other	1,865	-29.9	0.2	2.0	This study
Other	1,865	-30.1	-1.1	2.8	This study
Other	1,865	-30.2	-4.4	2.2	This study
Other	1,865	-31.3	0.1	1.7	This study
Other	1,805	-24.4	2.8	0.7	This study
Other	1,805	-25.0	1.9	0.8	This study
Other	1,805	-25.1	1.5	0.8	This study
Other	1,805	-25.9	0.3	8.4	This study
Other	1,805	-26.0	3.6	1.4	This study
Other	1,805	-26.3	4.2	0.5	This study
Other	1,805	-26.9	5.5	1.5	This study
Other	1,805	-27.3	4.3	0.6	This study
Other	1,805	-27.3	4.1	1.1	This study
Other	1,805	-27.5	1.2	2.0	This study
Other	1,805	-28.4	3.2	1.1	This study
Other	1,805	-28.6	5.7	2.1	This study
Other	1,805	-28.7	1.1	0.3	This study
Other	1,805	-29.0	-	-	This study
Other	1,805	-29.4	1.3	0.3	This study
Other	1,805	-29.5	-0.1	0.7	This study
Other	1,805	-30.5	3.0	0.6	This study
Other	1,755	-24.4	-1.5	0.8	This study
Other	1,755	-25.9	5.8	1.7	This study
Other	1,755	-26.9	0.0	0.7	This study
Other	1,755	-27.3	-0.2	1.0	This study
Other	1,755	-27.4	0.1	0.6	This study
Other	1,755	-27.4	4.5	4.2	This study

Appendix 4.3. continued

Classification ^a	Elevation ^b (m)	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference
Other	1,755	-27.4	-	-	This study
Other	1,755	-28.4	1.3	1.0	This study
Other	1,755	-28.5	-	-	This study
Other	1,755	-29.7	-1.8	1.6	This study
Other	1,755	-30.0	-	-	This study
Other	1,755	-30.2	-1.3	0.4	This study
Other	1,730	-26.1	-0.2	1.5	This study
Other	1,730	-28.6	1.2	0.9	This study
Other	1,730	-29.0	-0.9	0.3	This study
Other	Not recorded ^c	-22.8	-	-	This study
Other	Not recorded ^c	-24.7	-	-	This study
Other	Not recorded ^c	-24.8	5.2	5.3	This study
Other	Not recorded ^c	-25.1	0.1	10.6	This study
Other	Not recorded ^c	-25.6	0.1	0.9	This study
Other	Not recorded ^c	-25.6	0.1	4.6	This study
Other	Not recorded ^c	-26.4	1.2	6.4	This study
Other	Not recorded ^c	-26.8	5.8	1.5	This study
Other	Not recorded ^c	-26.9	1.9	0.9	This study
Other	Not recorded ^c	-27.1	-1.2	1.3	This study
Other	Not recorded ^c	-27.1	2.6	0.8	This study
Other	Not recorded ^c	-27.9	4.5	0.7	This study
Other	Not recorded ^c	-29.7	0.4	1.3	This study
Other	Not recorded ^c	-30.1	-0.4	4.3	This study

Notes:

^aBased on field observation, plants were classified into one of three categories: grass, cactus/succulent, or other.

^bPlants were collected over a 185m elevation interval from the Guila Naquitz rockshelter to the valley floor. When not obstructed by natural features, such as rock outcrops and streams, plants were collected at every 50m of vertical distance. The final collection zone was selected at only 25 m below the previous collection zone because lower elevations are now under cultivation. Plants were collected systematically (see Data Collection) unless otherwise indicated.

^cCollected non-systematically.

Appendix 4.4. Isotopic ratios of archaeological carbonized
plant remains from Middle America^a

Taxa ^b	Common name	Location collected	WHAMS ^c	BP	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$
C4 SAMPLES						
<i>Zea mays</i>	Maize	Atzompa, Oaxaca	OS-73462	405 ± 30	-9.4	5.1
C3 SAMPLES ^d						
Unknown	Unknown	Atzompa, Oaxaca	OS-73460	1600 ± 30	-25.3	4.0
Unknown	Unknown	Atzompa, Oaxaca	OS-73459	1590 ± 45	-23.4	-
Unknown	Unknown	Atzompa, Oaxaca	OS-73461	1590 ± 30	-22.3	-1.2
Unknown	Unknown	Atzompa, Oaxaca	OS-73458	1520 ± 25	-24.4	-1.8

Notes:

All samples measured for this study.

^aWest Indies are not included.

^bTaxa identification based on macroscopic inspection.

^cNational Ocean Sciences Accelerator Mass Spectrometry Facility at Woods Hole Oceanographic Institution sample identification number.

^dWood charcoal samples

Appendix 4.5. Isotopic ratios of historic Middle American^a economic plants

Taxa ^b	Common name ^c	Location collected ^d	Date collected	Botanical part	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference
C4 taxa								
<i>Amaranthus blitoides</i>	Amaranth	North Mexico	1941	Seed	-10.2	4.3	2.4	This study, H20
<i>Amaranthus chihuahhuensis</i>	Amaranth	Oaxaca	1894	Seed	-10.1	6.9	3.1	This study, H19
<i>Amaranthus hypochondriacus</i>	Amaranth	West Mexico	1886	Seed	-10.1	11.4	2.2	This study, H7
<i>Setaria leucopila</i>	Foxtail grass	North Mexico	1898	Seed	-10.0	4.9	2.6	This study, H30
<i>Zea mays</i>	Teosinte	Central Mexico	1892	Seed	-8.8	7.4	3.7	This study, H31
CAM taxa								
<i>Escontria chiotilla</i>	Chiotilla	Oaxaca	1906	Fruit	-10.0	1.2	0.9	This study, H23
<i>Myrtillocactus geometrizans</i>	Garambulla	Central Mexico	1891	Fruit	-10.5	-1.5	0.8	This study, H25
<i>Myrtillocactus geometrizans</i>	Garambulla	Central Mexico	1878	Fruit	-12.5	11.6	2.1	This study, H22
<i>Stenocereus pruinosus</i>	Pitaya	Oaxaca	1905	Fruit	-11.0	13.1	2.2	This study, H21
C3 taxa								
Legumes ^f								
<i>Acacia farnesiana</i>	Huizache	West Mexico	1902	Seed	-21.3	1.3	-	This study, H42
<i>Aeschynomene pinetorum</i>		Pacific Coast	1943	Pod	-24.5	-1.0	5.4	This study, H15
<i>Aeschynomene viscidula</i>		Oaxaca	1894	Pod	-24.2	-0.4	3.0	This study, H14
<i>Leucaena macrophylla</i>	Guaje	Central Mexico	1932	Fruit	-24.8	0.2	4.6	This study, H4
<i>Leucaena pulverulenta</i>	Tepeguaje	North Mexico	1930	Seed	-22.9	-1.5	3.7	This study, H34
<i>Lysiloma divaricata</i>	Tepeguaje	Oaxaca	1937	Seed	-21.4	2.7	-	This study, H37
<i>Phaseolus acutifolius</i>	Tepary bean	Northern Mexico	1940	Seed	-22.8	-1.3	4.4	This study, H39
<i>Phaseolus coccineus</i>	Runner bean	Northern Mexico	1906	Tuber	-24.9	2.8	1.1	This study, H38
<i>Senna polyantha</i>	Tepeguaje	Oaxaca	1894	Seed	-23.3	9.5	4.6	This study, H43
Non-legumes								
<i>Cardiospermum halicacabum</i>	Balloon vine	L. Central America	1922	Seed	-27.0	1.1	2.0	This study, H16
<i>Celtis pallida</i>	Desert hackberry	Oaxaca	1906	Fruit	-19.6	10.6	2.7	This study, H35
<i>Crataegus mexicana</i>	Hawthorn, xolocotzi	Central Mexico	1949	Fruit	-21.7	1.3	-	This study, H24
<i>Cucurbita ficifolia</i>	Chilicoyote squash	S. Maya Lowlands	1940	Seed	-23.6	8.2	5.7	This study, H1
<i>Cucurbita ficifolia</i>	Chilicoyote squash	S. Maya Lowlands	1940	Seed	-22.8	11.3	3.1	This study, H33
<i>Cucurbita moschata</i>	Ayote squash	S. Maya Lowlands	1922	Flower	-25.6	8.5	4.2	This study, H18

Appendix 4.5. continued

Taxa ^b	Common name ^c	Location collected ^d	Date collected	Botanical part	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	%N	Reference ^e
<i>Ipomoea pauciflora</i>	Morning glory	Oaxaca	1842	Seed	-25.7	8.0	1.4	This study, H10
<i>Jatropha curcas</i>	Physic nut	S. Maya Lowlands	1938	Seed	-29.4	4.7	4.1	This study, H12
<i>Malacomeles denticulata</i>	Madroño	North Mexico	1908	Fruit	-21.8	0.0	0.6	This study, H41
<i>Malacomeles denticulata</i>	Madroño	Oaxaca	1895	Fruit	-23.4	2.2	1.4	This study, H40
<i>Pinus cembroies</i>	Piñon pine	North Mexico	1889	Seed	-22.0	2.6	3.5	This study, H11
<i>Ribes ciliatum</i>	Currant	Central Mexico	1901	Fruit	-21.8	-3.6	1.4	This study, H9
<i>Ribes microphyllum</i>	Currant	Central Mexico	1896	Fruit	-21.5	3.4	2.7	This study, H8

Notes

^aWest Indies are not included.

^bOnly plants native to prehistoric Middle America are included. Taxa were selected because of their purported economic function during the Paleoindian/Archaic periods (Flannery 1986). Botanical names were verified in the International Plant Names Index (IPNI) internet database (www.ipni.org).

^cPlants commonly known in the United States are reported with their English names. Other plants are reported with either their common Spanish or regional names.

^dAll specimens were obtained from the Harvard University Herbaria.

^eSamples reported in this study are followed by their sample identification number. Gaps in the numbering system correspond to herbarium samples collected after 1950, which were ultimately not included in this study.

^fLegume classification verified in the International Legume Database and Information Service (ILDIS) internet database (www.ildis.org).

Appendix 4.6. Isotopic ratios of Middle American^a terrestrial fauna resources

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
MAMMALS								
Deer								
Cervidae	Deer	S. Maya Lowlands	Arch.	Collagen	-21.6	2.2	3.1	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	6.6	3.2	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	4.0	3.0	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-18.1	5.6	3.2	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Modern	Collagen ^d	-21.9	7.2	3.3	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-18.5	2.3	3.3	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-19.7	3.0	3.2	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-20.8	3.2	3.2	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-20.0	2.5	3.3	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-19.2	4.0	3.2	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-22.2	3.2	3.1	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-21.7	2.8	3.2	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-21.2	3.6	3.3	4
<i>Odocoileus virginianus</i>	White tailed deer	L. Central America	Arch.	Collagen	-20.6	3.5	3.2	4
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.8	3.4	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.9	8.8	3.3	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.1	4.9	3.2	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	4.5	3.3	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	4.4	3.5	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.4	4.2	3.5	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.8	4.2	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.9	7.8	3.3	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	3.6	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.1	3.9	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	5.8	3.3	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.5	4.9	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.7	4.4	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	4.7	3.4	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.6	4.3	3.4	6

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.2	2.7	3.2	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.1	3.5	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.6	3.6	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.7	4.4	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.0	4.7	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	5.2	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.0	4.7	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.1	4.4	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.2	5.1	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	5.4	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	4.3	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	-	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.3	5.2	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	3.8	3.6	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.5	3.6	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	3.5	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.3	3.7	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.3	3.5	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.6	3.1	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.7	4.7	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.8	4.9	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.2	4.9	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	7.4	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.3	7.8	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	4.3	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.1	3.9	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	6.8	3.6	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.1	-	3.0	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	3.5	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.6	4.9	3.3	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.4	3.7	3.4	3

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	3.7	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.8	5.1	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.1	4.6	3.4	3
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.5	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.5	-	2.9	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.8	-	3.0	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.9	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-18.8	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.8	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.4	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.7	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.3	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.9	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.2	-	2.9	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.3	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-17.5	-	2.8	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.6	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	-	3.0	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	-	3.5	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.2	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.8	-	3.5	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.1	-	2.9	2

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	-	2.9	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.9	-	3.0	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.2	-	3.1	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.9	-	3.0	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.1	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	-	3.5	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.1	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	-	3.0	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.2	-	2.8	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.6	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.7	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	-	3.5	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.2	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.3	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	-	3.2	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.8	-	3.4	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.1	-	3.3	2
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Modern	Collagen	-23.6	7.9	3.4	9, 10
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Modern	Unknown	-24.3	-	-	6
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Modern	Collagen	-23.3	-	-	5
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.5	5.2	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-7.3	5.0	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.7	4.7	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.3	6.6	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-12.7	6.7	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.8	4.2	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	5.4	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	5.7	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	5.6	3.2	7

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.4	3.3	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	6.6	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.3	5.0	3.5	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.3	5.9	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.3	6.1	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	5.0	3.4	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.8	6.0	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-17.9	4.1	3.5	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	4.1	3.5	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-18.9	7.2	3.1	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	7.5	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.5	7.6	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.7	4.7	3.4	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.1	5.9	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.3	2.7	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.9	3.9	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.0	3.4	3.1	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-20.6	3.7	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.7	4.2	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.0	6.3	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.0	4.0	3.4	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-19.4	3.8	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-22.4	6.1	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-21.3	4.2	3.2	7
<i>Odocoileus virginianus</i>	White tailed deer	S. Maya Lowlands	Arch.	Collagen	-16.8	5.2	3.3	7
<i>Odocoileus virginianus</i>	White tailed deer	Pacific Coast	Modern	Meat	-25.1	5.3	-	1
<i>Odocoileus virginianus</i>	White tailed deer	Pacific Coast	Modern	Meat	-24.1	10.7	-	1
<i>Odocoileus virginianus</i>	White tailed deer	Pacific Coast	Modern	Meat	-22.2	4.5	-	1
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-22.0	4.7	3.2	7
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-21.5	3.1	3.3	9, 10
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-14.0	5.1	3.2	9, 10

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-22.5	-	3.3	10
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-22.9	-	3.4	3
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Arch.	Collagen	-22.7	6.6	3.4	3
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Modern	Collagen	-22.0	4.3	-	8
<i>Mazama americana</i>	Brocket deer	S. Maya Lowlands	Modern	Collagen	-24.3	5.9	3.2	9, 10
Dog								
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-16.8	9.9	3.5	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-13.8	9.9	3.4	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-17.5	9.9	3.5	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-20.0	9.1	3.2	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-12.1	9.3	3.4	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-13.8	8.3	3.4	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-13.4	9.7	3.3	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.0	7.5	3.4	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-12.6	9.3	3.1	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-14.0	9.3	3.3	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.1	7.2	3.2	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-14.6	8.9	3.3	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-22.5	6.6	3.5	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-10.9	8.7	3.2	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-17.5	10.1	3.5	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-15.0	9.3	3.2	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-12.5	7.8	3.1	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-11.5	7.5	3.2	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-11.8	9.0	3.1	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.0	6.7	3.3	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-13.3	8.6	3.4	6
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-10.7	7.2	3.3	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.4	7.3	3.4	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-10.2	6.9	3.2	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-7.8	8.2	3.4	3

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.6	-	3.4	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.2	-	2.8	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.7	4.5	3.4	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.7	-	3.4	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.4	6.8	3.3	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.7	5.6	3.4	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.9	-	3.3	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.0	6.7	3.3	3
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-21.9	4.3	3.3	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-13.8	8.9	3.3	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-15.4	5.8	3.3	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-10.3	7.4	3.2	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.7	8.2	3.2	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-7.6	8.5	3.2	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.4	10.6	3.3	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-10.0	7.5	3.2	7
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-19.2	6.6	2.9	10
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.0	4.4	3.3	10
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.6	7.9	2.9	10
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-9.9	-	3.3	10
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.8	-	3.1	10
<i>Canis familiaris</i>	Dog	S. Maya Lowlands	Arch.	Collagen	-8.3	-	3.3	10
<i>Canis familiaris</i>	Dog	Pacific Coast	Modern	Meat	-11.7	10.1	-	1
<i>Canis familiaris</i>	Dog	Pacific Coast	Modern	Meat	-14.0	8.5	-	1
Peccary								
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.7	3.5	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-21.0	4.1	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.1	3.0	3.6	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-23.5	4.1	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-20.8	4.4	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-23.3	7.5	3.5	3

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.9	3.9	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.7	3.8	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-17.5	4.7	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.2	4.3	3.5	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-18.1	4.2	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-21.9	3.2	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-19.6	3.6	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-10.6	4.5	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-21.6	4.0	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.9	6.4	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.9	6.2	3.3	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.4	4.5	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-21.2	3.8	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-22.3	2.6	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Arch.	Collagen	-17.9	3.4	3.4	3
<i>Tayassuidae sp.</i>	Peccary	S. Maya Lowlands	Modern	Collagen	-23.3	-	-	5
<i>Tayassu pecari</i>	White-lipped peccary	S. Maya Lowlands	Arch.	Collagen	-21.4	3.3	3.0	9, 10
<i>Tayassu pecari</i>	White-lipped peccary	S. Maya Lowlands	Arch.	Collagen	-18.5	-	3.3	10
<i>Tayassu pecari</i>	White-lipped peccary	S. Maya Lowlands	Modern	Collagen	-23.7	4.7	3.2	9, 10
<i>Tayassu pecari</i>	White-lipped peccary	S. Maya Lowlands	Modern	Collagen	-24.2	4.3	2.9	9, 10
<i>Tayassu tajacu</i>	Collared peccary	L. Central America	Arch.	Collagen	-22.2	3.2	3.3	4
<i>Tayassu tajacu</i>	Collared peccary	S. Maya Lowlands	Arch.	Collagen	-19.6	-	3.3	10
<i>Tayassu tajacu</i>	Collared peccary	S. Maya Lowlands	Arch.	Collagen	-20.8	-	3.1	10
<i>Tayassu tajacu</i>	Collared peccary	S. Maya Lowlands	Arch.	Collagen	-20.7	-	3.3	10
<i>Tayassu tajacu</i>	Collared peccary	S. Maya Lowlands	Modern	Collagen	-13.0	6.1	3.3	9, 10
<i>Tayassu tajacu</i>	Collared peccary	S. Maya Lowlands	Modern	Collagen	-17.6	6.3	3.2	9, 10
Felids								
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-14.8	9.8	3.2	9
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-7.5	11.3	3.0	10
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-20.9	7.8	3.1	10
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-19.7	-	3.3	10

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-16.5	-	2.9	10
<i>Felis sp.</i>	Large cat	S. Maya Lowlands	Arch.	Collagen	-18.5	-	3.2	10
<i>Felis pardalis</i>	Ocelot	S. Maya Lowlands	Modern	Collagen ^e	-19.6	11.6	3.3	9, 10
Other Mammals								
<i>Cuniculus paca</i>	Paca	S. Maya Lowlands	Arch.	Collagen	-8.9	6.2	3.2	3
<i>Cuniculus paca</i>	Paca	S. Maya Lowlands	Arch.	Collagen	-9.3	-	3.2	10
<i>Cuniculus paca</i>	Paca	S. Maya Lowlands	Arch.	Collagen	-9.3	-	3.0	10
<i>Cuniculus paca</i>	Paca	S. Maya Lowlands	Modern	Collagen	-23.0	5.8	3.0	9, 10
<i>Cuniculus paca</i>	Paca	S. Maya Lowlands	Modern	Collagen	-22.6	5.3	3.3	9, 10
<i>Dasypus novencinctus</i>	Armadillo	S. Maya Lowlands	Modern	Collagen?	-27.2	-	-	6
<i>Didelphis marsupialis</i>	Oppossum	Pacific Coast	modern	Meat	-19.9	8.9	-	1
<i>Dasyprocta punctata</i>	Agouti	S. Maya Lowlands	Arch.	Collagen	-21.2	4.0	3.2	4
<i>Dasyprocta punctata</i>	Agouti	S. Maya Lowlands	Arch.	Collagen	-14.5	-	3.3	10
<i>Dasyprocta punctata</i>	Agouti	S. Maya Lowlands	Arch.	Collagen	-20.9	-	3.4	10
<i>Myocastor coypus</i>	Nutria	Pacific Coast	Modern	Meat	-25.9	8.0	-	1
<i>Myocastor coypus</i>	Nutria	Pacific Coast	Modern	Meat	-26.7	10.7	-	1
<i>Potos flavus</i>	Coati	S. Maya Lowlands	Modern	Collagen	-22.4	-	-	5
<i>Sylvilagus sp.</i>	Cottontail rabbit	Pacific Coast	Modern	Meat	-20.8	4.3	-	1
<i>Tapirus bairdii</i>	Tapir	S. Maya Lowlands	Modern	Collagen	-23.2	4.9	-	8
<i>Tapirus bairdii</i>	Tapir	S. Maya Lowlands	Modern	Collagen	-24.2	-	-	5
FOWL								
<i>Colombidae</i>	Dove	L. Central America	Arch.	Collagen	-20.8	2.7	3.3	4
<i>Crax rubra</i>	Great curassow	Pacific Coast	modern	Meat	-19.3	8.5	-	1
<i>Meleagris gallopavo</i>	Turkey	S. Maya Lowlands	Modern	Collagen	-9.9	8.3	3.4	9, 10
<i>Meleagris gallopavo</i>	Turkey (cooked)	Gulf Lowlands	Modern	Meat	-18.1	5.7	-	This study, SV60
REPTILES								
Iguanas								
Iguanidae	Iguana	Pacific Coast	Modern	Meat	-25.7	2.3	-	1
Iguanidae	Iguana	Pacific Coast	Modern	Meat	-24.4	4.3	-	1

Appendix 4.6. continued

Taxa	Common name	Location	Period	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N	Reference ^c
<i>Iguana iguana</i>	Iguana	Pacific Coast	Modern	Meat	-21.6	14.9	-	1
<i>Iguana iguana</i>	Iguana	L. Central America	Arch.	Collagen	-19.7	5.6	3.3	4
<i>Iguana iguana</i>	Iguana	L. Central America	Arch.	Collagen	-21.6	3.9	3.3	4
<i>Iguana iguana</i>	Iguana	L. Central America	Arch.	Collagen	-21.3	4.3	3.3	4
<i>Iguana iguana</i>	Iguana	L. Central America	Arch.	Collagen	-19.6	5.8	3.2	4
Snakes								
<i>Boa constrictor</i>	Boa constrictor	Pacific Coast	Modern	Meat	-19.1	7.9	-	1
<i>Boa constrictor</i>	Boa constrictor	Pacific Coast	Modern	Meat	-23.4	9.3	-	1
<i>Boa constrictor</i>	Boa constrictor	Pacific Coast	Modern	Meat	-16.5	11.5	-	1
<i>Bothrops asper</i>	Pit viper	S. Maya Lowlands	Modern	Collagen	-22.4	10.0	3.1	9, 10
<i>Crotalus durissus ssp.</i>	Rattle snake	Pacific Coast	Modern	Meat	-22.0	10.2	-	1
<i>Crotalus durissus ssp.</i>	Rattle snake	Pacific Coast	Modern	Meat	-20.1	7.4	-	1
<i>Micrurus sp.</i>	Coral snake	S. Maya Lowlands	Modern	Collagen	-21.6	12.7	3.8	9, 10
<i>Porthidium nummifer</i>	Pit viper	S. Maya Lowlands	Modern	Collagen	-24.4	17.8	2.9	9, 10
Unidentified	Viper	Pacific Coast	Modern	Meat	-17.8	9.3	-	1
INSECTS								
<i>Hypopta agavis</i>	Maguey worm	Oaxaca	Modern	Meat	-26.4	6.0	-	This study, SO41
<i>Hypopta agavis</i>	Maguey worm	Oaxaca	Modern	Meat	-26.4	6.1	-	This study, SO41
<i>Sphenarium spp.</i>	Chapulines grande	Oaxaca	Modern	Meat	-28.4	4.7	-	This study, WO77
<i>Sphenarium spp.</i>	Chapulines grande	Oaxaca	Modern	Meat	-27.2	8.6	-	This study, SO43
<i>Sphenarium spp.</i>	Chapulines pequeno	Oaxaca	Modern	Meat	-27.0	4.2	-	This study, SO42
Unidentified	Ants	S. Maya Lowlands	Modern	Unknown	-19.8	-	-	6
Unidentified	Armadillo earth worms	S. Maya Lowlands	Modern	Unknown	-22.0	-	-	6
Unidentified	Bee honey	Gulf Lowlands	Modern	Honey	-8.9	7.1	-	This study, SV78
Unidentified	Termites	S. Maya Lowlands	Modern	Unknown	-26.9	-	-	6

Notes:

^aWest Indies are not included.

^bCollagen samples are from bone unless otherwise noted.

^cSamples reported in this study are followed by their sample identification number. References to previously published samples are as follows: 1 = Chisholm and Blake 2006; 2 = Emery, Wright, and Schwarcz 2000; 3 = Gerry 1993; 4 = Norr 1991; 5 = van der Merwe et al. 2000; 6 = White et al. 2001;

7 = White et al. 2004; 8 = White and Schwarcz 1989; 9 = Wright 1994; 10 = Wright 2006

^dAntler collagen, ^eDentine collagen

Appendix 4.7. Isotopic ratios of Middle American^a aquatic fauna resources

Taxa	Common name	Location	Collection	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^c	Reference ^d
FISH								
Marine fish								
<i>Aetobatis narinari</i>	Spotted eagle ray	Pacific Coast	Modern	Meat	-12.0	18.5	-	1
<i>Aetobatis narinari</i>	Spotted eagle ray	Pacific Coast	Modern	Meat	-15.8	13.0	-	1
<i>Callorhynchus callorynchus</i>	Elephantfish	Pacific Coast	Modern	Meat	-14.2	16.7	-	1
<i>Caranx caballus</i>	Green jack	Pacific Coast	Modern	Meat	-16.3	11.8	-	1
<i>Caranx caninus</i>	Pacific crevalle jack	Pacific Coast	Modern	Meat	-14.8	15.2	-	1
<i>Centropomus nigrescens</i>	Black snoot	Gulf Coast	Modern	Meat	-24.9	12.3	-	1
<i>Diplectrum cf. pacificum</i>	Sand perch (inshore)	Pacific Coast	Modern	Meat	-15.0	13.7	-	1
<i>Hemicaranx leucurus</i>	Yellowfin jack	Pacific Coast	Modern	Meat	-14.6	13.9	-	1
<i>Isopisthus remifer</i>	Silver weakfish	Pacific Coast	Modern	Meat	-14.5	14.9	-	1
<i>Istiophorus platypterus</i>	Sailfish	Pacific Coast	Modern	Meat	-15.4	13.2	-	1
<i>Larimus acclivis</i>	Steeplined drum	Pacific Coast	Modern	Meat	-15.7	-	-	1
<i>Loliolopsis diomedea</i>	Dart squid	Pacific Coast	Modern	Meat	-16.6	11.9	-	1
<i>Lutjanus peru</i>	Pacific red snapper	Pacific Coast	Modern	Meat	-28.7	8.7	-	1
<i>Mugil cruema</i>	White mullet	Pacific Coast	Modern	Meat	-12.4	10.3	-	1
<i>Mugil cruema</i>	White mullet	Pacific Coast	Modern	Meat	-20.9	4.9	-	1
<i>Nebris occidentalis</i>	Pacific smalleye croaker	Pacific Coast	Modern	Meat	-14.0	13.9	-	1
<i>Octopus sp.</i>	Octopus	Pacific Coast	Modern	Meat	-13.7	9.7	-	1
<i>Oligoplites saurus</i>	Leatherjacket	Pacific Coast	Modern	Meat	-13.0	10.0	-	1
<i>Oligoplites saurus</i>	Leatherjacket	Pacific Coast	Modern	Meat	-13.5	14.8	-	1
<i>Paralonchurus goodei</i>	Goode croaker	Pacific Coast	Modern	Meat	14.2	15.5	-	1
<i>Pseudupeneus squamipinnis</i>	Goatfish	Pacific Coast	Modern	Meat	-14.1	16.0	-	1
<i>Selar crumenophthalmus</i>	Bigeye scad	Pacific Coast	Modern	Meat	-16.1	12.0	-	1
<i>Xiphopenaeus riveti</i>	Pacific seabob	Pacific Coast	Modern	Meat	-13.9	10.2	-	1
Unidentified	Peje caite	Pacific Coast	Modern	Meat	-14.6	13.4	-	1
Estuary Fish								
<i>Ariopsis sp.</i>	Marine catfish	Pacific Coast	Modern	Meat	-25.5	5.9	-	1
<i>Ariopsis sp.</i>	Marine catfish	Pacific Coast	Modern	Meat	-24.4	6.6	-	1
<i>Ariopsis sp.</i>	Marine catfish	Pacific Coast	Modern	Meat	-14.2	12.9	-	1
<i>Ariopsis sp.</i>	Marine catfish	Pacific Coast	Modern	Meat	-14.1	17.7	-	1
<i>Ariopsis sp.</i>	Marine catfish	Pacific Coast	Modern	Meat	-13.4	15.7	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-17.9	-	-	1

Appendix 4.7. continued

Taxa	Common name	Location	Collection	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^c	Reference ^d
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-22.7	-	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-23.3	-	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-17.7	6.0	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-20.1	-	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-19.3	3.3	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-19.4	-1.0	-	1
<i>Atractosteus spatula</i>	Alligator gar	Pacific Coast	Modern	Collagen	-20.9	0.7	-	1
<i>Cichlasoma sp.</i>	Mojarra	Pacific Coast	Modern	Meat	-26.7	6.7	-	1
<i>Cichlasoma sp.</i>	Mojarra	Pacific Coast	Modern	Meat	-14.0	13.5	-	1
<i>Diapterus peruvianus</i>	Peruvian mojarra	Pacific Coast	Modern	Meat	-16.4	8.8	-	1
<i>Eleotris picta</i>	Spotted sleeper	Pacific Coast	Modern	Meat	-28.2	4.9	-	1
<i>Parapsettus panamensis</i>	Panama spadefish	Pacific Coast	Modern	Meat	-15.0	15.4	-	1
<i>Polydactylus opercularis</i>	Yellow bobo	Pacific Coast	Modern	Meat	-14.3	12.9	-	1
<i>Pomadasys elongatus</i>	Elongate grunt	Pacific Coast	Modern	Meat	-18.8	10.5	-	1
Unidentified	Peje gallo robato (?)	Pacific Coast	Modern	Meat	-22.3	10.4	-	1
Freshwater Fish								
<i>Ictaluridae sp.</i>	Catfish	S. Maya Lowlands	Modern	Collagen	-22.3	11.6	3.3	3
<i>Lile stolifera</i>	Pacific piquitinga	Pacific Coast	Modern	Meat	-19.2	6.8	-	1
<i>Petenia splendida</i>	Bass	S. Maya Lowlands	Modern	Collagen	-29.5	12.3	-	3
<i>Petenia splendida</i>	Bass	S. Maya Lowlands	Modern	Collagen	-29.6	11.9	-	3
<i>Petenia splendida</i>	Bass	S. Maya Lowlands	Modern	Meat	-32.1	11.6	-	3
<i>Petenia splendida</i>	Bass	S. Maya Lowlands	Modern	Meat	-32.7	13.3	-	3
<i>Selenaspis dowii</i>	Catfish	L. Central America	Arch	Collagen	-14.3	9.0	3.3	2
<i>Selenaspis dowii</i>	Catfish	L. Central America	Arch	Collagen	-12.6	11.5	3.3	2
<i>Vieja fenestrata</i>	Guapote	S. Maya Lowlands	Modern	Collagen	-30.8	9.3	-	3
<i>Vieja fenestrata</i>	Guapote	S. Maya Lowlands	Modern	Collagen	-29.9	11.5	3.5	3
Unidentified	Catfish	S. Maya Lowlands	Modern	Meat	-29.4	18.0	-	3
Unidentified	Colorada fish	S. Maya Lowlands	Modern	Collagen	-28.6	9.2	-	3
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.6	15.2	3.2	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-10.1	11.9	3.2	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.6	13.4	3.2	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.1	12.5	3.2	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.8	10.9	3.4	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.5	13.6	3.2	2

Appendix 4.7. continued

Taxa	Common name	Location	Collection	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^c	Reference ^d
Unidentified	Unidentified	L. Central America	Arch	Collagen	-9.0	12.0	3.2	2
Unidentified	Unidentified	L. Central America	Arch	Collagen	-10.2	14.4	3.3	2
INVERTEBRATES								
Estuary Molluscs and Shellfish								
Unidentified	Crab	Pacific Coast	Modern	Meat	-22.1	5.6	-	1
Unidentified	Crab	Pacific Coast	Modern	Meat	-23.9	6.0	-	1
Unidentified	Crab	Gulf Coast	Modern	Meat	-20.3	8.6	-	This study, SV79
<i>Mytilis sp.</i>	Mussel	Pacific Coast	Modern	Meat	-16.0	8.2	-	1
Unidentified	Clam	Pacific Coast	Modern	Shell	-20.8	-1.8	-	1
Unidentified	Crayfish	Gulf Coast	Modern	Meat	-26.9	10.2	-	This study, SV81
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-25.4	6.3	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-20.3	5.9	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-25.9	4.8	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-11.7	2.2	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-17.9	2.1	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-14.4	10.7	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-14.2	12.2	-	1
Unidentified	Shrimp	Gulf Coast	Modern	Meat	-16.6	10.7	-	This study, SV29
Unidentified	Shrimp	Gulf Coast	Modern	Meat	-19.3	9.7	-	This study, SV28
Unidentified	Shrimp	Gulf Coast	Modern	Meat	-19.9	10.5	-	This study, SV80
Freshwater Molluscs and Shellfish								
<i>Pachychilus glaphyrus</i>	River snail	S. Maya Lowlands	Modern	Meat	-33.6	4.9	-	3
<i>Pachychilus glaphyrus</i>	River snail	S. Maya Lowlands	Modern	Meat	-30.0	5.5	-	3
Unidentified	Crab	Pacific Coast	Modern	Meat	-17.2	3.3	-	1
Unidentified	Shrimp	Pacific Coast	Modern	Meat	-15.7	10.5	-	1
FOWL								
<i>Cairina moschata</i>	Muscovy Duck	L. Central America	Arch.	Collagen	-11.6	5.7	3.3	2
<i>Fulica americana</i>	American coot	Pacific Coast	Modern	Meat	-18.7	7.0	-	1
<i>Mycteria americana</i>	Wood stork	Pacific Coast	Modern	Meat	-21.3	-	-	1
REPTILES								
Turtle								
Chelonidae	Turtle	L. Central America	Modern	Collagen	-13.5	6.6	-	2
<i>Chelonia mydas</i>	Green sea turtle	Pacific Coast	Modern	Meat	-14.7	12.6	-	1
<i>Trachemys sp.</i>	Pond slider turtle	Pacific Coast	Modern	Meat	-26.6	5.7	-	1

Appendix 4.7. continued

Taxa	Common name	Location	Collection	Tissue ^b	$\delta^{13}\text{C}_{\text{PDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N ^c	Reference ^d
<i>Trachyemys sp.</i>	Pond slider turtle	Pacific Coast	Modern	Meat	-27.7	4.9	-	1
<i>Trachyemys sp.</i>	Pond slider turtle	Pacific Coast	Modern	Meat	-26.4	9.9	-	1
<i>Kinosternon sp.</i>	Mud turtle	Pacific Coast	Modern	Meat	-25.9	5.9	-	1
<i>Kinosternon sp.</i>	Mud turtle	Pacific Coast	Modern	Meat	-16.9	6.4	-	1
Unidentified	Turtle	Pacific Coast	Modern	Meat	-23.2	5.3	-	1
Crocodile								
<i>Crocodylus acutus</i>	Crocodile	Pacific Coast	Modern	Meat	-22.9	4.2	-	1
<i>Crocodylus acutus</i>	Crocodile	Pacific Coast	Modern	Meat	-23.7	3.3	-	1
<i>Crocodylus acutus</i>	Crocodile	Pacific Coast	Modern	Meat	-26.9	6.5	-	1

Notes:

^aWest Indies are not included

^bCollagen samples are from bone unless otherwise noted.

^cArchaeological samples with no reported C/N ratio or with C/N ratios outside the accepted 2.9-3.6 range were excluded.

^dSamples reported in this study are followed by their sample identification number. References to previously published samples are as follows: 1 = Chisholm and Blake 2006; 2 = Norr 1991; 3 = Wright 1994

Appendix 4.8. $\Delta_{\text{collagen-meat}}$ offset in modern terrestrial and aquatic fauna

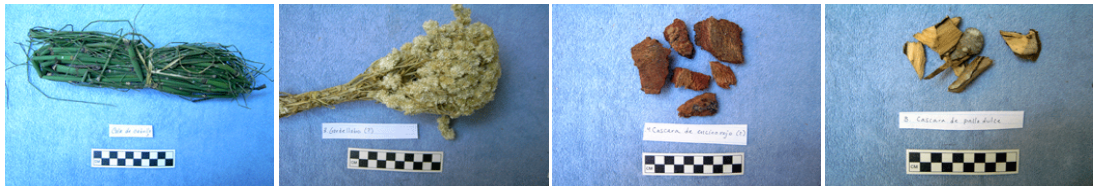
Taxa	Common name	N ^a	$\Delta^{13}\text{C}_{\text{coll-meat}}$			$\Delta^{15}\text{N}_{\text{coll-meat}}$			Ref. ^b	
			Avg $\pm 1\sigma$	Max	Min	N	Avg $\pm 1\sigma$	Max		Min
MAMMALS										
<i>Aepyceros melampus</i>	Impala	1	1.7	-	-	0	-	-	-	6
<i>Alcelaphus buselaphus</i>	Hartebeest	1	1.9	-	-	0	-	-	-	6
<i>Antidorcas marsupialis</i>	Springbok	3	1.9 \pm 0.6	2.0	1.8	2	0.3	1.6	-1.0	4, 6
<i>Arctocephalus pusillus</i>	Cape fur seal	0	-	-	-	1	-0.1	-	-	4
<i>Lepus capensis</i>	Hare	0	-	-	-	3	0.3 \pm 3.0	3.6	-2.3	4
<i>Mus musculus</i>	Mouse	20	2.4 \pm 0.7	3.8	1.4	1	-0.3	-	-	1, 2, 5
<i>Oryx gazella</i>	Gemsbok	1	0.7	-	-	0	-	-	-	6
<i>Ovis aries</i>	Sheep	2	4.1	4.1	4	0	-	-	-	6
<i>Pedetes capensis</i>	Springhare	0	-	-	-	1	-0.8	-	-	4
<i>Phacochoerus</i> sp.	Warthog	1	1.7	-	-	0	-	-	-	6
<i>Raphicerus campestris</i>	Steenbok	0	-	-	-	2	-0.1	0.2	-0.4	4
<i>Sus domesticus</i>	Pig	9	1.4 \pm 0.3	1.8	1.0	9	-0.3 \pm 0.3	0.3	-0.8	7, 8, 9
<i>Tragelaphus strepsiceros</i>	Kudu	2	2.4	2.8	1.9	0	-	-	-	6
	Mammal total	40	2.1 \pm 0.8	4.1	1.0	19	-0.1 \pm 0.4	1.6	-2.3	
FISH										
<i>Anisotremus virginicus</i>	Porkfish	1	3.8	-	-	1	-1.8	-	-	3
<i>Balistes vetula</i>	Queen triggerfish	2	4.2	4.5	3.8	1	-1.4	-	-	3
<i>Epinephelus striatus</i>	Red hind	1	4.5	-	-	1	-0.8	-	-	3
<i>Haemulon flavolineatum</i>	Yellow grunt	3	3.4 \pm 0.6	3.9	2.7	4	-2.2 \pm 0.6	-1.5	-2.8	3
<i>Haemulon parra</i>	Sailor's choice	1	3.3	-	-	1	-2	-	-	3
<i>Hemiramphus</i> sp.	Half beak	2	1.6	2.1	1.1	2	-1.4	-1.3	-1.4	3
<i>Lutjanus jocu</i>	Dog snapper	1	3.9	-	-	1	-1.3	-	-	3
<i>Lutjanus mahogani</i>	Hog snapper	1	2.7	-	-	1	-1.9	-	-	3
<i>Lutjanus synagris</i>	Lane snapper	1	3.7	-	-	1	-2.9	-	-	3
<i>Ocyurus chrysurtus</i>	Yellowtail snapper	1	4.5	-	-	1	-1	-	-	3
<i>Petenia splendida</i>	Bass	2	2.9	3.2	2.5	2	-0.4	0.3	-1	10
<i>Priacanthus cruentatus</i>	Bigeye	1	3.0	-	-	1	-0.9	-	-	3
	Fish total	18	3.3 \pm 0.9	4.5	1.1	18	-1.5 \pm 0.8	2.2	-2.9	

Notes:

^aIncludes only individuals for which paired collagen and meat samples are available.

^b1=DeNiro and Epstein 1978; 2=DeNiro and Epstein 1981; 3=Keegan and DeNiro 1988; 4=Sealy et al. 1987; 5=Tieszen and Fagre 1993; 6=Vogel 1978; 7=Warinner and Tuross 2009; 8=Warinner and Tuross in press; 9=Warinner and Tuross unpublished; 10=Wright 1994.

Appendix 4.9. Photographic collection of January 2006 Valley of Oaxaca market products

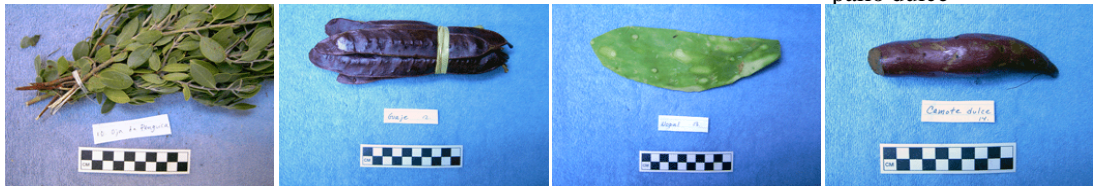


WO2. *Equisetum* sp., cola de caballo

WO3. *Gnaphalium* sp., gordolobo

WO4. *Quercus rubra*, cascara de encino rojo

WO8. *Eysenhardtia polystachya*, cascara de pallo dulce

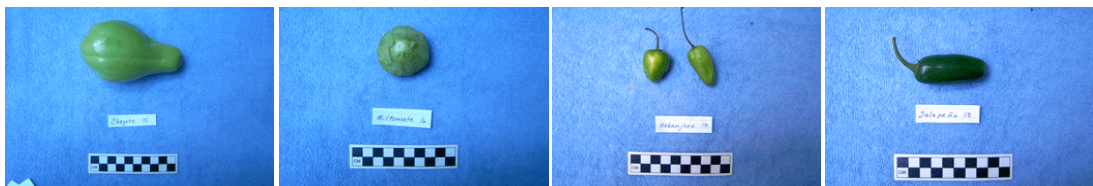


WO10. *Arctostaphylos pungens*, pinguica

WO12. *Leucaena esculenta*, guaje

WO13. *Opuntia ficus-indica*, nopal cactus

WO14. *Ipomaea batatas*, sweet potato

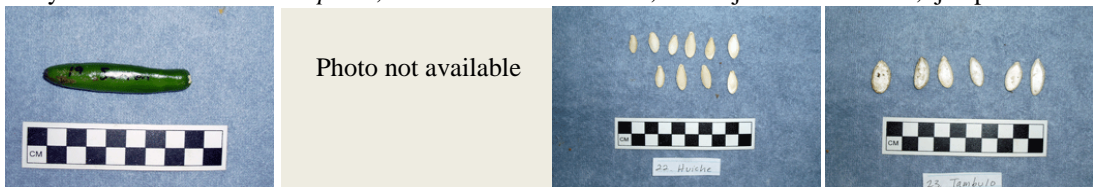


WO15. *Sechium edulis*, chayote

WO16. *Physalis philadelphica*, tomatillo

WO17. *Capsicum chinense*, habanero

WO18. *Capsicum annum*, jalapeno



WO19. *Capsicum annum*, serrano

WO20. *Capsicum annum*, jalapeno †

WO22. *Cucurbita* sp., huiche squash

WO23. *Cucurbita* sp., tambulo squash

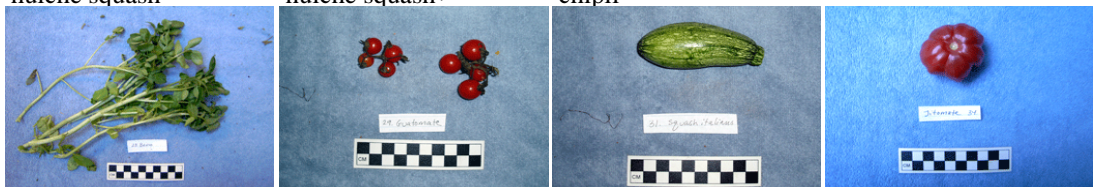


WO24. *Cucurbita* sp., huiche squash

WO25. *Cucurbita* sp., huiche squash†

WO26. *Crotalaria* sp., chipil

WO27. *Zea mays*, maize



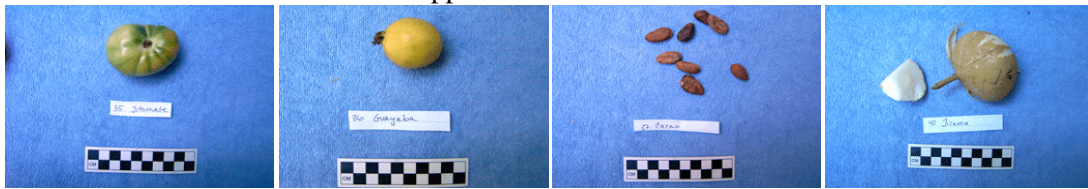
WO28. *Nasturium officinale*, berro

WO29. *Lycopersicon esculentum*, guatomate†

WO31. *Cucurbita* sp., zucchini

WO34. *Lycopersicon esculentum*, jitomate rojo

Appendix 4.9. continued

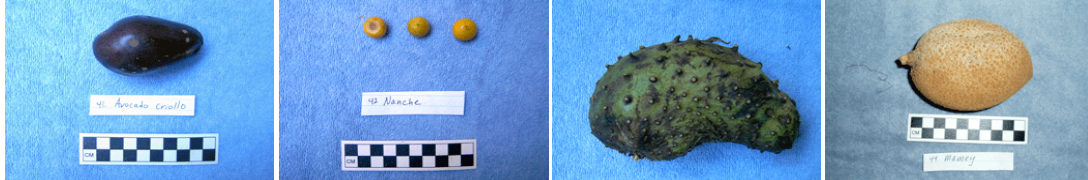


WO35. *Lycopersicon esculentum*, jitomate†

WO36. *Psidium guajava*, guava

WO37. *Theobroma cacao*, cacao

WO40. *Pachyrhizus erosus*, jicama



WO41. *Persea americana*, aguacate

WO42. *Byrsonima crassifolia*, nance

WO43. *Annona muricata*, guanabana

WO44. *Pouteria sapota*, mamey

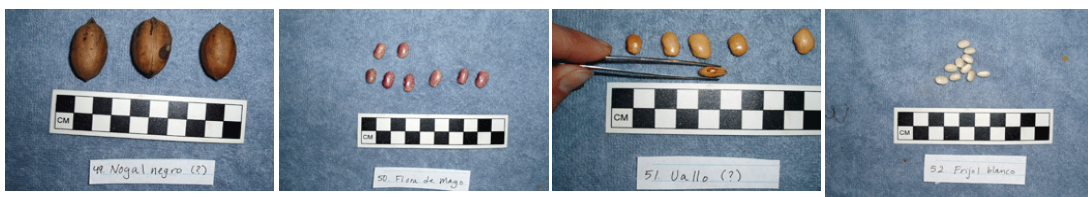


WO45. *Spondias purpurea*, ciruela

WO46. *Manilkara zapotilla*, chicozapote

WO47. *Diospyros digyna*, zapote negro

WO48. *Diospyros digyna*, zapote negro



WO49. *Juglans* sp., black walnut†

WO50. *Phaseolus vulgaris*, flor de mayo bean†

WO51. *Phaseolus vulgaris*, uallo bean

WO52. *Phaseolus vulgaris*, white bean



WO53. *Phaseolus vulgaris*, black bean

WO54. *Theobroma cacao*, cacao

WO60. *Helianthus annuus*, sunflower

WO63. *Phaseolus vulgaris*, mixed beans†



















WO66. *Phaseolus vulgaris*, red bean

WO68. *Zea mays*, blanco maize

WO69. *Zea mays*, negro maize

WO70. *Zea mays*, blanco maize (for pozole)

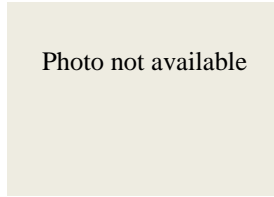
Appendix 4.9 continued

			
WO71. <i>Zea mays</i> , amarillo maize	WO72. <i>Salvia hispanica</i> , chiat†	WO73. <i>Cucurbita</i> sp., yellow squash†	WO74. <i>Cucurbita</i> sp., white squash†
		Photo not available	
WO77. <i>Sphenarium</i> sp., chapulines grandes	WO83. <i>Agave</i> sp., pulque	WO84. <i>Amaranthus</i> sp., amaranth†	WO86. <i>Crotalaria</i> sp., chipil
	Photo not available		
WO88. <i>Ipomaea batatas</i> , sweet potato	WO89. <i>Capsicum annuum</i> , pimienta	WO90. <i>Manihot esculenta</i> , yucca	WO91. <i>Lippia graveolens</i> , Mexican oregano
	Photo not available		
WO93. <i>Leucaena</i> sp., tepeguaje†	WO94. <i>Bixa orellana</i> , achiote	WO98. <i>Prosopis</i> sp., mesquite†	WO100. <i>Sechium edulis</i> , spiny chayote
Photo not available			
WO101. <i>Manilkara zapotilla</i> , chicozapote	WO102. <i>Capsicum annuum</i> , chile guajillo†	WO103. <i>Capsicum annuum</i> , chile†	WO104. <i>Capsicum annuum</i> , chile ancho†
			
WO105. <i>Capsicum annuum</i> , chile ancho†	WO106. <i>Capsicum annuum</i> , chile†	WO107. <i>Capsicum annuum</i> , chile†	WO108. <i>Capsicum annuum</i> , chile de arbol†

Appendix 4.9. continued



WO109. *Capsicum annuum*, chile†



WO110. *Chenopodium ambrosioides*, epazote

Note: Gaps in the numbering system represent plants that were identified as non-native introductions. These plants were excluded from further analysis. †Multiple samples from this specimen were measured.

Appendix 4.10. Photographic collection of July 2006 Valley of Oaxaca market products

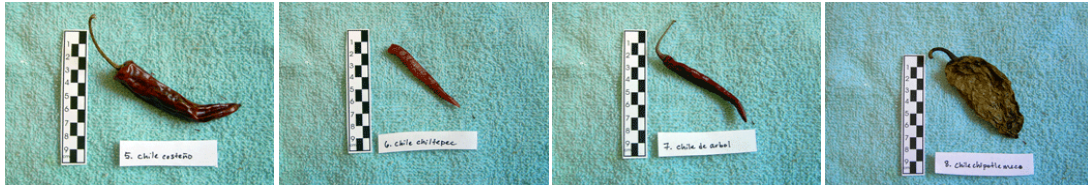


SO1. *Capsicum annuum*, chile pulla

SO2. *Capsicum annuum*, chile de onza

SO3. *Capsicum annuum*, chile morita

SO4. *Capsicum annuum*, chile costeno amarillo



SO5. *Capsicum annuum*, chile costeno

SO6. *Capsicum annuum*, chile chiltepec

SO7. *Capsicum annuum*, chile de arbol

SO8. *Capsicum annuum*, chipotle meco



SO9. *Capsicum annuum*, chile cascabe

SO10. *Capsicum annuum*, chile mulato

SO11. *Capsicum annuum*, chipotle rojo

SO12. *Capsicum annuum*, chile guajillo



SO13. *Capsicum annuum*, chile ancho rojo

SO14. *Capsicum annuum*, pasilla mexicana

SO15. *Capsicum annuum*, chile tuxtla

SO16. *Capsicum annuum*, chile chintepe

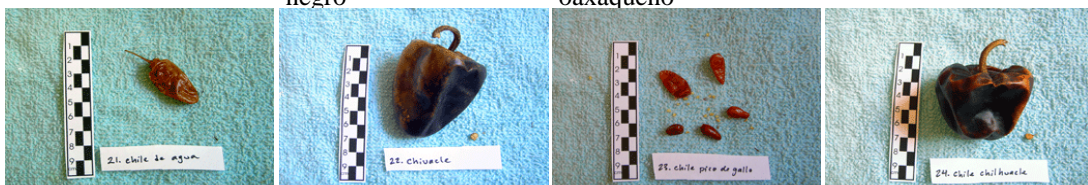


SO17. *Capsicum annuum*, chile mulato

SO18. *Capsicum annuum*, chile ancho negro

SO19. *Capsicum annuum*, pasilla oaxaquena

SO20. *Capsicum annuum*, chile de onza



SO21. *Capsicum annuum*, chile de agua

SO22. *Capsicum annuum*, chihuacle

SO23. *Capsicum annuum*, pico de gallo

SO24. *Capsicum annuum*, chile chihuacle rojo

Appendix 4.10 continued

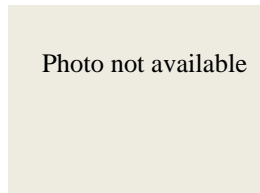


SO25. *Capsicum annuum*, chile de onza amarillo

SO26. *Capsicum annuum*, chile costeno amarillo

SO28. *Spondias purpurea*, ciruela

SO29. *Passiflora edulis*, maracuya



SO30. *Psidium guajava*, guava

SO31. *Persea americana*, aguacate

SO32. *Sechium edulis*, chayote grande

SO33. *Sechium edulis*, chayote

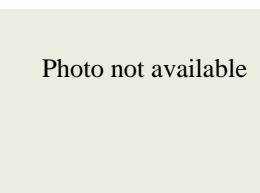


SO34. *Persea americana*, aguacate

SO35. *Prosopis* sp., mesquite

SO36. *Opuntia ficus-indica*, nopal cactus

SO37. *Persea americana*, aguacate

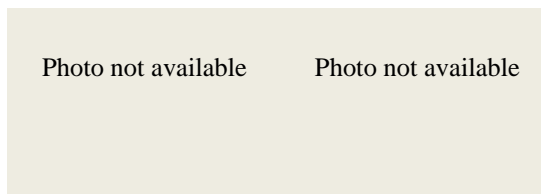


SO38. *Opuntia* sp., red prickly pear

SO39. *Opuntia* sp., green prickly pear

SO41. *Hypopta agavis*, gusanos de maguey

SO42. *Sphenarium* sp., chapulines pequenos



SO43. *Sphenarium* sp., chapulines grandes

SO44. *Opuntia* sp., green prickly pear

SO45. *Cucurbita* sp., squash

Note: Gaps in the numbering system represent plants that were identified as non-native introductions. These plants were excluded from further analysis. †Multiple samples from this specimen were measured.

Appendix 4.1.1. Photographic collection of July 2006 Villahermosa market products



SV1. *Byrsonima crassifolia*, nance



SV2. *Carica papaya*, papaya



SV3. *Psidium guajava*, guava



SV6. *Persea americana*, avocado



SV7. *Capsicum annuum*, chile picante



SV8. *Capsicum annuum*, chile dulce



SV9. *Capsicum chinense*, habanero



SV10. *Manihot esculenta*, yucca



SV11. *Sechium edulis*, chayote



SV13. *Cucurbita* s.p., squash



SV14. *Hylocereus undatus*, pitaya



SV15. *Parmentiera edulis*, guajilote



SV17. *Cucurbita* sp., zucchini



SV18. *Opuntia ficus-indica*, nopal cactus



SV19. *Pachyrhizus erosus*, jicama



SV23. *Lycopersicon esculentum*, jitomate rojo



SV24. *Lycopersicon esculentum*, jitomate verde



SV25. *Opuntia* sp., green prickly pear



SV26. *Capsicum annuum*, chile



SV28/29. Unidentified, dried shrimp



SV30. *Bactris* sp., chiquijul



SV31. *Zea mays*, maize



SV32. *Ananas cosmosus*, pineapple

Appendix 4.11 continued



SV37. *Asclepias curassavica*, cancerillo



SV38. *Zea mays*, white maize



SV39. *Phaseolus vulgaris*, bayo bean



SV40. *Phaseolus vulgaris*, flor de mayo bean



SV42. *Cucurbita* sp., pipian squash



SV45. *Helianthus annuus*, sunflower



SV55. *Arctosaphylos pungens*, pinguica



SV56. *Agastache mexicana*, toronjil



SV57. *Phaseolus vulgaris*, black bean



SV58. *Phaseolus vulgaris*, white bean



SV59. *Cucurbita* sp., squash



SV60. *Meleagris gallopavo*, cooked turkey meat



SV61. *Cnidoscolus chayamansa*, chaya



SV62. *Capsicum annuum*, chile anachiito



SV65. *Crotalaria* sp., chipil



SV67. *Chenopodium ambrosioides*, epazote



SV68. *Sicana odorifera*, melocoton, cassabanana



SV70. *Anonna scleroderma*, bandesopa, poshte



SV71. *Xanthosoma sagittifolium*, macal



SV73. *Ipomaea batatas*, sweet potato

Appendix 4.11 continued



SV74. *Passiflora edulis*,
maracuya

SV75. *Psidium*
guajava, guava

SV76. *Pouteria sapota*,
mamey

SV77. *Manilkara*
zapotilla, chicozapote



SV78. Bee honey

SV79. Unidentified crab

SV80. Unidentified
shrimp

SV81. Unidentified
crayfish

Note: Gaps in the numbering system represent plants that were identified as non-native introductions. These plants were excluded from further analysis. †Multiple samples from this specimen were measured.

**CHAPTER 5: DEATH, DEMOGRAPHY, AND DIET IN EARLY COLONIAL
NEW SPAIN: A SCIENTIFIC INVESTIGATION OF TWO 16TH CENTURY CEMETERIES
AT TEPOSCOLULA YUCUNDAA¹**

A portion of this chapter was presented in the paper “More than 100% maize” at the 2008 Society for American Archaeology conference in Vancouver, Canada.

5.1. Chapter summary

This study explores evidence for changing health, demography, religious practices, and economy in early colonial New Spain through mortuary, paleodemographic, stable isotopic, and archaeogenetic analysis of two cemeteries at the Mixtec site of Teposcolula-Yucundaa, located in Oaxaca, Mexico. One cemetery, located in the site’s Grand Plaza, is shown to be a catastrophic death assemblage, most likely resulting from the unidentified 1545-1548 “cocoliztli” pandemic. Four primary conclusions can be drawn from the Teposcolula study: 1) epidemic disease extended beyond the areas of historical record and played an important role in facilitating the Spanish coerced resettlement program known as *congregación*; 2) although 16th century population decline was severe, evidence of increased genetic drift through altered haplogroup frequencies is not apparent; 3) the adoption of Christianity did not mean the total abandonment of traditional practices, even at successful mission sites; and 4) in contrast to production, consumption of European agricultural staples was minimal. This study reaffirms the importance of archaeological and bioarchaeological evidence in investigating complex social and biological processes of the past.

¹This research was conducted under permit 401-3-5113 issued by the Instituto Nacional de Antropología e Historia de Mexico (INAH), and was supported by grants from the David Rockefeller Center for Latin American Studies, the Harvard University Owens Fund, and the Harvard University Graduate Student Council. I am deeply indebted to the entire Proyecto Arqueológico Pueblo Viejo Teposcolula-Yucundaa archaeological team, especially to the project directors Dr. Nelly Robles Garcia and Dr. Ronald Spores, and I owe a special thanks to archaeologist Laura Diego and physical anthropologist Laura Roldán.

5.2. Introduction

In 1550, while passing through the Mixteca Alta on his way to Peru, Viceroy Antonio de Mendoza unexpectedly interfered with the planned relocation of an indigenous mountaintop community. He wrote to his successor, Viceroy Luis de Velasco, in Mexico City Tenochtitlan, “do not permit it, as it will destroy that town” (Torre Villar and Navarro de Anda 1991:115).² This was an odd request, given that Mendoza was the architect of the Spanish colonial policy of *congregación*, a coerced resettlement program aimed at relocating indigenous communities into planned Spanish-style towns. In the end, Velasco approved the relocation in 1552, and the new *alcaldía mayor* (regional capital) of San Pedro y San Pablo de Teposcolula was established in the valley (Calderón Galván 1988:64).

In subsequent centuries, Mendoza’s warning proved all too true, and after a brief boom time in the 1550s and 1560s, Teposcolula, like other Mixtec communities, fell victim to a number of hardships, including multiple epidemics, the exhaustion of gold placer deposits, and the collapse of the Mexican silk industry (Borah 2000; Romero Frizzi 1990; Spores 1984). To counterbalance their economic losses, Mixtecs at Teposcolula and other communities increasingly rented out their mountain slopes for sheep grazing, which led to uncontrolled erosion, soil infertility, and the eventual agricultural collapse of what had once been described by the Spanish as the land of milk and honey (Burgoa 1934; Pérez Rodríguez 2006; Terreciano 2001).

The role of pastoralism in the downfall of many rural Mexican communities has been well studied (Melville 1994; Miranda 1958; Romero Frizzi 1990; Terreciano 2001), especially for periods after 1580, when historical documentation is more consistent and

² See Appendix 5.A.5.

Spanish colonial bureaucrats are more prolific. By contrast, the sixty years leading up to this time, from the arrival of the Spanish in 1519 to the establishment of large herds in the 1560s and 1570s, are not as well understood.

In the Mixteca Alta, historians have theorized that epidemic disease and depopulation paved the way for intensive sheep/goat pastoralism by inducing labor shortfalls and creating vast stretches of *tierras baldias*, or fallow land. The shortage of peasant labor to maintain agricultural terraces and to work the rich fields of the valleys facilitated the relocation of towns to the valleys under *congregación*, which in turn freed up the formerly occupied mountain slopes for less labor intensive pastoralism (Terreciano 2001). Recent excavations at the site of Pueblo Viejo Teposcolula Yucundaa³ present a robust means for testing this hypothesis through the archaeological investigation of an early colonial Mixtec community (Robles Garcia and Spores 2004, 2005, 2006).

During the 2004-2006 field seasons at Pueblo Viejo Teposcolula, two large colonial cemeteries were discovered. These cemeteries provide a unique opportunity to investigate early colonial life at Teposcolula, as well as the internal factors that precipitated the relocation of the town to the valley. Through an integrated study of historical, mortuary, paleodemographic, ancient genetic, and stable isotopic data, I examine the social and biological dimensions of early colonial Mixtec life at Teposcolula

³ Teposcolula Yucundaa is a hybridized name that reflects the Mixtec, Aztec, and Spanish heritage of the site. *Teposcolula* is the hispanicized form of a Nahuatl (Aztec) word meaning “place of the copper axes,” which has several spelling variants in the colonial record, including *Tepozcollollan* (Chimalpahin 1997) and *Tepuzculula* (Berdan and Anawalt 1997). In Mixtec, the town was called *Yucundaa* (Jimenez Moreno and Mateos Higuera 1940), which may be translated as “on the plain of the hill” or “blue hill” (Alavez 1988:92; Alavez Chávez 2006:32; Restall et al. 2001:139). In the early colonial period, the Spanish renamed the community San Pablo Teposcolula (see Appendix 5.A.2). They also called the new town in the valley San Pablo Teposcolula (Calderón Galván 1988:50). By the 18th century, the new town had acquired a second patron saint, Saint Peter, and the valley town has since borne the name San Pedro y San Pablo Teposcolula. Today, the mountaintop archaeological site is locally referred to in Spanish as *Pueblo Viejo*, or “old town.”

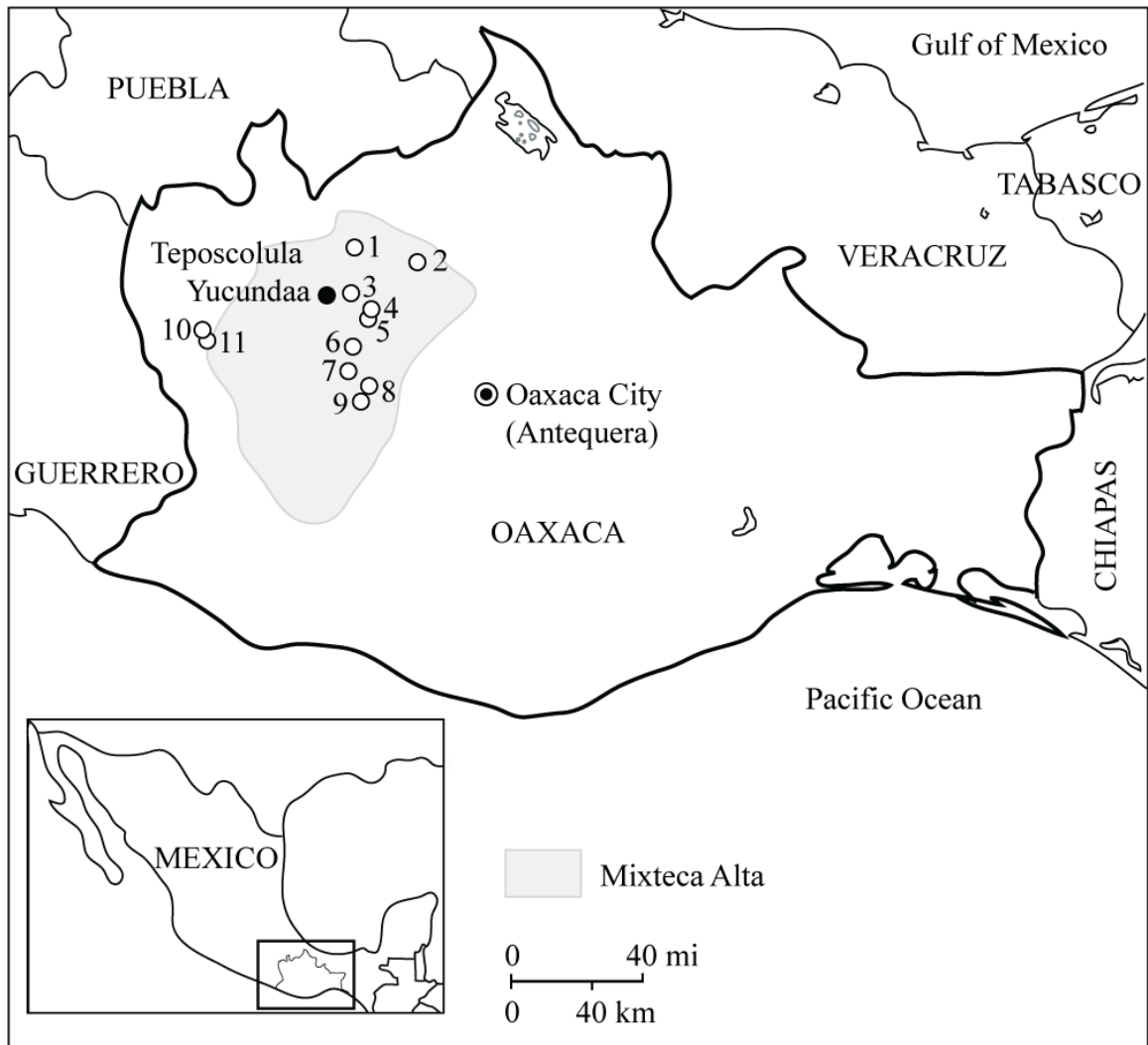


Figure 5.1. Location of Teposcolula and other communities discussed in the text. Numbered communities: 1) Coixtlahuaca; 2) Apoala; 3) Yanhuitlan; 4) Nochistlan; 5) Etlatongo; 6) Tilantongo; 7) Mitlatongo; 8) Tamazola; 9) Teozacualco; 10) Tecomaxtlahuaca; 11) Justlahuaca.

and demonstrate that epidemic disease played a major role in the ultimate abandonment of the site.

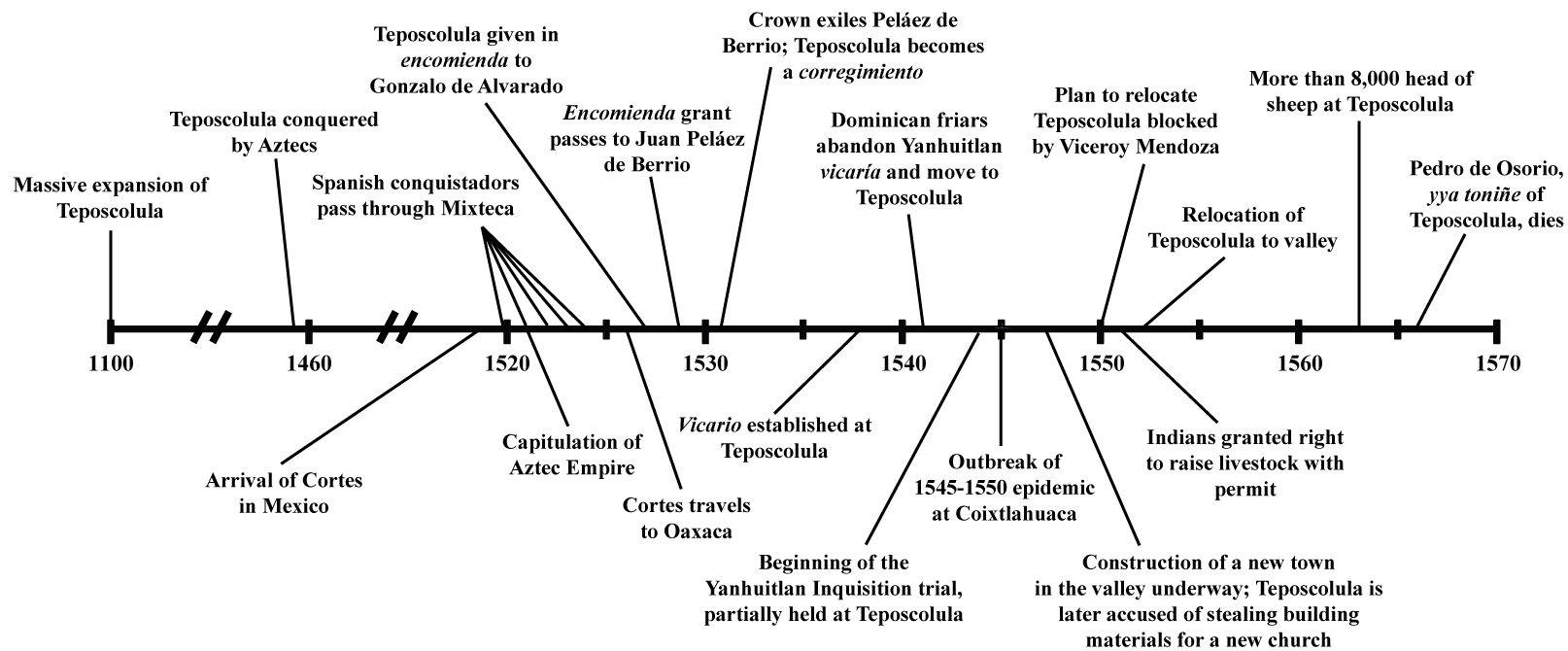
5.3. Site background

The archaeological site of Pueblo Viejo Teposcolula Yucundaa is located in Southern Mexico on a mountain ridge in the highland region of the Mixteca Alta (Figure 5.1). Beginning around AD 1100, Teposcolula Yucundaa experienced a massive

expansion, transforming it into a first-order regional capital in the Mixteca Alta (Figure 5.2; Stiver 2001).⁴ At its Prehispanic height, Teposcolula Yucundaa controlled a territory of approximately 500 km² with an estimated population of up to 60,000 (Balkansky et al. 2000). Its urban core, with an estimated population of 7,000-8,000, covered 250 ha and was ringed by a 2 km long raised road that enclosed numerous structures and features, including a royal compound, elaborate stone masonry civic-ceremonial buildings, multiple paved plazas, over 30 “palaces,” a ballcourt, and more than 1000 residential terraces (Spores and Robles Garcia 2007; Stiver 2001; Balkansky et al. 2000).

From 1458-1520, Teposcolula was a subject of the Aztec Triple Alliance, paying gold, cochineal, textiles, jade beads, and quetzal feathers in tribute (Berdan and Anawalt 1997; Chimalpahin 1997). After the conquest of Mexico Tenochtitlan in 1521, Teposcolula became a subject of the Spanish Crown, and at least six parties of early Spanish explorers and conquistadors passed through the region from 1520-1525 (Oudijk and Restall 2007). Teposcolula was held briefly in *encomienda* from 1527-1531, first by Gonzalo de Alvarado and then Juan Pal  ez de Berrio (Calder  n Galv  n 1988). Infamous for his abuses, Juan Pal  ez de Berrio was exiled by the second *Audencia* in 1531 (Chance 1978), and Teposcolula was reestablished as a *corregimiento*, henceforth paying taxes directly to the Spanish Crown. In 1538, Dominican friars Francisco Mar  n and Pedro

⁴Kevin Terraciano (2001) and Ronald Spores (1967, 1974) have conducted detailed analyses of Mixtec political terminology during the Postclassic and early colonial periods. A *  uu*, or local state, represented the smallest autonomous political unit among the Postclassic Mixtecs. During the colonial period, powerful *  uus*, called *cabeceras* by the colonial Spanish, often politically controlled one or more smaller *  uus*, referred to as *sujetos*. When the male hereditary ruler of a *cabecera* (called a *yya toni  e* in Mixtec and a *cacique* by the Spanish) married the female hereditary ruler of another *cabecera* (called a *yya dzehe toni  e* in Mixtec and a *cacica* in Spanish), two *cabeceras* were united to form a *yuhuitayu*, a joint state which the Spanish referred to as a *se  or  o* or *cacica  go*. The lordly establishment at a *cabecera*, including the royal palace and royal lands, was called an *ani  e*. During the early colonial period, Teposcolula was a prosperous *yuhuitayu* with multiple subject *  uus*, including San Juan Teposcolula Nicayuju. A residential household at this site recently excavated by Veronica P  rez Rodr  guez (2006) is instructive about the daily life of Mixtec commoners during the Postclassic period.



Location of Teposcolula	Mountaintop (Pueblo Viejo Teposcolula Yucundaa)		Valley	
Reigning <i>yya toniñe</i> (Mixtec lord)			Pedro de Osorio	
Foreign subject relationship	Aztec subject	Encom.	Corregimiento	
Tribute and taxation	see Codex Mendoza	Not recorded	Gold/wheat	Gold/silk/wheat
Missionary presence	Resident Dominican friars			

Figure 5.2. Timeline of events discussed in the text

Fernández successfully founded a *vicaría* at the site,⁵ in the wake of two failed attempts at the nearby site of Yanhuitlan (Pérez Ortiz 2003).⁶ Friar Diego de Medinilla and Friar Francisco Marín are listed in the Dominican *Actas* as the first vicars (Mullen 1975:209; Vences Vidal 2000:206).⁷

Although the Dominicans constructed a well-built, stone masonry church and monastery at Pueblo Viejo Teposcolula Yucundaa, they do not appear to have anticipated using it for very long.⁸ Plans to establish a new town in the valley, in accordance with the

⁵The date of the acceptance of Teposcolula as a *vicaría* in 1538 has been misinterpreted by various scholars as 1540 or 1541, a point which Mullen (1975:28-31) clarifies through a close reading of Dominican chapter records and a careful exercise in deductive reasoning. In brief, seven unnamed residences founded in the Mixteca Alta by Provincial Domingo de Betanzos, founder of the Dominican Province of Santiago de México, were accepted as *vicarías* at the August 1538 provincial chapter meeting. The chapter meeting record also specifically mentions the good missionary work of Friar Francisco Marín and Friar Pedro Fernández in the region. Records from the next chapter meeting, held in January 1540, do not mention the acceptance of any additional *vicarías*. At the next chapter meeting in 1541, ten extant *vicarías* are named, three of which are known from other sources to have been founded before Betanzos was named Provincial in 1535: Oaxtepec, Guatemala, and Oaxaca. This leaves seven named *vicarías* that provide the identities of the seven unnamed *vicarías* from 1538; among these is Teposcolula.

⁶ Dominican friars may have visited Teposcolula as early as 1534 (Pita Moreda 1992:114), but the nature of this early contact is unclear, and it is unlikely that any of the Dominican friars spoke Mixtec at that time. According to a letter written in December 1540 by Domingo de Betanzos to Cardinal García de Loaysa, President of the Council of the Indies, the first Dominican friar to successfully learn the Mixtec language was Friar Domingo de Santa María (see Appendix 5.A.1; Robles Sierra 1990; Kiracofe 1996:116). This must have occurred after Friar Domingo de Santa María moved to Yanhuitlan in either 1538 or 1540 (Burgoa 1934:280-281; Jimenez Moreno and Mateos Higuera 1940:28; Pérez Ortiz 2003:103-10). According to Curate Francisco de Aguilar Martel, author of the 16th century *Relación de 1569*, language acquisition among the early missionaries typically required 6-12 months (Mullen 1975:27-28).

⁷ The early Dominican history in the Mixteca Alta has been largely reconstructed by Mullen (1975) from the official records, called *Actas*, of the Dominican chapter meetings held in Mexico from 1540-1590. The *Actas* are currently housed in two archives: the Bancroft Library in Berkeley, California and the Archivo Histórico of the Instituto Nacional de Antropología e Historia (INAH) in Mexico. Vences Vidal (2000) has recently reanalyzed the *Actas* in a reinterpretation of the early Dominican architectural history at Coixtlahuaca and other Mixtec communities. She identifies at least fifteen different Dominican friars assigned to Teposcolula between 1538 and 1552, with as many as six friars mentioned for a given year. These friars include: Francisco Marín, Pedro Fernández, Diego de Medinilla, Domingo de Santa María, Alfonso del Espíritu Santo, Bernardino de Santa María, Juan Cabrera, Francisco Loyando, Antonio de la Serna, Tomás de Santa María acólito, Gonzalo de Santo Domingo, Francisco de Santa Ana, Miguel de Alvarez diácono, Gonzalez Lucero, and Tomás de Medina (Vences Vidal 2000:205-207).

⁸ The following chronology represents a revision of previous architectural histories written by Kiracofe (1995), Kubler (1948), McAndrew (1965), Mullen (1975), and Toussaint (1939). This is in large part because it was not known until excavations began in 2004 that a Dominican church and monastery had been built at Pueblo Viejo Teposcolula Yucundaa (Spores and Robles Garcia 2007), which an earlier archaeological survey (Guzmán 1934) had failed to detect. Believing that the only significant Dominican architecture at Teposcolula was that in the valley, earlier historians were forced to grapple with many seeming inconsistencies in the architecture of the Teposcolula church-monastery complex, including the

policy of *congregación*, may have begun as early as 1540,⁹ and the construction of a new church and open-air chapel was in an advanced state by 1550,¹⁰ when Antonio de Mendoza visited the site and halted construction.¹¹ After a two year hiatus, the town formally relocated to the valley in 1552 by direct order of Viceroy Luis de Velasco (Gerhard 1977; Zavala 1982:316-317).¹² By the mid-1550s, the new town of Teposcolula was well-established and had been elevated to the status of *alcaldía mayor* and placed in charge of a large province with 18 *encomienda* grants (Calderón Galván 1988:64). The construction of the new town's open-air chapel, headed by Friar Francisco Marín,¹³ may

absence of early architectural forms at the valley church, save for the sculpture and reused capitals adorning the Teposcolula church façade (James Kiracofe *pers. comm.* 2010; Kiracofe 1996:157-158; Wiesmann 1985:143; Toussaint 1939:27). The discovery of an earlier Dominican church-monastery complex at Pueblo Viejo Teposcolula Yucundaa allows a reinterpretation of the primary historical sources that is more consistent with the archaeological and architectural evidence at Pueblo Viejo Teposcolula Yucundaa and San Pedro y San Pablo Teposcolula. See Appendices 5.B.2-4 for early colonial pictorial evidence of Dominican architecture in the Mixteca Alta.

⁹ The difficulty of evangelizing a dispersed population was discussed at the Dominican chapter meeting in January 1540, and it was decided to attempt to congregate the Mixtecs into new towns founded at convenient locations so that the missionaries could more easily instruct them (Mullen 1975:28). See appendix 5.B.6 for 16th century depictions of Spanish-reorganized Mixtec communities.

¹⁰ In addition to Mendoza's letter to Viceroy Luis de Velasco (see Appendix 5.A.5), evidence that construction of the valley church was well underway by 1550 is also provided by a report, dated October 4, 1550, that armed Teposcolulans were raiding Yanhuitlan in order to obtain building materials for their new church (see Appendix 5.A.4). The Pueblo Viejo church and monastery may have served as a source of cut stones for the new valley church. Excavations at Pueblo Viejo Teposcolula Yucundaa have revealed evidence of several dismantled walls in the church-monastery complex (Robles Garcia and Spores 2005).

¹¹ Among the objections raised by Antonio de Mendoza was the fact that the new location was humid and built upon uneven ground. Kubler (1948:533) and others have noted that while the new town is built on a slope, the land is well-drained and not particularly humid. James Kiracofe (*pers. comm.* 2010) believes that there was once a large lake in the valley, which has since been drained. As evidence, he notes painting of Teposcolula, dated 1746, in which a large lake is depicted. This painting (currently in storage at the residence of the Teposcolula parish priest) depicts the famous open-air chapel at San Pedro y San Pablo Teposcolula on the left and the ruins of Pueblo Viejo Teposcolula on the right. In between is a large lake with a canoe visible on the shore (see Appendix 5.B.11). There is currently a small river that runs through the Teposcolula Valley that, if dammed, could have produced a lake. Such a lake would have made the valley humid, and would also explain why the modern town (including the former royal residence) was partially built on the lower slopes of a mountain instead of on the true valley floor. It may also explain why fish bones have been recovered from Postclassic and colonial middens at Pueblo Viejo Teposcolula (personal observation; Pérez Roldán et al. n.d. a,b; see Appendix 5.D.1). The possibility of a lake at Teposcolula hints at the large scale and sophistication of Postclassic and colonial Mixtec irrigation technology and warrants further study.

¹² See Appendices 5.A.7 and 5.C.11.

¹³ Friar Francisco Marín, the great architect friar, was assigned to Teposcolula twice in the 1540s, first in 1541 and then again in 1548 (Mullen 1975:127-128). His assignment to Teposcolula may have been

have been completed by 1555¹⁴ (see Appendix 5.C.12), and a palace for the *yya toniñe* of Teposcolula, Pedro de Osorio, was constructed on a small hill near the new town square at the same time (see Appendix 5.C.14; Calderón Galván 1988:74-75; Kiracofe 1995).¹⁵

Dominican missionaries considered Teposcolula to be their first successfully missionized Mixtec community, and in 1540 Provincial Domingo de Betanzos hailed it as a model for the entire Mixteca Alta (see Appendix 5.A.1). Teposcolula benefited substantially from its favored status with the Dominican friars, *corregimiento* tax classification, and political designation as an *alcaldía mayor*. As a testament to its prosperity, a legal case regarding the contested inheritance of Teposcolula following Pedro de Osorio's death in 1566 revealed that the *aniñe* of Teposcolula was valued at over 6,000 gold pesos, a considerable sum in the mid-16th century (Spores 1997).

5.4. Excavation of the Grand Plaza and Churchyard cemeteries

Excavations began at the site of Teposcolula Yucundaa in 2004 under the direction of Dr. Ronald Spores and Dr. Nelly Robles Garcia. To date, many areas of the site have been explored, including the Dominican church and monastery,¹⁶ the churchyard,¹⁷ administrative buildings and plazas, the royal palace, elite residences,

connected to the two major church-monastery construction projects at Teposcolula, the first at Pueblo Viejo, and the second in the valley.

¹⁴ There is some disagreement among scholars over when the open-air chapel was completed. Mullen (1975) states that construction was completed by 1555, while Kubler (1948), McAndrew (1965), and Toussaint (1939) argue that the chapel was not completed until c. 1575. However, Kubler, Toussaint, and McAndrew also support an impossibly late start date for the construction of the chapel. Because Mullen's analysis is based on historical sources rather than architectural and artistic impressions, I have chosen to follow his chronology for the completion of the Teposcolula open-air chapel.

¹⁵ This palace is known today as the *Casa de la Cacica*. See Appendix 5.C.14.

¹⁶ The term monastery will be used throughout the text to refer to this structure, although other translations are possible (see McAndrew 1965:26-27 and Mullen 1975:57 for a discussion). The 1544-1546 Yanhuítlan Inquisition trial records indicate that during the early colonial period the Dominican friars referred to such residences *monasterios*. Today, the corresponding monastic residence at the valley church in San Pedro y San Pablo Teposcolula is called a *convento*. Although I have chosen to use the term monastery, it should be noted that the kind of cloistered life generally implied by the English word monastery was not practiced at 16th century *monasterios*, but rather was reserved only for Dominican houses given the Latin designation

commoner residences, and agricultural terraces (Robles Garcia and Spores 2004, 2005, 2006; Spores and Robles Garcia 2007).

A new focus on colonial population decline and epidemic disease emerged during the first season of excavation when simple pit burials were found cut into the plaster floor of the Grand Plaza in the administrative center of the site (Figure 5.3). After additional excavation, it became clear that the Grand Plaza had functioned as a massive cemetery shortly before the site's abandonment (Spores and Robles Garcia 2007). Excavations in the churchyard revealed that it too had served as an early colonial cemetery. From 2004-2006, 28 burials containing 54 individuals were recovered from five areas of the Grand Plaza (Figure 5.3a) and three areas of the churchyard (Figure 5.3b).¹⁸

Based on historical and archaeological evidence, the cemeteries may have been in use for as many as 16 years, beginning with the arrival of Dominican missionaries and the establishment of a church and monastery at the nearby site of Yanhuitlan in 1536 (Jimenez Moreno and Mateo Higuera 1940; Perez Ortiz 2001). However, a more likely estimate is 14 years, from the founding of Teposcolula as a *vicaría* in 1538 until the site's official abandonment in 1552. Given the number of grave cuts observed per excavated square meter and the average number of individuals per excavated grave, the Grand Plaza and Churchyard cemeteries may together contain the remains of more than 2,000 individuals.

conventus. In 1550, only three Dominican houses in New Spain held this designation: Santo Domingo Mexico, Santo Domingo Oaxaca, and Santo Domingo Puebla (Mullen 1975:38).

¹⁷ In Spanish, this area is referred to today as the *atrio*, or atrium, of the church. However, in the early colonial period, such areas were called *patios* (McAndrew 1965:234; for examples see Appendix 5.A.2 and Mendieta 1945:70, 72). Interestingly, the term *atrium* meant cemetery in medieval Latin (McAndrew 1965:234). The early colonial use of the *patios* as cemeteries may be why these same areas came to be known as *atrios* during the 17th century. In order to avoid the use of the anachronistic term *atrio*, as well as the potentially misleading term *patio*, I have chosen to refer to the walled area in front of a church by the more generic English term churchyard.

¹⁸ See Appendices 5.C.6-7, 9-10.

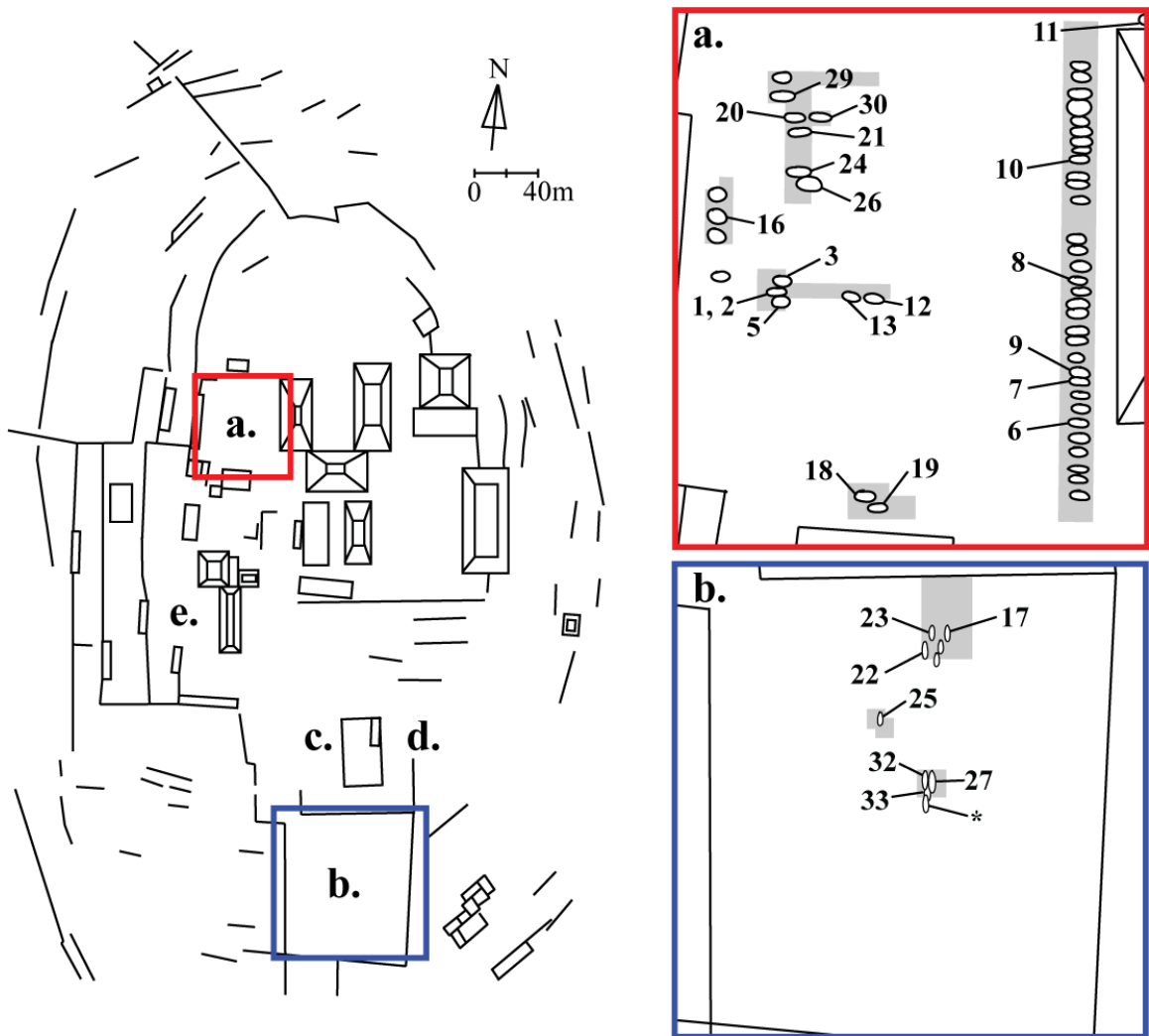


Figure 5.3. Central zone of Teposcolula with enlarged insets of the a) Grand Plaza and b) Churchyard cemeteries. The c) church, d) monastery, and e) royal residence are also indicated. Insets are drawn to different scales; areas explored are highlighted in gray, and excavated burials are numbered. The left foot of the starred individual was excavated and reburied without further analysis. Map modified from Stiver 2001.

5.5 Methods

5.5.1. Collection of mortuary and paleodemographic data

Mortuary data including body orientation, placement, and position were recorded for 28 burials, and 54 individuals were examined by Instituto Nacional de Antropología e Historia (INAH) physical anthropologists Laura Roldán and Juan Carlos García Jiménez

for age, sex, and trauma/pathology indicators. Although many studies have commented on the poor quality of bone preservation in Mexico (e.g. Duncan et al. 2008; Hodges 1987; Mansell et al. 2006; Tiesler et al. 2004), the gross preservation of skeletal remains at Teposcolula was excellent.

Forty-two individuals could be assigned sex on the basis of pelvic and cranial features (Buikstra and Ubelaker 1994; Ferembach et al. 1979; Salas Cuesta 1982; White and Folkens 1991). Age was estimated on the basis of dental development, epiphyseal union, dental attrition, and degeneration of the pubic symphysis and auricular surface (Buikstra and Ubelaker 1994; Krogman and Iscan 1986; Lovejoy et al. 1985; Ubelaker 1978, 1989). Forty-eight individuals were fully examined for age indicators, and six individuals were assigned to basic age categories on the basis of field examination. Incisor shoveling, a frequent dental trait among Native American and Asian populations (Scott and Turner II 1997), was common. No evidence of recent trauma was observed among the skeletons, although healed limb fractures were observed in at least three individuals. In general, the individuals exhibited good skeletal health at the time of death, with arthritis and dental caries being the most common pathologies observed. Only one subadult presented evidence of a life-threatening illness, an advanced infection of the cervical vertebrae and kyphosis.

5.5.2. Ancient DNA extraction, amplification, and sequencing

All ancient DNA extraction and PCR set-up was performed in a dedicated ancient DNA laboratory where no modern human material had ever been analyzed. Standard ancient DNA laboratory procedures were followed throughout the extraction procedure to

prevent contamination.¹⁹ Internal negative controls were performed to ensure that the extraction protocol did not introduce contamination, and all PCR and post-PCR analysis was conducted in a non-contiguous building.

Samples of compact midshaft femoral bone were obtained for 46 individuals and ground to a fine powder under liquid nitrogen using a SpexMill. Approximately 400-800mg of bone powder was soaked in 1.5mL of 6M guanidine thiocyanate/5mM TRIS solution twice for four hours each to remove loosely bound organic contaminants. The bone powder was then etched in a wash of sterile, nuclease-free 0.5M EDTA solution (Amresco) to remove remaining moderately bound contaminants, and decalcified overnight in 1.5mL of fresh 0.5M EDTA under agitation to collect extracted DNA. The extract solution was passed through a 0.45µm PVDF syringe filter (Millipore, Pall) to remove suspended particulates. The extract was then filtered using 30kDa Amicon Ultra centrifugation units. In order to facilitate the removal of residual EDTA, the filtration unit was washed with 1.5mL sterile nuclease-free water in 0.5mL increments. The remaining DNA solution was collected and diluted to a volume of 250µL using sterile nuclease-free water, and 100µL of this solution was then purified using a QIAquick PCR purification kit (Qiagen; see Yang 1998).

Ancient DNA extracts were amplified with newly developed primer sets (Table 5.1) designed to detect mitochondrial coding region polymorphisms that define macrohaplogroups N and M and haplogroups A, B, C, and D.²⁰ All extracts were amplified at least twice to determine macrohaplogroup and haplogroup assignment, and yielded consistent results in all cases. As an internal control, seven individuals were

¹⁹ See Appendix 5.E.1 for a more detailed description of contamination prevention measures.

²⁰ See Appendices 5.E.2-7.

Table 5.1. Mitochondrial coding region primers

Primer ^a	Marker	Signif.	T _A ^b (°C)	Sequence (5'-3')	Target length ^c	Ref. ^d
NMF-10363 [†] NMR-10480	10398 G 10400 C	MHg N MHg M	49	TGGCCTATGAGTGACTACAA ATGAGGGGCATTTGGTAAATAT	118	This study 1
AF-00635 AR-00745	663 G	Hg A	49	CACCCCATAAACAAATAGGTTTGG TTGATCGTGGTGATTTAGAGG	118	This study 1
BF-08196 BR-08316	8281- 8289 del	Hg B	47	ACAGTTTCATGCCCATCGTC ATGCTAAGTTAGCTTTACAG	121/112	1 1
CF-13239 CR-13366	13263 G	Hg C	51	CGTAGCCTTCTCCACTTCAAGT CGGTGCACATAAAATAGTATGGCT	128	This study This study
DF-05150 DR-05274	5178 A	Hg D	51	CCTACTACTATCTCGCACCTG CTTCGATAATGGCCCATTTGGG	125	1 This study

Notes:

[†]This primer pair amplifies a region with two AIMs. An A→G transition at nucleotide position (np) 10398 is characteristic of macrohaplogroup N, which includes haplogroups A and B, while a T→C transition at np 10400 is characteristic of macrohaplogroup M, which includes haplogroups C and D.

^aAll primers were designed to amplify targets less than 130 bases in length.

^bAnnealing temperature employed in PCR reactions.

^cIncludes primers

^dReferences: 1=Kolman and Tuross 2000

typed twice for haplogroup assignment, and in all cases yielded identical and unambiguous results.

PCR amplification of 1-2µL of DNA was performed in a 25µL reaction volume containing 12.5µL Sahara mix (Bioline), 1µL BSA, 1µL of forward and reverse primers (IDT) diluted to a concentration of 0.5µM, and 8.5-9.5µL sterile nuclease-free PCR water (Bioline). Negative controls and blanks were included with each amplification. All amplifications consisted of 50 cycles of 95°C (30 seconds), primer-dependent annealing temperature (30 seconds; see Table 5.6), and 72°C (45 seconds). The first cycle was preceded by a 5 minute “hot start” denaturation step at 95°C, and the final extension step was 5 minutes at 72°C.

Amplification products were electrophoresed using 2% agarose E-Gel cassettes (Invitrogen) with either EtBr or SybrSafe dye. Positive amplifications were purified of

primers and excess dNTPs using ExoSap-IT (USB). Sequencing was conducted in a thermocycler with 1 μ L PCR product, 1 μ L 0.5 μ M primer, 1 μ L BigDye v.3.0 (ABI), 2 μ L 5x buffer (ABI), and 4 μ L sterile nuclease-free PCR water (Bioline).

Sequencing products were purified using Centri-Sep purification columns (Princeton Separations), and analyzed using an Applied Biosystems 3130XL or 3730XL DNA Sequencer. The ABI Sequencing Analysis 5.1.1 software analysis protocol was optimized for short read sequences, and sequences were visualized using ABI Sequencing Analysis 5.1.1 and Sequencher 4.8. All automated base calls were visually verified using sequence chromatograms.

5.5.3. Stable isotope analysis (C, N, O, H)

Bone collagen was isolated from tibia or femur shaft samples and analyzed for $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, $\delta^{18}\text{O}$, and δD according to the methods described in Chapters 2 and 3,²¹ omitting the chloroform:methanol²² step. C/N for all bone collagen samples fell within the accepted range of 2.8-3.6 for intact, biological collagen (DeNiro 1985).

Enamel apatite was collected from third molars and analyzed for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ according to the methods described in Chapter 2.²³ The third molar (M3) is the last tooth of the dentition to form, with crown formation primarily occurring between ages 10 to 15 and eruption between ages 15 to 21 (Ubelaker 1989).²⁴ Carbonate samples from the Grand Plaza plaster floors were also sampled and analyzed to determine the $\delta^{13}\text{C}$ of local

²¹ See Appendices 5.F.1-2.

²² Chloroform:methanol is used to remove lipids from fresh bone during the isolation of bone collagen. The lipid content of archaeological bone is very low, making this step unnecessary.

²³ See Appendix 5.F.3.

²⁴ First and second molars were not measured because their crown formation occurs much earlier, at 1-4 and 4-8 years of age respectively. The isotopic values of M1s and M2s therefore record a nursing and early childhood diet, which is not directly comparable with collagen data in adults.

environmental carbonate sources.²⁵ Because adsorbed carbonates can affect the isotopic ratios of archaeological apatites (Koch et al. 1997; Trueman et al. 2004), a duplicate aliquot of each sample was soaked for 50 minutes in a 0.1M acetic acid solution to remove loosely bound carbonates.²⁶ Comparison of the untreated and treated apatite aliquots yielded no significant difference in either $\delta^{13}\text{C}$ or $\delta^{18}\text{O}$ ($p > 0.1$, ANOVA), and minimal pairwise differences between the two aliquots ($0.1 \pm 0.6\text{‰}$ in $\delta^{13}\text{C}$ and $0.3 \pm 1.3\text{‰}$ in $\delta^{18}\text{O}$) suggest that the archaeological enamel has undergone little taphonomic alteration from environmental carbonates.

5.6. Mortuary and demographic analysis of the Teposcolula burial assemblages

5.6.1. Grand Plaza skeletal assemblage

A total of 21 burials containing 46 individuals were excavated from the Grand Plaza cemetery (Table 5.2). The bodies were laid supine in an east or west orientation with arms generally folded across the chest or abdomen, and some individuals with legs crossed at the ankles. Exceptions to this pattern, which include the positioning of a body on its side or in a semiflexed position, may be an unintended consequence of body stacking and shifting.

Bone beads and a fragment of leather were found in isolated burials, but no other clearly associated grave goods were encountered in the Grand Plaza burials (see note for burials 21 and 26 in Table 2). Fourteen of the 21 burials contained more than one individual, with a maximum of five individuals in a single grave. In seven graves (3, 5, 6, 9, 18, 19, 31), the bodies were stacked in an alternating head-to-foot orientation. No

²⁵ See Appendix 5.F.5.

²⁶ See Appendix 5.F.4.

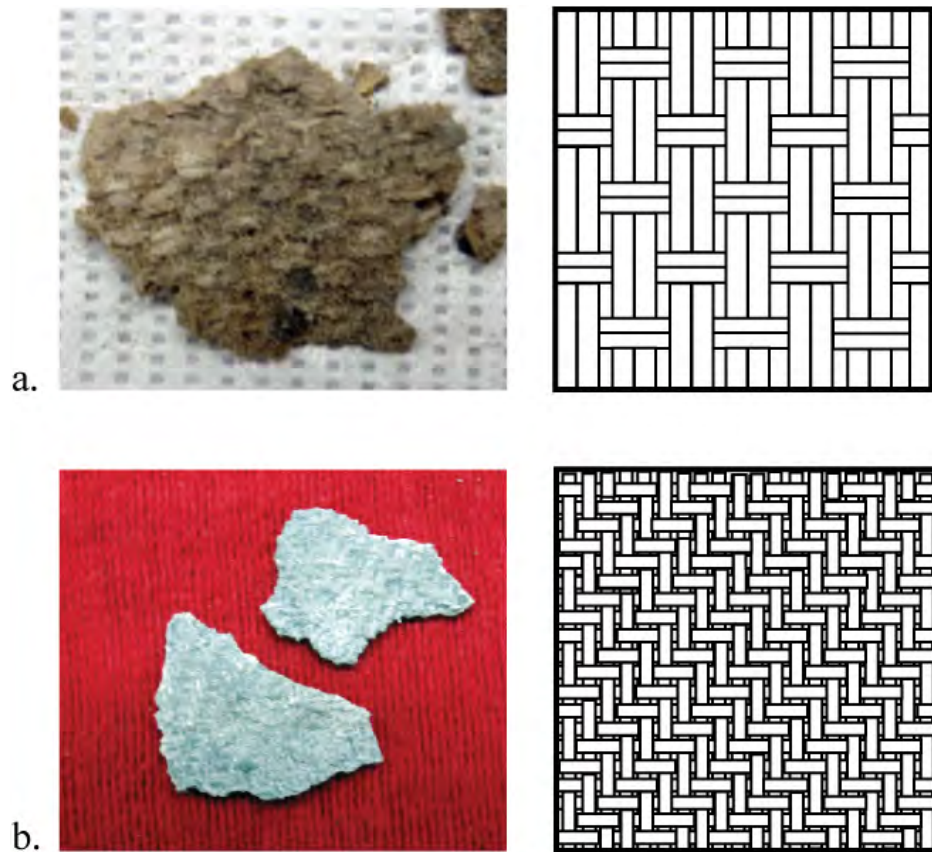


Figure 5.4. Textile impression fragments from burial 20. The weave style in (a) is consistent with a basket weave, while the weave style in (b) appears to be a twill weave. Idealized representations of a basket weave and a twill weave are provided for comparison.

sediment was encountered between the skeletons, indicating that each grave represented a single burial event.

Decomposed lime (or possibly calcrete) was observed in several burials, most notably in burial 21, in which it formed a thick layer directly above the remains. Thin scales of textile impressions were preserved underneath some of these deposits (Figure 5.4). The use of lime, possibly to speed decomposition, has also been observed in burials at the colonial mission at St. Augustine in La Florida (Koch 1983), although its use at Teposcolula Yucundaa is at least 50 years earlier. It is unknown if the textile impressions

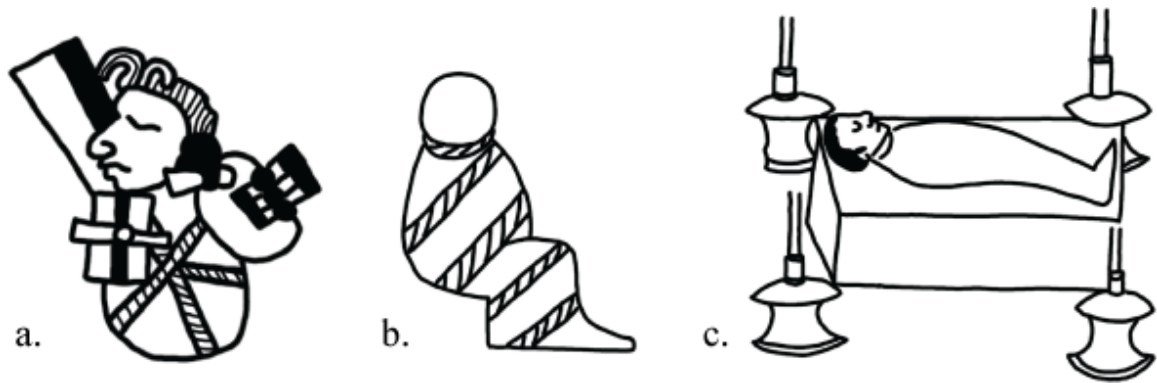


Figure 5.5. Preparation of the body for burial during a), b) Prehispanic, and c) colonial times. Note that both before and after Spanish conquest, the deceased were wrapped in a white cloth. Details from a) folio 20r of the Codex Zouche Nuttall, a Postclassic Mixtec book, and b) and c) the Codex Azcatitlan, a Mexica history composed during the late 16th century. Inquisition trial records from the early colonial period indicate that Mixtec sacrificial victims were buried wrapped in a *petate*, or reed mat, instead of a white cloth (see Appendix 5.A.2). Drawings by the author.

indicate the use of burial shrouds (*mortajas*), which were used during the 16th century to wrap the bodies of the dead in both Spain (Eire 1995:105; Foster 1960:145) and New Spain (Figure 5.5). Preliminary analysis identified at least two weave patterns among the fragments: a basket weave associated with individual 39, and a twill weave associated with individual 40.²⁷

Grave depth ranged from 18-110 cm, and single-individual burials were generally shallower than those with multiple-individuals. The burials were laid out in an orderly fashion according to what appears to be a gridded plan. Unlike other early colonial cemeteries, there is little evidence for grave disturbance in the Grand Plaza, and only two neighboring graves (1, 2) in the center of the plaza display evidence of having been disturbed subsequent to burial.

Thirty-seven individuals could be assigned sex on the basis of pelvic and cranial

²⁷ See also Appendix 5.D.2.

Table 5.2. Mortuary and physical characteristics of the Teposcolula Yucundaa skeletal assemblage

Burial ^a	Depth ^b	Indiv. ^c	Orient. ^d	Body placement	Body position	Arm position	Ankles crossed	Age ^e	Sex ^f	Grave goods ^g
GRAND PLAZA CEMETERY										
1*	>29	1	W	Extended	Supine	Across abdomen	Yes	20-21	M	Beads (bone) ^l
		2	W	Extended	Right side	At sides	Disturbed	25 ± 1	F	None
2	>32	3	N	Semiflexed	Supine	Across abdomen	n.r.	7 - 8	I	None
3	>68	4†	W	Extended	Supine	Disturbed	No	26 ± 2	F	None
		5†	E	Extended	Supine	Across chest	Disturbed	> 50	F	None
5	>68	6	N	Extended	Left side	At sides	No	18 ± 1	M	None
		7‡	E	Extended	Supine	Across chest	Disturbed	13	F	None
		8	W	Extended	Right side	Across abdomen	No	20 ± 1	F	None
		9	E	Extended	Supine	Across abdomen	Yes	20 ± 1	M	None
6	79	10	E	Extended	Supine	Across chest	Yes	20-21	M	None
		11	W	Extended	Supine	Across chest	No	> 45	F	None
		12	E	Extended	Supine	Across abdomen	No	AD	I	None
7	30	13	E	Extended	Supine	Across abdomen	No	AD	I	None
8	85	14	E	Extended	Supine	Across abdomen	No	28 ± 2	M	None
		15	E	Extended	Supine	Across abdomen	No	AD	I	None
9	110	16	W	Extended	Supine	Across abdomen	Yes	40 ± 3	M	None
		17	E	Extended	Supine	Across abdomen	No	> 45	M	None
		18†	W	Extended	Supine	Across abdomen	Disturbed	35 ± 4	F	None
		19†	W	Extended	Supine	Across abdomen	Disturbed	30 ± 3	F	None
		20	E	Extended	Supine	At sides	No	22 ± 2	F	None
10	102	21	E	Extended	Supine	Across abdomen	No	35 ± 3	M	None
		22	E	Extended	Supine	Across abdomen	Yes	30 ± 3	M	None
		23	E	Extended	Left side	Across chest	No	12 ± 2	I	None
		24	E	Semiflexed	Supine	Across chest	No	20 ± 3	M	None
11	18	25	W	Extended	Supine	At sides	No	33 ± 3	F	None
12	28	26	E	Extended	Supine	Across chest	Yes	40 ± 4	F	None
13	30	27	E	Extended	Supine	Across abdomen	Yes	40 ± 5	M	None
16	90	30	E	Extended	Supine	Across abdomen	No	23 ± 2	F	None
		31	E	Extended	Supine	Across abdomen	Disturbed	41 ± 2	F	None
18	92	33†	E	Extended	Supine	Across abdomen	Yes	16 ± 2	I	None
		34†	W	Semiflexed	Right side	Across chest	No	AD	I	None
		35	E	Extended	Supine	Across abdomen	Yes	AD	I	None

Table 5.2. continued

Burial ^a	Depth ^b	Indiv. ^c	Orient. ^d	Body placement	Body position	Arm position	Ankles crossed	Age ^e	Sex ^f	Grave goods ^g
GRAND PLAZA CEMETERY (continued)										
19	109	36	W	Extended	Supine	Across abdomen	No	24 ^k	M	Leather ^h
		37	E	Extended	Supine	Across abdomen	Yes	YA	F	Textile ⁱ
		38	W	Extended	Supine	Across abdomen	No	24 ^k	F	None
20	83	39	E	Extended	Supine	Across abdomen	No	24 ^k	F	Textile ⁱ
21**	82	40†	E	Extended	Supine	Across chest	No	46	F	Textile ⁱ
		41†	E	Extended	Supine	At sides	No	20	F	None
24	20	44	W	Extended	Supine	Across abdomen	Disturbed	46	F	None
26**	>57	46†	W	Extended	Supine	Across abdomen	No	46	M	None
		47†	W	Extended	Supine	Across abdomen	Yes	36	F	None
29	~73	51	E	Extended	Supine	Across abdomen	No	24	F	None
		52	E	Extended	Supine	Across abdomen	Yes	32	M	None
31	~94	54	E	Extended	Supine	Across abdomen	Yes	19	F	None
		55	W	Extended	Supine	Across chest	Yes	16	I	None
		56	E	Extended	Supine	Across chest	No	32	M	None
CHURCHYARD										
17	96	32	N	Extended	Supine	Across chest	No	19 ± 1	F	None
22	30	42	S	Extended	Supine	Side and chest	No	5	I	None
23	57	43	N	Extended	Supine	Across chest	No	24 ^k	M	None
25	>69	45	S	Extended	Supine	Across abdomen	Yes	36	F	None
27	~30	48	S	Semiflexed	Left side	Near head	No	32 ± 2	F	Multitude ^j
32*	>29	57	S	Extended	Supine	At sides	No	24 ^k	F	None
		58	S	Extended	Supine	At sides	No	2	I	None
33	>51	59	Disturbed	Disturbed	Disturbed	Disturbed	Disturbed	5	I	None

Notes:

Information not recorded is noted as n.r. Positions are described as disturbed when the relevant skeletal elements have been displaced by bioturbation (e.g., root growth), cultural modification (e.g. partial disinterment), or body settling during decomposition. Individuals are described as semiflexed when laying on the side with moderate natural leg flexion, or when supine with the legs flexed to allow the body to fit in limited grave space

* Individuals numbered from lowermost to uppermost.

** Although no grave goods were found deposited with the interred individuals, the grave fill was very carbon-rich and almost black. Obsidian blades and fragments of ritual ceramics, including incense burner handles, were recovered from the grave fill of burials 21 and 26. Burial 21 contained fragments of polychrome pottery and incense burner handles, and a complete ceramic phallus was found in the fill of burial 26. A thick layer of lime (or possibly calcrete) deposited in burial 21 preserved flakes of textile impressions near the sternum of individual 46.

† Individuals are side by side.

‡ Individual 7 shows evidence of advanced infection and kyphosis of the cervical vertebrae. Individual additionally appears to have been pregnant at time of death. Fetal remains recovered from the abdominal cavity were highly fragmentary and not further analyzed.

^a Burial 4 was later recognized to be bones displaced from burials 1 and 2 during the interment of burial 3.

^b Burial depth is given in centimeters from the colonial plaster surface to the depth of the lowest skeletal element. Where the plaza surface has been damaged, a minimum depth is provided. Because only part of the churchyard was plastered, depth estimates for burials 25, 27, 32, and 33 are rough estimates only.

^c Unless otherwise noted, individuals within each burial are numbered from uppermost to lowermost.

^d Orientation of head relative to the body. A western orientation, for example, indicates that the head is in the west and the feet in the east. Note: There are numerous errors regarding orientation in the original site reports. Orientation was verified through consultation of original burial photographs.

^e Unless otherwise noted, age was determined by physical anthropologists Laura Roldán (burials 1-18, 27) or Juan Carlos García Jiménez (burials 19-26, 28-33). Roldán provides age range estimates, while García Jiménez provided point estimates only. Age codes: AD = adolescent, 12-18 years; YA = young adult, 19-24 years; MA = middle-aged adult, 25-44 years; OA = older adult > 45 years. For the purpose of paleodemographic modeling, adolescents were included in the 15-24 age category.

^f Sex is recorded as female (F), male (M), or indeterminate (I).

^g Includes only grave goods displaying clear association with the burial; objects recovered from grave fill are not included.

^h A small leather fragment (~1cm²) was found in association with the chest cavity of individual 36 in burial 19.

ⁱ Small fragments (~1-3cm²) of textile impressions (or calcified fibers) were recovered *in situ* from burials 20 and 21. Preliminary analysis identified at least two different weave patterns (basket and twill); both weave types were known to Precolumbian and European weavers (Carrie Brezine, personal communication 2008). Additional fragments were subsequently identified in burial 19 through fine (~2mm) sieving of burial soil samples.

^j Burial 27 is among the richest burials ever recovered in the Mixteca Alta and included a wide variety of greenstone, shell, flint, obsidian, ceramic, mica, wooden, and copper objects, including beads, pendants, figurines, axe heads, and blades. Large numbers of bird bones and two carbonized maize cobs were also found. Beads and zoomorphic and anthropomorphic stone figurines were found in particular abundance. The number of special finds from this grave total more than 48,000.

^k The individual was originally assigned an estimated age of 25 on the basis of epiphyseal fusion, pubic symphysis, and auricular surface indicators. However, subsequent dental examination revealed the presence of encrypted and/or early stage erupting third molars, which is more typical of individuals aged 18-21. An age assessment of 25 would place this individual in the age category 25-34 for paleodemographic analysis, a category to which this individual almost certainly does not belong. Thus, in order to class this individual in the more appropriate 15-24 age category, the author adjusted the age assessment to 24.

^l The beads were found in association with individual 1's hands and may have been part of a rosary.

features. The sex distribution is slightly biased toward females, who make up 59% of the adults whose sex could be determined, compared to males who make up 41%. The number of infants (0), children under 12 (1), and adults 45 and older (6) is noticeably low, and there is a relatively large number of adolescents and young adults with partially or recently erupted 3rd molars (26) compared to middle-aged adults between the ages of 25-34 (6) and 35-44 (7).

5.6.2. Churchyard skeletal assemblage

Eight burials containing seven individuals were excavated from three small test pits in the Churchyard cemetery (Table 5.2). As in the Grand Plaza cemetery, individuals were buried in an extended supine position with the arms folded across the chest, abdomen, or lying at the sides. Unlike the Grand Plaza cemetery, however, the burials were oriented to the north or south, along the same axis as the colonial church. Also in contrast to the Grand Plaza cemetery, most of the burials in the Churchyard cemetery were single burials; the only multiple interment was that of an adult male and an approximately 2 year-old child. Three burials intruded into a colonial plaster floor and exhibited grave depths ranging from 30-96 cm; however, because most of the churchyard was on a slope and not paved, it was difficult to assess the level of the colonial ground surface, and thus grave depth, for the remaining five churchyard burials.

Five individuals from the Churchyard cemetery could be assigned sex on the basis of pelvic and cranial features: 4 females and one male. Notably, three of the eight individuals excavated from the churchyard are age five or younger. Seven of the eight graves contained no grave goods. One grave, burial 27, located in the center of the

Table 5.3. Published reports of excavated 16th century cemeteries in New Spain

Cemetery	Dates of use	N ^a	References
CENTRAL MEXICO			
Convento de San Gabriel	c. 1519†	671	Castro Morales and Garcia Moll 1972; McCafferty 2000; Ocaña del Río 1985
Huexotla/Chapingo	c. 1524-1600	60	Malvido et al. 1985, 1986; Mansilla and Pompa 1992
San Sebastian Molango	c. 1550-1600	71	Charleton et al. 2005
San Jeronimo	16 th -19 th cent.	147	Mansilla et al. 1992; Romano Pacheco and Jaén Esquivel 1985
OAXACA			
Teposcolula Yucundaa	c.1538-1552	46	Spores and Robles Garcia 2007; Warinner et al. <i>in prep</i>
YUCATAN AND BELIZE			
Tancah	c.1543-1688	20	Miller and Farriss 1979
Lamanai	c. 1544-1641	179	Graham et al. 1989; Pendergast 1991; White et al. 1994
Tipu	c. 1567-1638	>550	Cohen et al. 1994; Danforth et al. 1997; Jacobi 2000
CHIAPAS			
Coapa	c.1554-1680	84	Lee 1979a, b
LA FLORIDA‡			
San Juan del Puerto	c. 1587-1702	5	Dickinson 1989; Larsen 1993
Nuestra Senora de Soledad	c. 1597-1784	28	Koch 1983
Santa Catalina de Guale	c. 1597-1680	432	Larsen 1993; Larsen 1990; Larsen et al. 1990

Notes:

†Evidence of violence suggests that the cemetery contains the remains of the 1519 Cholula massacre victims; the cemetery may also contain some individuals interred at a later date.

‡A wealth of bioarchaeological data have been produced for colonial cemeteries in La Florida; however, most excavated La Florida cemeteries date to the 17th and 18th centuries, a time period outside the scope of this paper. See Larsen 1993 for more information about these cemeteries.

^aIncludes only excavated individuals.

churchyard, contained many grave goods and differed markedly from the other burials (see below).

5.6.3. Placing the Teposcolula cemeteries in context

The placement and mortuary treatment of most of the bodies in the Teposcolula cemeteries differ in important ways from Prehispanic practices in the Mixteca and resemble those observed at other 16th century cemeteries throughout New Spain (Table

Table 5.4. Sex distribution of arm position

Sex	N	Arm position (%)			
		Abdomen	Chest	Sides	Other
Females	25 [†]	52	24	20	4 [‡]
Males	16	69	25	6	0

Notes:

[†] The upper body of individual 4 in burial 3 was too disturbed to determine original arm position.

[‡] Burial 27, individual 48. This high status woman was buried on her side with her hands folded under her head. The mortuary treatment of her burial is distinct from all others at Teposcolula.

5.3). Broad similarities in colonial burial practices from Central Mexico to La Florida attest to the success of the mendicant orders in enforcing Spanish Catholic burial customs (Eire 1995; Foster 1960) among indigenous populations, despite marked variation in local Prehispanic mortuary traditions.

Prior to the arrival of Spanish missionaries, the Mixtecs typically buried their dead in simple pit burials, stone-lined crypts, or family tombs located in residential compounds. Grave goods such as ceramic vessels were frequently, but not always, included. The bodies of adults were usually laid out in an extended supine position, with arms placed at the sides (Acosta 1992; Blomster 2004; Gaxiola González 1984; Robles Garcia 1988). Multiple-interment tomb assemblages resulting from ongoing tomb use have also been documented for high status Mixtec individuals in the Valley of Oaxaca (see Middleton et al. 2008 for a discussion).

At Teposcolula, the most notable break from Prehispanic tradition is the concentration of colonial burials into cemeteries, a practice unknown before the arrival of the Spanish. Arm position also differs between Prehispanic and colonial interments, and at Teposcolula, more than 80% of the individuals in the colonial cemeteries were buried with their arms crossed over their chest or abdomen. This burial position, which places the body in a position of devotion, has its origins in the early Catholic Church (Rush

Table 5.5. Body orientation in the Grand Plaza and Churchyard cemeteries

Location	Orientation (%)					
	N	East	West	North	South	Other
Grand Plaza	46	61	35	4	0	0
Churchyard	7	0	0	29	71	0

Note: Body orientation is reported with respect to the head relative to the feet.

1941:110) and was common among Spanish Catholics during the 16th century (Koch 1983; Eire 1995). At Huexotla, a contemporary colonial cemetery in Central Mexico, arm position was found to correlate with sex: males' arms were crossed over their chest, while females' arms were crossed over their pelvis (Malvido et al. 1986; Mansilla y Pompa 1992). An examination of the colonial Teposcolula assemblage reveals no sex-based patterns with respect to arm placement (Table 5.4).

One notable feature of both cemeteries at Teposcolula is the low frequency of burial disturbance; only three of the 29 excavated graves showed any evidence of reentry or disinterment. Other colonial cemeteries (e.g., at Tipu, Huexotla, and the Nuestra Señora de Soledad cemetery in St. Augustine) show high levels of burial disturbance, as old graves were partially disinterred to make room for the new. Because both Teposcolula cemeteries appear to be full, the short period of use of the Teposcolula cemeteries (<16 years) may partially explain both the infrequency of disinterment and the presence of two cemeteries. Once the Churchyard cemetery became full, disinterment was not a viable option as the bodies had not had time to fully decompose. This is clear from the remains of individual 59, who had been partially disinterred to make room for the burial of individuals 48, 57, and 58 (as well as an unexcavated individual to the south). Individual 59 is represented by lower vertebrae, a complete pelvis, two widely splayed femora, and a fibula, all anatomically articulated, as well as a partial arm. The

Table 5.6. Distribution of individuals within burials

Location	Individuals	Burials	Avg. indiv./burial	% Single	% Multiple
Grand Plaza	46	21	2.2	33	67
Churchyard	8	7	1.1	86	14

position and incomplete nature of the body indicates that it was still partially fleshed when disinterred and reburied in an unnatural position. Faced with the prospect of disinterring hundreds of partially decomposed bodies, it appears that the Teposcolulans or the Dominican friars instead decided to create a new cemetery in the Grand Plaza and to bury more people per grave in order to accommodate large numbers of dead.

One important difference between the Grand Plaza and Churchyard cemeteries is the orientation of the graves (Table 5.5). Traditional Christian practice orients the head to the west so that the dead will face the rising sun in the east when Christ returns during the Resurrection (see Koch 1983). Within the Churchyard cemetery, none of the excavated graves have a west-east orientation. Instead, most of the bodies are oriented with the head the south. From this position, they face the Teposcolula church, which was constructed on a north-south axis. The orientation of the church is unusual and follows the contours of the mountain slope upon which Teposcolula is located.²⁸ According to Foster (1960:148), burying the dead with their feet toward the church is a common custom in north and northwest Spain, and orientation of the dead toward churches built on a non-east-west axis has been widely documented in colonial cemeteries across New Spain, especially in La Florida (e.g., Koch 1983; Larsen et al. 1990).

In contrast to the Churchyard cemetery, the burials of the Grand Plaza cemetery are oriented on an east-west axis; however, most of the bodies are oriented with the head

²⁸ See McAndrews (1965:223-225) for additional examples early colonial church complexes constructed in an unorthodox form in order to fit into previously existing native spaces.

to the east rather than the west. Thus, they face neither the rising sun, nor the church, which is located to the southeast of the Grand Plaza (Figure 5.2). The presence of two different orientation schemes at a colonial site is has not been previously documented.

It is likely that the Grand Plaza served as an expedient overflow cemetery during an epidemic outbreak (see below). Two-thirds of the burials within the Grand Plaza contain more than one individual (Table 5.6), with as many as five bodies within a single grave. In approximately half of the graves with multiple individuals, bodies were stacked in alternating east and west orientations, perhaps as a space-saving measure. In the haste of burial, eastward or westward orientation may not have been as important as at other sites, where a single burial orientation predominates at frequencies over 90% (e.g., at Huexotla, Tipu, and the Convento de San Gabriel in Cholula, as well as many 17th century cemeteries in La Florida, including Santa Mara de los Yamassee, San Martin de Timucua, and San Luis Talimali; see Larsen 1993).

Teposcolula is unusual for having a colonial cemetery not associated with a church or churchyard. In 16th century Spain, most Catholics were buried within churches or chapels, or, at the very least, within consecrated walled churchyard cemeteries with a cross at the center (Eire 1995:94).²⁹ Excavated early colonial cemeteries in New Spain also conform to this pattern, with a high density of burials within and immediately surrounding the church (Malvido 1997; see citations in Table 5.3). By contrast, no burials

²⁹ Walled churchyards are amply attested in 16th century Mixtec historical records (see Appendix 5.B.8), and the Pueblo Viejo Teposcolula Yucundaa churchyard is surrounded by a well-preserved stone wall (see Appendix 5.C.8). The colonial practice of using a churchyard as a cemetery in New Spain is first historically attested in an engraving from the book *Rhetorica Christiana*, printed in 1579 (See Appendix 5.B.10). The engraving depicts a funeral procession within a walled churchyard, in addition to what Kubler identifies as fourteen rectangular burial plots (1948:320). By the eighteenth century, the close association between churchyards and cemeteries is attested by a map of Tzintzuntzan in Michoacán, published in 1770 by Father Beaumont (1932, Vol. 3, Map 5), in which the churchyard is clearly labeled “Cimiterio” (see Appendix 5.B.9).



Figure 5.6. Examples of *chalchihuitles* (precious stones) recovered from burial 27. Note that the two figures on the right appear to have their eyes closed in death and their arms across their chest. The figure on the left may depict Dzahui, the Mixtec rain deity.

or evidence of repaired *rompimientos* (burial cuts) were encountered within the Teposcolula church; however, subfloor excavations were not performed.

Burial 27, a special case

Burial 27, a simple colonial pit burial located in the approximate center of the Churchyard cemetery, contained the remains of an adult woman of middle age. She was buried on her left side in a semiflexed position and was accompanied by a large quantity of grave offerings (more than 48,000 objects total; see Table 5.2, note j), including the burned bones of doves and quail, more than 2,000 anthropomorphic stone figurines (Figure 5.6),³⁰ and a ceramic effigy of the deity Dzahui (Figure 5.7). Bird sacrifice is commonly associated with funerary rites in Postclassic Mixtec codices, as is ritual burning (Figure 5.8). A blackened soil feature was observed in association with Burial 27 that suggests that ritual burning had occurred. Considering of the extreme wealth of the burial, this woman may have been a *yya dzehe*, or Mixtec queen.

³⁰ Many of the carved stone figurines recovered from burial 27 bear a strong resemblance to stone figurines recovered from excavations of the *iglesia vieja* at Chachoapan (Spores 1984:86) and Monte Alban periods III-V (Caso 1965, especially figures 10, 15, 30, and 31).



Figure 5.7. Depictions of ceramic effigies the Mixtec rain deity Dzahui in a) folio 17r of the Postclassic Mixtec Codex Zouche Nuttall, and b) among the grave goods of burial 27 at Teposcolula Yucundaa. The “goggles” characteristic of Dzahui are evident in both depictions. Unfortunately, the mouth piece of the burial 27 vessel was found damaged and could not be fully reconstructed. Drawings by the author.

The presence of a mixed Catholic/Precolumbian-style burial in the middle of the Churchyard cemetery is provocative, especially given the fact that in 1545 Teposcolula briefly hosted the inquisition trial of the *yya toniñe* of nearby Yanhuitlan on charges of idolatry, among other crimes (Jimenez Moreno and Mateos Higuera 1940; Pérez Ortiz 2003).³¹ At the trial, which lasted from 1544-1546, residents of Etlatongo, Apoala, and Teposcolula testified that Yanhuitlan’s *yya toniñe*, Don Domingo, and governors, Don Francisco and Don Juan, possessed idols made of “chuchuy” stone (*chalchihuitl*, a precious stone, usually greenstone) and made sacrifices of doves and quail, according to ancient custom. Don Martín, a noble of Teposcolula reported that he had heard that at the funeral³² of the previous *yya toniñe* of Yanhuitlan, to which the nobles of Teposcolula were invited but did not attend, the nobles of Yanhuitlan buried the deceased *yya toniñe*

³¹ See Appendix 5.A.2 for a transcript of selected excerpts from the trial records. See also Appendix 5.B.1 for a possible depiction of testimony being given at this trial.

³² According to the Inquisition trial records, the previous *yya toniñe* of Yanhuitlan died seven years before this testimony was collected in 1546, placing his death c. 1539.

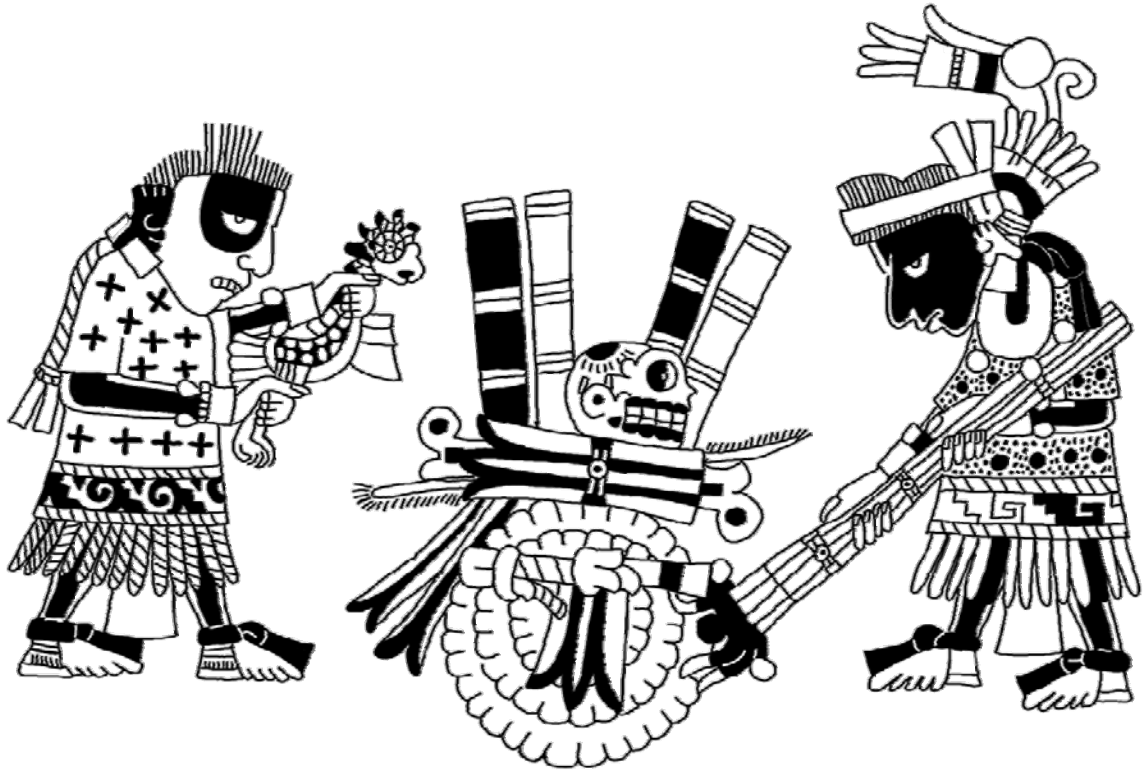


Figure 5.8. Depiction of bird sacrifice in association with funerary rites from folio 84v of the Codex Zouche-Nuttall, a Postclassic Mixtec document. Note that the figure on the right is lighting the funerary bundle with a torch. The black body paint on both figures indicates that they are priests (Terraciano 2001:270). Drawing by the author.

with a greenstone idol on his chest. The pious positioning of the Teposcolula nobles, who complained at the trial that the residents of Yanhuitlan taunted their commoners for being good Christians, stands in stark contrast to the excavated reality of burial 27, which reveals that traditional burial practices continued at Teposcolula as well, at least in the context of very important people.³³

³³ There is some evidence that aspects of Postclassic Mixtec funerary ritual may also have take place in the Grand Plaza cemetery. Burials 21 and 26 were found to contain a layer of blackened soil with charcoal inclusions, as well as numerous obsidian blades and fragments of ritual ceramics. Notably, several broken incense burner handles, similar to that depicted in the hand of the female individual in Figure 5.7, were also recovered. In both burials, this blackened layer was located above a lighter colored layer containing the skeletal remains. In burial 21, the skeletons were embedded in a thick layer of lime or possibly calcrete.

The location of such a high status burial in center of the Churchyard cemetery is also interesting for what it reveals about innovative missionary practices at the site, as well as Mixtec adoption of certain Catholic ideas and values. High status burials in 16th century Spain were typically buried within the church and as close to the altar as possible (Eire 1995), and archaeological evidence for grave crowding within colonial churches in New Spain also suggests that burial in close proximity to the altar was highly desired (e.g., Jacobi 2001:57, 100-107). Although preliminary excavation of the Teposcolula Churchyard cemetery was limited, there does not appear to be crowding toward the northern end of the cemetery, the area closest to the church, and hence, the altar; instead, grave density is highest in the center of the Churchyard cemetery. This unexpected burial focus may be related to experimentation with evangelization methods and architectural forms that are well documented in the new town of Teposcolula in the valley.

One widely documented problem encountered by the first missionaries in New Spain was that many indigenous groups, unaccustomed to large interior architectural spaces, disliked churches and preferred to remain outdoors during religious services. Additionally, in many areas, the indigenous population was simply too large to fit within a church nave. The Mendicant Orders adapted to this problem by innovating a new architectural style, the *capilla de indios* (later referred to as *capilla abierta*, or open-air chapel),³⁴ which allowed friars to conduct mass to an outdoor congregation within a walled churchyard (McAndrew 1965:204-209; Pita Moreda 1992:214). The new valley chapel, dedicated to Saint John the Baptist, contains one of the earliest and best-known

³⁴ The term *capilla de indios* was used throughout the colonial period to refer to an outdoor chapel facing a walled churchyard in which an indigenous congregation attended Mass. This architectural form is now commonly referred to as a *capilla abierta*, or open-air chapel, a term coined by the 20th century historian Manuel Toussaint (McAndrew 1965:340).

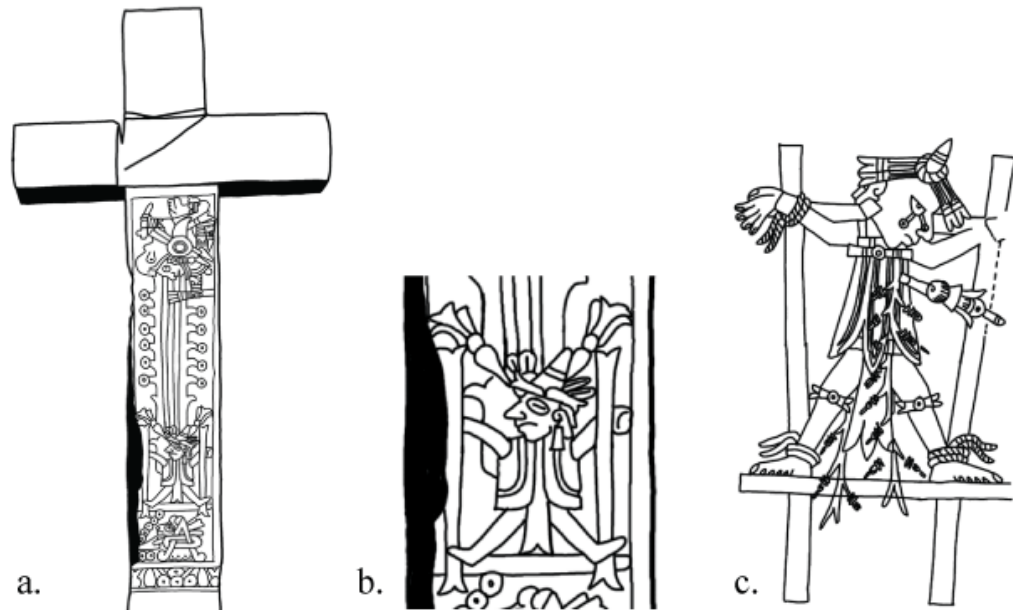


Figure 5.9. Images of Xipe Totec sacrificed with arrows on the a) and b) San Pedro Topiltepec churchyard cross, and in c) the Codex Zouche Nuttall, a Postclassic Mixtec book. Drawings by the author.

examples of this form of architecture (Kubler 1948; McAndrew 1965:543-555; Mullen 1975; Ortiz Lajous 1991; Perry 2006).³⁵

The churchyard of the new open-air chapel at San Pedro y San Pablo Teposcolula also served as a cemetery for the town from the 16th century until relatively recently, when a modern cemetery was constructed on the outskirts of town. In form, the churchyard conforms closely to that prescribed by the provincial Church Council of Granada in 1565, which dictated that outdoor cemeteries must be “blessed, walled in, and locked, with a cross in the center” (Eire 1995; Tejada y Ramiro 1855).

It is tempting to think that the original church at Pueblo Viejo Teposcolula served as a model for the later church/cemetery compound at San Pedro y San Pablo Teposcolula, and that the presence of a high status grave in the center of the churchyard

³⁵ See Appendix 5.C.12.

may indicate a reorientation of the locus of salvation from the altar to the central cemetery cross. A large wooden or stone cross was an essential feature of early colonial churchyards in New Spain,³⁶ and the remains of a crude stone wall, which may have served as a platform for the erection of a cross, were found immediately adjacent to burial 27. If the location of salvation had been transferred from the altar to the churchyard cross, it may explain why the Churchyard cemetery burials exhibit both northward (toward the church) and southward (toward the center of the churchyard) orientations.

On the other hand, there are also several historically documented cases in which churchyard crosses received special devotion because secret caches of idols had been deposited near them (McAndrew 1965:253-254), thereby raising the possibility that burial 27 functioned as such a cache. That central churchyard crosses could acquire non-Christian ritual significance in the Mixteca Alta is evidenced by an early colonial stone churchyard cross (Figure 5.9) at the nearby Mixtec site of San Pedro Topiltepec, in which an arrow-riddled male dressed as Xipe Totec is depicted in the place of a crucified Christ (Callaway 1993; Caso 1956).³⁷ Although the exact meaning of burial 27 remains unknown, its presence surely invested the Teposcolula Churchyard cemetery with a ritual significance beyond that which was likely intended by the Dominican friars.

5.7. Evidence for a catastrophic mortuary assemblage

The mortuary treatment of the Teposcolula Grand Plaza cemetery is highly suggestive of mass burials during an epidemic. Soren (2003) has outlined several

³⁶ Churchyard crosses were an integral part of the early colonial church-monastery-churchyard complex. During the early to mid-16th century, such crosses were usually made of wood and richly adorned with flowers and garlands. So important was the existence of a central cross within the churchyard that architectural historian John McAndrew has written that the cross “seemed to be its very heart” (McAndrew 1965:247). Today, a large stone masonry cross and platform is featured prominently in the churchyard at San Pedro y San Pablo Teposcolula in the valley (see Appendix 5.C.13).

³⁷ Interestingly, a warrior wielding the femur of an ancestor is depicted hovering above the sacrificed Xipe Totec figure.

characteristics typical of epidemic cemeteries, including: 1) evidence of mass burial or multiple individuals within a single grave; 2) rapid, successive vertical depositions; 3) installment in a single layer at one time or in a large cluster; and 4) corroborating historical evidence. The Teposcolula Grand Plaza cemetery meets each of these criteria.

Three epidemics are recorded in New Spain between the arrival of the Dominicans in Teposcolula in 1538 and the site's abandonment in 1552: the smallpox epidemic of 1538, the unidentified "pestilence" of 1545-1550, and an epidemic of mumps in 1550 (Prem 1992). Although it is possible that the Teposcolula cemetery contains smallpox victims, it seems unlikely because the plaza floor was never replastered after the intrusion of the burials, making an early epidemic unlikely. The 1550 epidemic of mumps may have also contributed to the cemetery, although it is improbable. The epidemic is mostly reported around the area of Tacuba in Central Mexico, and was of relatively short duration (one year). There is no evidence to suggest that it reached the Mixteca Alta, and it did not spread to Guatemala or other more distant areas. This leaves the epidemic of 1545-1548 as the most likely source of victims for the Grand Plaza cemetery.

The epidemic of 1545-1548 is poorly understood, but sources agree that it was "devastating," with a mortality rate of 60-90% (Prem 1992; Motolinía 1971). Witnesses, both Spanish and native, had never seen anything like it before and had no name to describe it, calling it instead *pujamiento de sangre* ("abundant bleeding" or "full bloodiness") and *huey cocoliztli* ("great pestilence") (Cook 1998; Prem 1992). It is one of three 16th century epidemics that can be described as a true pandemic, which spread from Central Mexico to Guatemala and beyond (possibly to Peru), eventually infecting all of

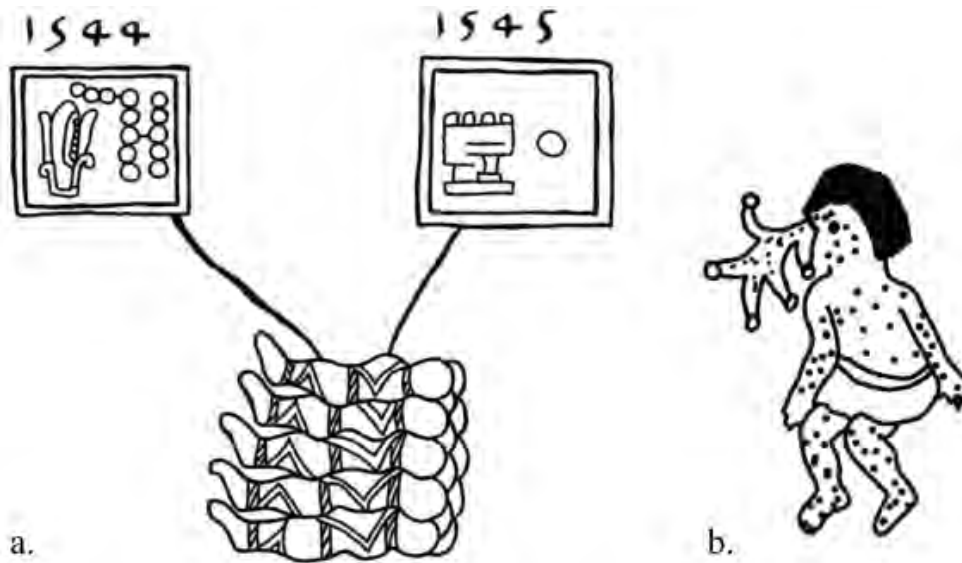


Figure 5.10. Depictions of the 1545-1550 epidemic in native documents: a) Codex Telleriano Remensis, folio 46v; and b) Codex en Cruz. A Spanish gloss (not shown) below the Codex Telleriano Remensis illustration reads, “In the year of 1544 and fifteen hundred and forty-five there was a great mortality among the Indians.” Note the stacking of the bodies. The Codex en Cruz illustration depicts two commonly described symptoms of the epidemic: severe bleeding from the nose and a body rash. Drawings by the author.

New Spain and perhaps lingering in Guatemala until 1563 (Prem 1992; Lovell 1992; Newson 1992).

Located along the principal trade routes between Mexico and Guatemala, the Mixteca Alta became infected as well. A document from 1545 records that at the Mixtec community of Coixtlahuaca (located approximately 30 km to the northeast of Teposcolula), burial could not keep pace with the 30-40 people who were dying each day (Terraciano 2001:362), and Friar Bernardino de Santa María, the vicar of Teposcolula in 1546, also fell ill³⁸ at this time (Jimenez Moreno and Higuera 1940:47). Thirty years later, four other neighboring Mixtec communities, Mitlatongo, Tamazola, Justlahuaca, and Tecomaxtlahuaca, remembered the 1545-1548 “pestilence” as the only epidemic to

³⁸ Unfortunately, it is not recorded if his illness was related to an epidemic (see Appendix 5.A.2).

reach the Mixteca Alta between c. 1530 and 1577 (Acuña 1984a:288, 1984b:240, 246).³⁹

Contemporary accounts attest to the virulence of the new disease and describe its horrific symptoms (see Cook 1998; Prem 1992). Friar Jerónimo Mendieta (1945) recorded that it was characterized by the sudden onset of a high fever, followed by bleeding of the orifices (especially the nose). Notably, it seems to have affected Europeans and native peoples alike (Cook 1998:99-100), thus making it distinct from previous epidemics caused by common European childhood diseases for which most Spaniards had some immunological immunity from previous exposure. In Central Mexico, where the epidemic is documented in numerous sources (Figure 5.10), Friar Bernardino de Sahagún claimed to have personally supervised the burial of 10,000 people when he himself came down with the illness and nearly died (Sahagún 1956, 3:356).⁴⁰ The cause of the great pestilence of 1545-1548 is unknown, but may have been epidemic typhus (Fields 2008; Humboldt 1966; Sticker 1932; Zinsser 1934), pneumonic plague (MacLeod 1973; Malvido y Viesca 1985; Orellana 1987), or a viral hemorrhagic fever (Acuna-Soto et al. 2000, 2002; Marr and Kiracofe 2000).

The large number of dead buried over a short period of time in multi-individual graves, combined with historical evidence for a contemporaneous high-mortality epidemic, provides strong evidence that the Grand Plaza cemetery is a catastrophic death assemblage. In addition to mortuary evidence, the paleodemographic profile of the Teposcolula Grand Plaza cemetery conforms to a catastrophic, rather than attritional, pattern. Figure 5.11 compares the mortality profile of the Teposcolula Grand Plaza cemetery to attritional and catastrophic mortality profiles derived from historical and

³⁹ These Mixtec records were collected from the *Relaciones Geográficas*, a census conducted c. 1579-1581 across all of New Spain (see Appendix 5.A.10). The *relación* for Teposcolula has unfortunately been lost.

⁴⁰ See Appendix 5.A.11.

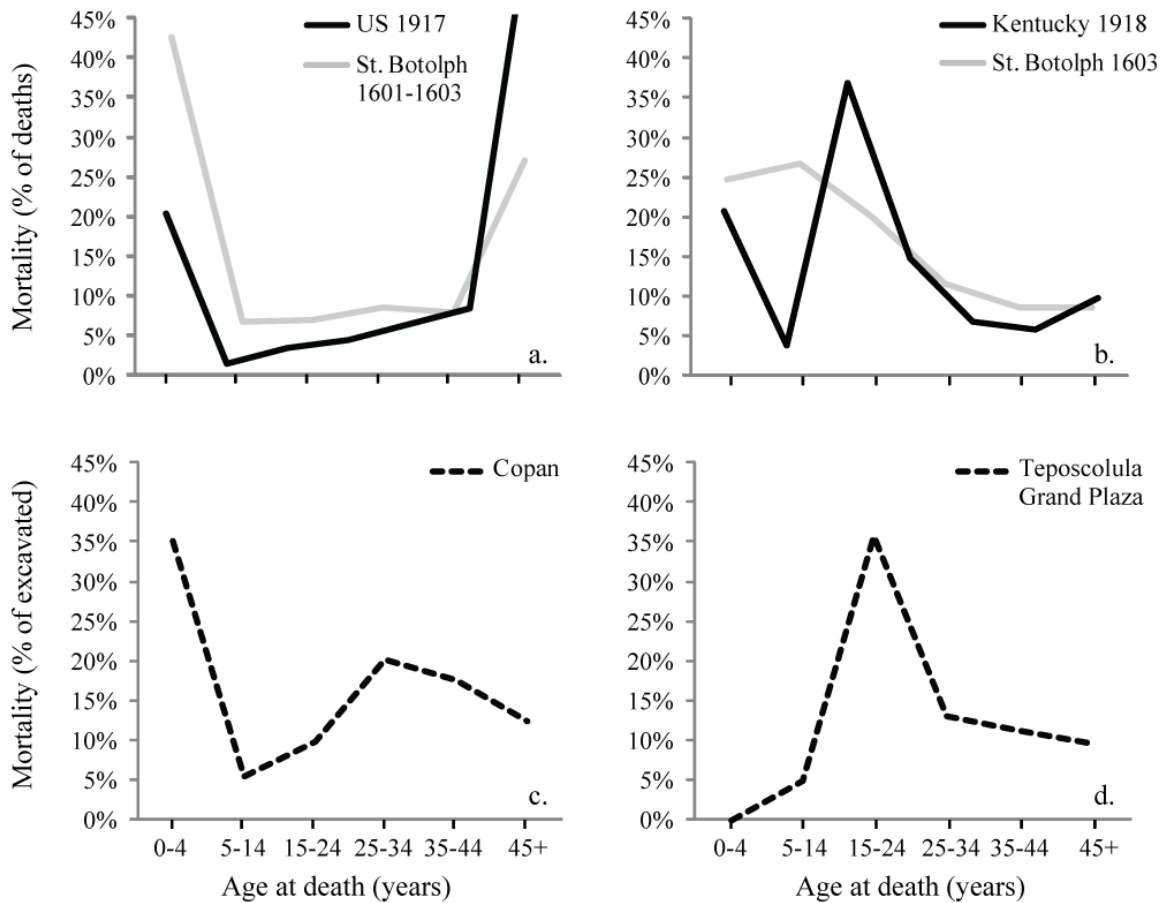


Figure 5.11. Comparison of a), c) attritional and b), d) catastrophic mortality profiles. Solid lines represent mortality curves derived from historical data; dashed lines were reconstructed from bioarchaeological data.⁴¹

bioarchaeological data. Although straightforward comparison of mortality profiles obtained from diverse data sets is made problematic by “age-heaping” in historical data (see Chamberlain 2006:45-46) and statistical biases in age determination from osteological data (see Hoppa and Vaupel 2002), attritional and catastrophic patterns can

⁴¹ US 1917 and Kentucky 1918 curves adapted from Crosby (1976:22, 24). US 1917 includes mortality data for US deaths in 1917 from influenza. Kentucky 1918 includes mortality data for Kentucky deaths from influenza or pneumonia associated with the 1918 influenza epidemic. Data for St. Boltolph (London, England) collected from Hollingsworth and Hollingsworth (1971). St. Boltolph 1601-1603 includes mortality data for 39 months preceding the 1603 plague epidemic. St. Boltolph 1603 includes mortality data for the 6 months of the 1603 plague. Data for Copan (Honduras) was obtained from Whittington (1989) and spans the Maya Late Classic period (c. AD 400-900).

nevertheless be discerned from both historical and bioarchaeological data (e.g., Gowland and Chamberlain 2005; Signoli 2006).

The Teposcolula Grand Plaza cemetery is characterized by a very high frequency of adolescents and young adults aged 15-24, an ordinarily healthy age group usually making up less than 10% of attritional cemeteries. Excessively high mortality of adolescents and young adults is a typical feature of catastrophic epidemics and has been historically documented for plague outbreaks in Medieval and Early Modern Europe (Hollingsworth and Hollingsworth 1971; Signoli et al. 2002), as well as the 1918 influenza pandemic in the United States (Crosby 1976). Bioarchaeological evidence from European plague cemeteries shows a similar, although more complex, trend.

Four known or suspected European plague cemeteries have been excavated and analyzed for the purpose of characterizing evidence of catastrophic mortality from a skeletal assemblage: the Royal Mint Black Death cemetery in London (DeWitte and Wood 2008; Gowland and Chamberlain 2002; Margerison and Knüsel 2002; Waldron 2001), the L'Observance plague pit in Marseilles (Signoli 2006; Signoli et al. 2002); the Délos plague trenches in Martigues (Signoli 2006; Signoli et al. 2002), and the Fédons cemetery in Lambesc (Signoli 2006). Unfortunately, very different methods were employed to generate age-at-death profiles for the four skeletal assemblages, thus precluding direct comparison of the results and obscuring overall paleodemographic patterns. For example, at the French plague sites of L'Observance, Délos, and Fédons, adult age was assessed using only cranial suture closure, epiphyseal fusion, indications of osteoarthritis and osteopenia, and dental wear evidence. Pelvic examination of the pubic symphysis and the auricular surface, which are widely considered to be the two most

reliable markers for assessing adult age, was not performed. The British Royal Mint cemetery, by contrast, has been analyzed four times using a variety of methods, but with the greatest reliance on pelvic indicators, and no evaluation of cranial suture closure.

The paleodemographic profiles of the European plague cemeteries exhibit substantial variation, which may reflect real historical and demographic differences among the plague contexts, or, more likely, result from inherent inaccuracies in osteological adult aging techniques. For example, the paleodemographic profile of the Royal Mint cemetery arrived at by Waldron (2001) and Margerison and Knüsel (2002) using conventional aging techniques is unusual and idiosyncratic. However, after applying Bayesian statistical methods to correct adult age assessments using age-stage likelihoods calculated from the Portuguese Coimbra and British Spitalfields reference collections and prior probabilities obtained from Coale and Demeney model life tables, Gowland and Chamberlain (2002) found that the revised Royal Mint paleodemographic profile conformed more closely to predicted catastrophic models.

Bayesian methods were not applied to the Teposcolula assemblage, in part because there are no known-age Native American reference collections from which to establish age-stage likelihoods, nor is it clear which life table priors would be most appropriate. However, Bayesian methods largely work to correct underaging of older individuals within a skeletal assemblage; they have relatively little effect on age assessment of adolescents and young adults below the age of thirty. This is because age assessment in these age classes is based primarily on biologically-regulated developmental markers (e.g., dental development and epiphyseal fusion), rather than on skeletal degeneration, which is known to be highly variable and environmentally

dependent. Thus the presence of a large number of adolescents and young adults at Teposcolula can be confidently asserted even without statistical post-analysis of conventional age assessments.

Excessively high mortality of adolescents and young adults is a classic hallmark of epidemic disease, and the mortality of this age group at Teposcolula differs markedly from that observed at Prehispanic Copan, which is thought to be an attritional skeletal assemblage. However, the number of adults age 25 and older in the Teposcolula cemeteries is surprisingly small, amounting to only 21 individuals, compared to 25 individuals aged 15-24. The small number of middle aged and older adults in the Teposcolula cemeteries may be indicative of a previous epidemic event. Historical documents from the Mixteca Alta record that the region was struck with a pox-like epidemic in the early 1530s (Acuña 1984, 3:240, 246),⁴² which may account for the low number of adults in the Teposcolula cemeteries fifteen years later. Alternatively, the comparatively high number of adolescent and young adults compared to middle-aged and older adults may reflect differences in baptismal rates among these age groups, as unbaptized individuals would not have been allowed burial in consecrated cemeteries. Historical records of names within royal Mixtec families indicate that the rulers in power at the time of the Spanish Conquest did not acquire Christian names during their lifetime, suggesting that they remained unbaptized; their children and subsequent generations, by contrast, appear in historical records with both Christian and indigenous names (Caso 1977-1979; Terraciano 2001:151-154).

The complete lack of children under the age of 7 in the Grand Plaza assemblage is unusual and suggests that infants and young children may have been buried elsewhere.

⁴² See Appendix 5.A.10, entries for Mitlantongo and Tamazola.

The presence of three young children in the Churchyard cemetery, however, complicates this hypothesis. At present, the absence of young children in the Grand Plaza cemetery remains unexplained.

5.8. Demographic implications of epidemic disease

The demographic impact of epidemic disease on Teposcolula is difficult to reconstruct with any precision. On the basis of settlement survey data, Stiver (2001) estimates that the population of Teposcolula and its immediate hinterlands numbered between 20,000 and 44,500 people at Spanish contact. By contrast, a colonial census conducted just after the 1545-1548 epidemic (c. 1548-1550) at Teposcolula records 2934 households and 9386 people over the age of three (Paso y Troncoso 1981). This dramatic difference may reflect substantial mortality and population decline during the epidemic, or may result from differences in the delineation of territorial boundaries and methods used to arrive at population estimates. Unfortunately, census records before 1548, which would have served as an important internal check, have been lost, and later records report the combined population of the entire Teposcolula district, which included more than a dozen towns (Gerhard 1993; Cook and Borah 1968).

Although historical documents are inconclusive regarding the impact of early epidemics at Teposcolua, census records from 1570-1650 indicate that the population of the Teposcolula jurisdiction fell from 26,500⁴³ to 14,100 after the epidemics of 1576-1581, 1591-1592, and 1599, and reached a low point of 6,522 in 1646, a population decline of over 75% in less than a hundred years (Cook and Borah 1968; Gerhard 1993).

⁴³ Church records for the bishopric of Oaxaca dating to c. 1572 record the population of Teposcolula as 18,000, but the accuracy of this estimation is uncertain (Pita Moreda 1992:124).

Several studies have speculated that the severe population declines resulting from 16th century epidemics may have caused a reduction in genetic diversity in indigenous American populations, even possibly resulting in a genetic bottleneck (e.g., Crawford 1998). This hypothesis is difficult to test using modern genetic data, but ancient DNA analysis, in combination with oxygen stable isotope analysis, can provide direct evidence. The Teposcolula Grand Plaza and Churchyard cemeteries, being comprised largely of individuals who died during a 16th century epidemic, represent a unique study population to investigate this hypothesis.

5.8.1. Oxygen stable isotope analysis of the Teposcolula cemeteries

Before beginning genetic analysis of the Teposcolula cemeteries, the oxygen isotopic composition of third molar enamel apatite (carbonate) and bone collagen was first assessed from a subset of the assemblage. Oxygen isotopic values of mineralized tissues have been shown to correlate with precipitation and temperature gradients (Longinelli 1984; Luz and Kolodny 1989), and oxygen isotopic analysis can be used to investigate archaeological histories of human migration across diverse ecological zones (e.g., Price et al. 2010; Quinn et al. 2008; Schroeder et al. 2009). Oxygen isotope analysis was conducted in order to determine whether the Teposcolula cemeteries represent a local population or if there is evidence for non-local migration at the site.

At Teposcolula, the relatively narrow range of $\delta^{18}\text{O}_{\text{VSMOW}}$ measured for both bone collagen (6.4-10.2‰, N=48) and enamel apatite carbonates (19.8-22.1‰, N=16) is consistent with that expected for a local population.⁴⁴ Additionally, the average $\delta^{18}\text{O}$ of bone collagen in the Teposcolula cemeteries ($8.3 \pm 0.8\text{‰}$) compares closely with that of

⁴⁴ Bone collagen and enamel apatite form through very different metabolic processes and are thus not expected to have equivalent oxygen isotopic values. The complex relationship between drinking water

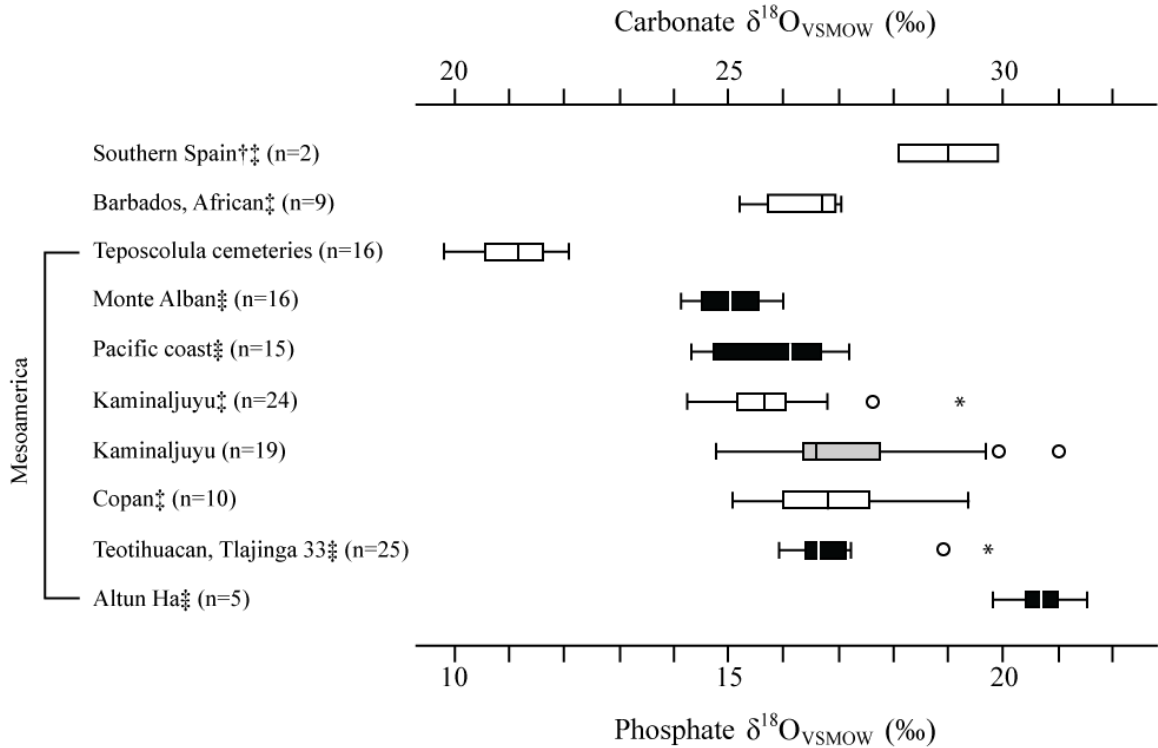


Figure 5.12. Box plots of oxygen isotopic values for enamel carbonate and bone and enamel phosphate. Error bars signify 95% confidence intervals. Human enamel measurements are from third molars only. Black bars signify bone phosphate data; gray bars signify enamel phosphate data; white bars signify enamel carbonate data. Scales are adjusted to account for empirically observed ~10‰ offset between phosphate and carbonate $\delta^{18}\text{O}$ (Bryant et al. 1996; Iacumin et al. 1996). † Data from modern horse enamel; no human enamel from Holocene Spain has been analyzed for carbonate or phosphate $\delta^{18}\text{O}$. ‡ Original $\delta^{18}\text{O}$ reported relative to VPDB; to approximate $\delta^{18}\text{O}$ on the VSMOW scale, 31‰ was added to each value (see Coplen et al. 1983; Werner and Brand 2001). § Original $\delta^{18}\text{O}$ adjusted by +2‰ to account for empirically observed ~2‰ offset between paired bone and enamel samples (Warinner and Tuross 2009). Data from Bell et al. 2006; Metcalfe et al. 2009; Price et al. 2010; Schroeder et al. 2009; White et al. 1998; White et al. 2000; White 2001; White et al. 2004; Wright and Schwarcz 1998; and this study. Figure adapted from Price et al. 2010.

$\delta^{18}\text{O}_{\text{VSMOW}}$ and that of proteinaceous and apatitic tissues is an emerging area of research (e.g., Ehleringer et al. 2008; Tuross et al. 2008; Warinner and Tuross 2010). For considerations of time and cost, only a subset of the Teposcolula samples were analyzed for collagen $\delta^{18}\text{O}_{\text{VSMOW}}$. The $\delta^{18}\text{O}_{\text{VSMOW}}$ of enamel apatite carbonate was measured for all individuals for which at least one third molar was available (excluding individuals 49-59, who had not yet been excavated at the time of sampling). The sample size (N=16) is smaller than that of the total number of individuals available for sampling (N=46) because many individuals had either not yet fully developed their third molars or had lost their third molars through heavy dental wear and/or attrition.

two Postclassic/Colonial low-status, non-cemetery infant burials⁴⁵ recovered from outlying residential terraces at Teposcolula (7.8‰, 8.4‰), suggesting that the individuals interred in the cemeteries are indeed of local origin. Comparison of the $\delta^{18}\text{O}_{\text{VSMOW}}$ of Teposcolula apatite to that measured at other sites also supports the interpretation that the Teposcolula cemeteries do not contain long-distance migrants from Spain, Africa, or other parts of Mesoamerica (Figure 5.12). The relatively depleted enamel apatite $\delta^{18}\text{O}_{\text{VSMOW}}$ observed at Teposcolula is consistent with the relatively cool and wet climate characteristic of the Mixteca Alta, especially compared to that of Southern Spain and the other Mesoamerican and Caribbean regions that have been analyzed.

5.8.2. Ancient DNA analysis of the Teposcolula cemeteries

Forty-six individuals from the Teposcolula cemeteries were tested for mitochondrial ancestry informative markers (AIMs) characteristic of the major macrohaplogroups found outside of Africa, M and N, and the four major Native American haplogroups A, B, C, and D (Figure 5.13).⁴⁶ Thirty-six individuals could be assigned to macrohaplogroup N because they exhibited the G→A transition at nucleotide position (np) 10398 characteristic of macrohaplogroup N, and lacked the C→T transition at np 10400 characteristic of macrohaplogroup M. The remaining ten individuals exhibited the C→T transition at np 10400 and lacked the G→A transition at np 10398, identifying them as members of haplogroup M.

Members of haplogroup N were then further tested for AIMs characteristic of

⁴⁵ These infants, individuals 28 and 29, were recovered from burials 14 and 15, respectively. Subsequent ancient genetic analysis revealed that these infants exhibit markers characteristic of mitochondrial haplogroup A, a common Native American haplogroup (see Appendix 5.E.2-7).

⁴⁶ For ease of reading, the AIMs are reported relative to the forward strand even though in some instances it was the reverse strand that was actually sequenced. Additionally, transitions are reported relative to the hypothetical human common ancestor.

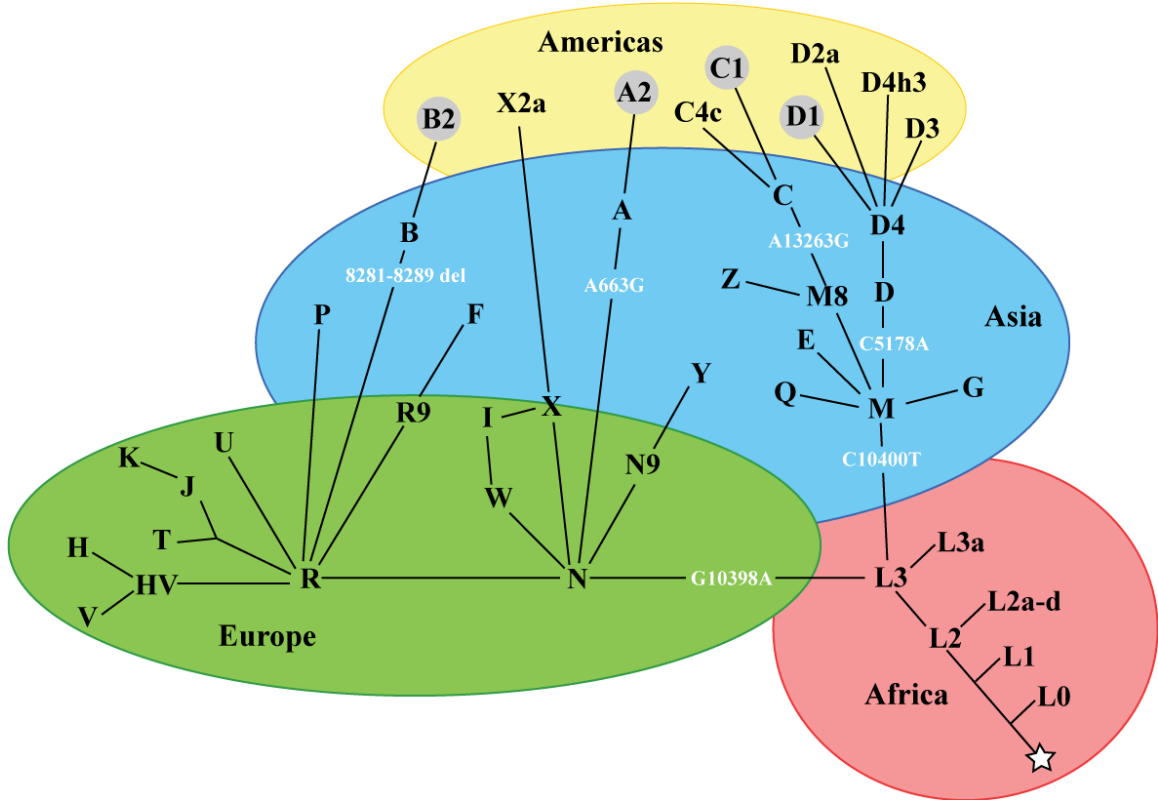


Figure 5.13. Simplified human mitochondrial DNA haplogroup tree. Ancestry informative markers (AIMs) sequenced in this study are indicated in white. The four pan-American haplogroups are highlighted in gray. The hypothetical common human ancestor is marked with a star. The revised Cambridge Reference Sequence (rCRS) (Andrews et al. 1999) belongs to haplogroup H. Branch length is not indicative of genetic distance. Adapted from MITOMAP (2009) and Achilli et al. (2008).

haplogroups A and B, two major subgroups of macrohaplogroup N found among Native Americans. Twenty-five individuals exhibited an A→G transition at np 663 characteristic of haplogroup A, while the remaining eleven individuals contained a 9bp deletion at np 8281-8289 characteristic of haplogroup B. No individuals exhibited mutations consistent with both haplogroups.

The ten members of macrohaplogroup M were tested for AIMs characteristic of haplogroups C and D, the two major subgroups of macrohaplogroup M found among Native Americans. Seven individuals exhibited an A→G transition at np 13263

characteristic of haplogroup C, and three individuals exhibited a C→A transition at np 5178 characteristic of haplogroup D. No individuals exhibited polymorphisms consistent with both haplogroups.

Five sequences yielded ambiguous base reads at ancestry informative sites. In three cases, base ambiguity resulted from a mixed base C/T peak at the nucleotide position of interest, and one case exhibited a full C→T transition. C→T transitions are a common artifact observed in PCR-based studies of ancient DNA, and they occur when deaminated deoxycytidine residues are mistakenly read as deoxythymidine residues by *Taq* polymerase, the enzyme employed in PCR (Hofreiter et al. 2001). These samples were reamplified, and subsequent sequencing yielded an unambiguous base read of C. One sequence yielded an ambiguous base read resulting from a mixed G/A peak. G→A transitions are also an artifact of cytosine deamination and occur when a deaminated cytosine is read as a thymine by *Taq* polymerase during PCR and an adenine is incorporated into the complementary strand of DNA. Subsequent reamplification and sequencing of this sample yielded an unambiguous base read of G.

In order to verify the quality of the haplogroup assignments, twenty-five individuals were selected for reamplification. Individuals 1, 16, and 18 were reamplified for the M and N macrohaplogroup SNPs at nucleotide positions 10398 and 10400, individuals 39-45 were reamplified for the A haplogroup SNP at np 663, individuals 18, 19, 21, 22, and 32 were reamplified for the B haplogroup 9bp deletion, individuals 13, 20, 24, 28, and 29 were reamplified for the C haplogroup SNP at np 13263, and individuals 16, 17, 23, and 27 were reamplified for the D haplogroup SNP at np 5178. In all cases, the reamplified SNP sequences matched the original sequence. Forty-eight

individuals were also screened for SNPs characteristic of haplogroups belonging to the other macrohaplogroup; thirty-eight individuals belonging to macrohaplogroup N were screened for markers characteristic of haplogroups C and/or D, and ten individuals belonging to haplogroup M were screened for markers characteristic of haplogroups A and/or B. No individuals exhibited genetic markers for a non-matching macrohaplogroup-haplogroup pair.

Mitochondrial haplogroup analysis of the Teposcolula cemeteries confirms that all tested individuals are of Native American ancestry, a result in accordance with dental observations.⁴⁷

Spanish presence at Teposcolula

Notably, none of the individuals in the Teposcolula cemeteries exhibited mitochondrial AIMs consistent with European or African ancestry. This is in agreement with the results of the oxygen stable isotope analysis, which found no evidence for foreign-raised individuals in the cemeteries. Historical records indicate that throughout the 1540s at least one and as many as six Dominican friars lived in residence at Teposcolula at any given time (Vences Vidal 2000:206-207), and excavations of the Teposcolula monastery in 2005 identified at least seven small rooms that may have served as cells for resident or traveling friars (Spores and Robles Garcia 2007; Robles García and Spores 2005). Dominican records for the period do not indicate that any of the Teposcolula friars died before the move to the valley, although at least one, Friar Bernardino de Santa María, became gravely ill.⁴⁸

⁴⁷ Shovel-shaped incisors, a common dental trait among Native American populations, was observed for many individuals in the Teposcolula cemeteries. Unfortunately, scoring of this trait was inconsistent and largely qualitative, thus precluding comparative analysis of this trait with mitochondrial genetic data.

⁴⁸ See Appendix 5.A.2.

Historical records indicate that non-ecclesiastical Spanish settlers first began moving to the Mixteca Alta in the late 1530s and early 1540s to assist with the burgeoning sericulture (silkworm-raising) and livestock herding industries (Romero Frizzi 1990:358).⁴⁹ At the Mixtec community of Texupa, for example, three Spanish brothers were issued a five-year viceroial license in 1538 to teach local Mixtecs the silk-raising trade and to found a sustainable silk-producing operation (Borah 2000). Silk-raising was also introduced at Teposcolula, and by 1544 Teposcolula was one of the largest producers of silk in the entire Mixteca, producing approximately 2,000 pesos of silk annually (Borah 1963). Nevertheless, it is not known if Spaniards other than the friars lived at Teposcolula before the move to the valley in 1552. After the move, Teposcolula rapidly became an important regional town, and records from the 1560s and 1570s document many Spanish residents (Romero Frizzi 1990). Because the 1545-1548 epidemic is known to have infected Europeans in addition to Native Americans, it is not unreasonable to assume that if Spaniards had been living at Teposcolula in appreciable numbers, they would be represented in the Teposcolula cemeteries. The absence of non-indigenous individuals in the Teposcolula cemeteries suggests that before the move to the valley, Teposcolula was a predominantly indigenous community.

Ancient and modern mitochondrial haplogroup frequencies of indigenous populations

Recent genetic studies of modern Native American populations have revealed significant regional patterning in mitochondrial haplogroup frequency distributions (Torrioni et al. 1993; Malhi et al. 2002; Schurr 2004). The American Southwest, for example, is generally characterized by high frequencies of haplogroup B (Malhi et al.

⁴⁹ During the early colonial period, Spanish and Mestizo residence within indigenous communities was generally discouraged (Terraciano 2001; see Appendix 5.A.6).

Table 5.7. Mitochondrial haplogroup frequencies of colonial Teposcolula and selected Native American populations

Study	N ^a	Haplogroup frequency (%)					References ^b
		A	B	C	D	X	
MESOAMERICA							
Colonial Mixtec†	46	54	24	15	7	0	This study
Mixtec	123	67	23	7	3	0	7, 10, 13, 21, 28
Zapotec	100	41	24	30	5	0	7, 10, 13, 28
Mixe	68	38	29	24	9	0	7, 10, 13, 28
Ancient Nahua	37	62	16	5	10	0	5, 8
Nahua	404	56	29	8	6	0	7, 10, 13, 15, 16, 21
Ancient Maya (Xcaret)*	24	88	4	8	0	‡	6
Ancient Maya (Copan) ^{c**}	9	0	0	8	1	‡	17
Maya	91	59	23	11	7	0	2, 21, 25, 26
AMER. SOUTHWEST							
Ancestral Puebloan ^{**}	38	9	76	15	0	‡	3, 4
Ancestral Puebloan ^{d**}	21	9.5	81	9.5	0	‡	13
Zuni ^{**}	50	16	76	8	0	‡	7, 10, 13, 15, 16
Akimel O'odham ^{**}	146	5	47	48	1	‡	7, 10, 13, 15, 16, 27
Jemez ^{**}	71	0	86	4	0	10	7, 10, 13, 15, 16, 25
CARIBBEAN							
Ancient Taino ^{**}	24	0	0	75	25	‡	12
Ancient Ciboney ^{**}	15	7	0	60	33	0	11
ANDEAN							
Ancient Andean ^{e**}	187	24.5	39	24.5	12	‡	9, 14, 19, 20, 22, 23
Quechua ^{**}	51	20	61	8	12	0	1, 18
Aymara ^{**}	205	5	72	11	12	0	1, 18

Notes:

†Only 46 individuals from the Teposcolula cemeteries were genetically analyzed because 9 individuals had not yet been excavated at the time of sample collection. Haplogroup was determined for all 46 tested individuals.

‡Testing for haplogroup X was not performed, and the haplogroup assignment of at least one individual from this population is given as “other” (i.e., not A, B, C, or D).

Haplogroup frequency significantly different from Teposcolula at 0.05 level (), at 0.01 level (**) using Chi-square test for homogeneity.

^aExcludes individuals with haplogroups indicative of European or African admixture, as well as individuals for whom haplogroup assignment was not determined.

^bPooled published data from: 1=Bert et al. 2001; 2=Boles et al. 1995; 3=Carlyle et al. 2000; 4=Carlyle 2005; 5=De la Cruz et al. 2008; 6=Gonzalez Oliver et al. 2001; 7=Kemp 2006; 8=Kemp et al. 2005; 9=Kemp et al. 2009; 10=Kemp et al. 2010; 11=Lalueza fox et al. 2001; 12=Lalueza Fox et al. 2003; 13=LeBlanc et al. 2007; 14=Lewis et al. 2007; 15=Lorenz and Smith 1996; 16=Malhi et al. 2003; 17=Merriwether et al. 1997; 18=Merriwether et al. 1995; 19=Moraga et al. 2001; 20=Moraga et al. 2005; 21=Peñaloza-Espinosa et al. 2007; 22=Rothhammer et al. 2003; 23=Schurr et al. 1990; 24=Shinoda et al. 2006; 25=Smith et al. 1999; 26=Torrioni et al. 1992; 27=Torrioni et al. 1993; 28=Torrioni et al. 1994.

^cThe unusual haplogroup distribution found in this study is likely an artifact of poor preservation and amplification bias.

^dAncient DNA in this study was recovered from cultural artifacts rather than human remains.

^eAncient DNA haplogroup frequency data from Sicán and Sipán (Shimada et al. 2005; Shimada et al. 2004) were excluded because individuals within the tomb assemblages exhibited close maternal relationships.

2003), while Mesoamerican populations typically have high frequencies of haplogroup A and very low frequencies of haplogroup D. By contrast, haplogroups B, C and D tend to dominate among Andean populations (Bert et al. 2001; Merriwether et al. 1995; see Melton et al. 2007). The haplogroup frequency distribution of the Teposcolula skeletal assemblage is consistent with a Mesoamerican pattern (Table 5.8), and is distinct ($p < .001$, Chi-square test for homogeneity) from modern and ancient indigenous populations in the American Southwest (e.g., Zuni, Jemez, Akimal O'odham, and Ancestral Puebloan), ancient Caribbean populations (e.g., Taino and Ciboney), and modern and ancient Andean populations (e.g., Quechua, Aymara, and ancient Andean).

Within Mesoamerica, the haplogroup frequency distribution of colonial Teposcolula compares well with that of modern Mixtecs, and to a lesser extent with other indigenous populations in Oaxaca, including the Zapotecs and Mixe ($p > 0.1$, Chi-square test for homogeneity). Despite severe declines in population throughout the 16th and 17th centuries, the relative genetic continuity observed between colonial and modern Mixtecs argues against a dramatic rise in genetic drift during the early colonial period, and suggests that 16th century population decline did not induce a severe population bottleneck. However, haplogroup frequency analysis is not a sensitive indicator of genetic change, and further genetic testing of the HVI and HVII regions of the mitochondrial genome is necessary to quantitatively estimate the severity of past population decline (e.g., see Chan et al. 2006) and to better refine our understanding of the genetic impact of colonial era epidemics.

5.9. Parameters of social and economic change

The period of 1520-1550 bore witness to rapid social and economic changes in the Mixteca Alta (Riquer 1990; Romero Frizzi 1990). The expansion of former tribute obligations through the establishment of the *encomienda* and *corregimiento* systems, the formalization of mandatory tithing, and the assessment of *sobras* (community taxes) increased production burdens on the peasant class (Borah 1941; Spores 1967:77, 121; Terreciano 2001:234),⁵⁰ and the introduction of currency and credit (later formalized into the *repartamiento* system) increasingly entangled native farmers in webs of debt encouraged through coerced borrowing and abusive and unfavorable trade conditions (Farriss 1984:39-47; Spores 1967:75-77; Taylor 1972; Terreciano 2001:236, 357). At the same time, native populations declined, in large part because of epidemic mortality, creating labor shortages (Spores 1967:72; Terreciano 2001:198, 362). In response to these changes, agricultural production transitioned from extensive to intensive (Riquer 1990), a strategy poorly suited to the long-term productivity of an agricultural landscape as mountainous as the Mixteca Alta (Terreciano 2001).⁵¹

Many Spanish agricultural species were introduced to New Spain at this time, including wheat, barley, garbanzo beans, fava beans, quince, parsley, coriander, onion, mustard, pigs, and chickens (Pellicer 1990; Romero-Frizzi 1990:78). Sericulture became an important industry in the Mixteca Alta, and at Teposcolula in particular, beginning in the late 1530s (Borah 1963; Pérez Ortiz 2003; Romero Frizzi 1990:70). In contrast, records for small livestock, such as sheep and goats (*ganado menor*), indicate that pastoralism did not become important economically until after 1551, when a royal charter

⁵⁰ See Appendices 5.A.3 and 5.A.8 for selected excerpts of colonial Mixtec taxation records.

⁵¹ See Appendices 5.C.1-2, 4-5.

allowing natives to raise livestock was issued (Riquer 1990). In the late 1550s, after the abandonment of Pueblo Viejo and the relocation to the valley below, Teposcolula became a major center of sheep herding in the Mixteca Alta (Spores 1967:83), and by 1563, Teposcolula boasted more than 8,000 head of sheep (Romero Frizzi 1990:94). Sheep and goat herding continues to be practiced at Teposcolula today.⁵²

Preliminary faunal analysis (Pérez-Roldán et al. n.d. a, b) of archaeological deposits in both the site core and outlying commoner residential terraces indicates that sheep and goats were present at Teposcolula before the relocation of the town in 1552 and hints at an earlier and more complex livestock economy at Teposcolula than indicated in historical records. In addition to sheep and goats, the remains of other European domesticates, including pigs, chickens, cattle, and at least one horse, were also identified.

The earliest historical records for economic production at Teposcolula date to 1531 and relate to a court decision to revoke the *encomienda* grant of Teposcolula's second *encomendero*, Juan Peláez de Berrio, because of cruelty and excessive demands of gold payments (Gerhard 1993:286; Pérez Ortiz 2003; Romero Frizzi 1990:50-53).⁵³ During the 1520s, there were no restrictions on the amount of goods or services an *encomendero* could demand from a native community, and such forms of abuse were common.⁵⁴ Teposcolula was reestablished as a *corregimiento*, the first in the Mixteca Alta, and henceforth had no *encomendero*, but rather paid tribute directly to the Spanish Crown. From 1531-1563, Teposcolula paid an annual royal tax of 900 gold pesos and the

⁵² See Appendix 5.C.3.

⁵³ See Appendix 5.B.5.

⁵⁴ See Chance (1978:18, 40, 51-52) for specific examples of abuse committed by Juan Peláez de Berrio during this period. The *encomienda* system was reformed in the 1530-1540s, and fixed periodic quotas of tribute and labor were established (Romero Frizzi 1990:50-51; Spores 1967:76).

yield of a field planted with 3 *fanegas* (approx. 43 kg) of wheat seed (Pérez Ortiz 2003:135; Spores 1967:79). Although the size of the field is not indicated, the nearby community of Yanhuitlan, which also paid tribute in gold and wheat, planted approximately 63 acres of wheat (Spores 1967:162).⁵⁵ At Teposcolula, an unknown amount of additional tribute was levied in the form of *sobras* and obligatory tithes⁵⁶ for civic and church purposes.

Pellicer (1990) has argued that wheat became an important fallback grain for indigenous communities during the early colonial period. Annual frost dates and rainfall in the Mixteca Alta are variable, and crop damage or failure occurs on average 5 out of 10 years in communities such as Teposcolula (Peña 1950:19; Riquer 1990). The Mediterranean variety of wheat introduced by the Spanish was relatively frost resistant and required less water than maize. At high elevations, such as in the Mixteca Alta, the introduction of wheat allowed farmers to grow maize in the summer and fall (during the warm rainy season), and wheat in the winter and spring (during the cold dry season) (Riquer 1990).

While it is clear from colonial taxation records that significant amounts of wheat were being grown in the Mixteca Alta, it is not clear how much wheat was actually consumed by Mixtecs in the early colonial period. In the *Relaciones Geograficas* (c.1579-1581), at least one Mixtec community lists wheat bread (*pan de Castilla*) as food consumed by the noble class (Acuña 1984b:239), but most other communities only refer to wheat in terms of its production. In order to determine the importance of wheat in

⁵⁵ See Appendix 5.B.6.

⁵⁶ After 1544, the Bishopric of Oaxaca established a tithe rate of 10% on all European goods produced. In the Mixteca, tithes were generally paid in wheat, silk, sheep, and goats (Borah 1941; Romero Frizzi 1990:79).

native diets at Teposcolula, bone and enamel apatite samples were collected from individuals in the Grand Plaza and Churchyard cemeteries, as well as from two Postclassic/Colonial infant burials excavated in an outlying commoner residential terrace, and were measured for carbon, nitrogen, and oxygen stable isotope values. In order to provide a framework for paleodietary interpretation, samples of native (see Chapter 4, Appendix 4.5) and non-native (see Appendices 5.G.1-2) domesticated crop plants from modern Mesoamerican markets were also collected and measured according to the protocols described in Chapter 4. The colonial Teposcolula population was then compared to Prehispanic highland and lowland populations throughout Mesoamerica, including 17 individuals from the nearby Valley of Oaxaca (see Chapter 4, Appendix 4.1).

5.9.1. Carbon and nitrogen stable isotope analysis of the Teposcolula cemeteries

The enriched $\delta^{13}\text{C}$ of collagen and enamel apatite within the Teposcolula population is consistent with a diet high in C4 and CAM plant resources (see Chapter 4), and the collagen $\delta^{13}\text{C}$ distribution of the Teposcolula population closely resembles that observed among highland Prehispanic populations in Central Mexico and the Valley of Oaxaca (Figure 5.14). A strong weaning signal is observed among children under 3, and the observed enrichment of collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ in these infants is consistent with a maternal diet similar to that inferred for Teposcolula adults. When broken down by age group, collagen $\delta^{13}\text{C}$ for adults age 25 and older is not significantly different from that of individuals aged 7-24, who grew up almost entirely during the period of wheat cultivation at Teposcolula ($p > 0.1$, ANOVA).

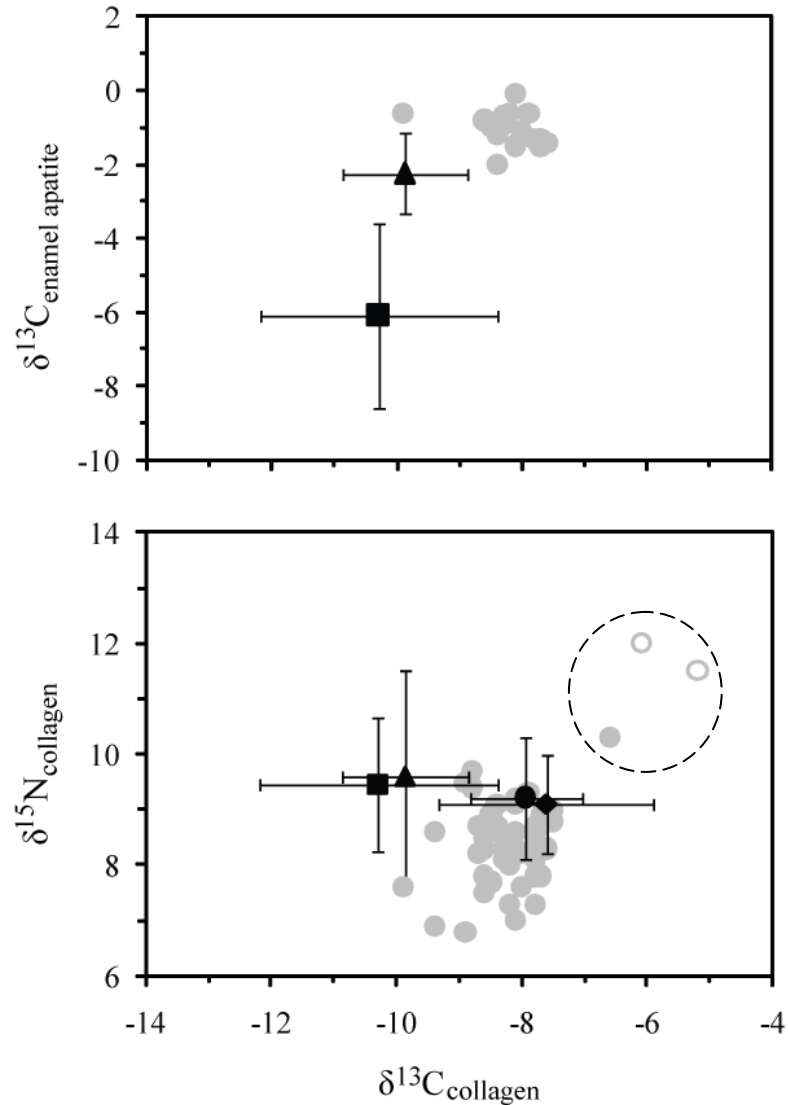


Figure 5.14. Carbon and nitrogen isotopic distribution of M3 enamel apatite and bone collagen of the Teposcolula Grand Plaza and Churchyard cemeteries (●) compared to other populations in the Valley of Oaxaca (●), Central Mexico (◆), the Southern Maya Lowlands (■), and the Maya Highlands (▲).⁵⁷ Bone collagen samples from two additional Postclassic/Colonial Teposcolula infants recovered from residential contexts (○) are included for comparison. Data points within dashed circle are infants under the age of 3.

⁵⁷ Collagen: populations represented include: Tehuacan Valley, Teotihuacan (Central Mexico); El Paragüito, Lambityeco, Monte Alban, Atzompa, San Miguel Albarradas, San Pedro Ixtlahuaca, Xatachio (Valley of Oaxaca); Aguateca, Altar de Sacrificios, Altun Ha, Arroyo de Piedra, Baking Pot, Barton Ramie, Cahal Pech, Chau Hiix, Copan, Copan area, Dos Pilas, Holmul, Itzan, K'axob, Lamanai, La Paciencia, Pacbitun, Punta de Chimino, Seibal, Tamarindito, Uaxactun (Southern Maya Lowlands); Kaminaljuyu (Maya Highlands); only samples with reported C/N ratios between 2.8-3.6 are included. Enamel apatite: populations represented include: Chau Hiix, Lamanai, Pacbitun (Southern Maya Lowlands); Iximche, Kaminaljuyu (Maya Highlands); includes only M3 data. See Chapter 4, Appendix 4.1 for references.

The $\delta^{13}\text{C}$ of third molar enamel apatite also indicates dietary continuity before and after the introduction of wheat at Teposcolula (Figure 5.14). The enamel of individuals aged 18-24 formed between approximately 1530 and 1545, the period of wheat cultivation at Teposcolula, while individuals 25 and older formed their M3 enamel between approximately 1505 and 1530,⁵⁸ the period before wheat introduction at Teposcolula. A comparison of third molar enamel apatite $\delta^{13}\text{C}$ between individuals 18-24 and individuals 25 and older reveals no significant carbon isotopic differences between the two age groups ($p > 0.1$, ANOVA). Although minor consumption of wheat cannot be ruled out,⁵⁹ carbon isotopic analysis of bone collagen and enamel apatite indicates no evidence of a substantial shift towards wheat consumption in early colonial Teposcolula.

5.9.2. Paleodietary lessons from Teposcolula enamel apatite data

In addition to being informative about dietary trends at Teposcolula during the colonial period, the Teposcolula enamel apatite data is also instructive for paleodietary modeling generally. The average enamel apatite $\delta^{13}\text{C}$ at Teposcolula is more enriched than that observed among both lowland and highland ancient Maya populations (Figure 5.9). This is not entirely unexpected because, in addition to maize, carbohydrate-rich CAM plants such as agave and nopal cactus were likely an important component of Mixtec diets in the colonial period, as they are today. What is unexpected is that the average $\delta^{13}\text{C}$ of Teposcolula apatite meets or exceeds⁶⁰ the theoretical $\delta^{13}\text{C}$ threshold of a

⁵⁸ Because of antemortem tooth loss, the third molar enamel apatite sample size ($N = 16$) is smaller than the adult skeletal sample size ($N = 28$).

⁵⁹ Many Mixtecs probably consumed a small amount of wheat on a weekly basis in the form of a Eucharistic host. During this period, all religious in New Spain received annual quantities of wine and flour in order to celebrate Mass (Mullen 1975:23; see Appendix 5.A.9).

⁶⁰ In order to compare the enamel apatite $\delta^{13}\text{C}$ of the Teposcolula population to the bone apatite $\delta^{13}\text{C}$ of the rodent studies, the Teposcolula enamels should be adjusted by -2% , to account for isotopic differences between enamel and bone apatite. See Chapter 2 for a discussion.

pure C4 diet (-3‰), as empirically determined in controlled feeding experiments of rodents (Jim et al. 2004; Tieszen and Fagre 1993).

As discussed in the methods section, chemical pretreatment to remove adsorbed carbonates did not alter enamel $\delta^{13}\text{C}$, suggesting that the high $\delta^{13}\text{C}$ of enamel apatite is not likely the result of contaminating environmental carbonates. Nevertheless, six plaster floor samples were collected from the Grand Plaza cemetery to determine if they could be a source of contaminating enriched carbonate. Plaster floor carbonate $\delta^{13}\text{C}$ averaged $-5.9 \pm 1.8\text{‰}$, with a total range of -3.0‰ to -8.0‰ . Thus, contamination by environmental carbonates would serve to deplete, rather than enrich, the $\delta^{13}\text{C}$ of the Teposcolula enamel apatite.

There is a growing body of evidence that rodent-derived data may not be appropriate for use in developing dietary models for larger animals, including humans (Passey et al. 2005; Patterson et al. 2008; Warinner and Tuross 2009). Developing a better model has been difficult, however, because most animals fail to thrive on a pure C4 diet. The colonial Tepsocolula skeletal assemblage provides a natural experiment that demonstrates that our current paleodietary models (e.g., Kellner and Schoeninger 2007) may be overestimating C4/CAM consumption in archaeological populations. Further enamel sampling of other highland Mesoamerican populations is urgently needed to determine if this is a general trend.

5.10. Conclusions

Excavations at the site of Pueblo Viejo Teposcolula have yielded important insights into early colonial life at a Mixtec community undergoing rapid political, cultural, demographic, and economic change. Paleodemographic analysis of the Grand

Plaza cemetery, the first unequivocal epidemic cemetery excavated in 16th century Mexico, substantiates the catastrophic mortality of the historically documented 1545-1548 pandemic, and bone specimens collected from the cemetery provide valuable biological samples for future ancient genetic testing of the cause of this poorly understood epidemic.

The preservation of ancient DNA in the skeletal remains is very good, and mitochondrial haplogroup typing confirms the Native American ancestry of the dead in both cemeteries. Oxygen isotope analysis indicates that the Teposcolula cemeteries represent a local population. Additionally, the haplogroup frequency profile of the Teposcolula cemeteries resembles that of modern Mixtecs, thus arguing against claims that epidemic-related population decline caused severe population bottlenecks.

Mortuary analysis of both the Grand Plaza and Churchyard cemeteries reveals interesting similarities and differences with other early colonial cemeteries, as well as evidence of the continued practice of some ancient burial customs. Additionally, stable isotope-based paleodietary analysis of the cemeteries indicates dietary continuity, even as agricultural production was undergoing rapid change. The exceptionally high enamel apatite $\delta^{13}\text{C}$ values measured at Teposcolula additionally indicate that current paleodietary models may be insufficient to characterize highland Mesoamerican diets.

The Teposcolula cemeteries provide a rich and complex perspective on early colonial life in the Mixteca Alta and reaffirm the importance of archaeological and bioarchaeological evidence in investigating complex social and biological processes of the past.

5.11. Bibliography

- Acosta, Jorge R. 1992. Tipo físico. In *Exploraciones en Monte Negro, Oaxaca*, Jorge R. Acosta and Javier Romero, eds. Pp. 137-153. Mexico, D.F.: Antologias, Serie Arqueologia, Instituto Nacional de Antropología e Historia.
- Acuña, René. 1984. *Relaciones geográficas del siglo XVI*. Vol. 2-3, Antequera. México: Universidad Nacional Autónoma de México.
- Acuna-Soto R., Romero L.C., Maguire J.H. 2000 Large epidemics of hemorrhagic fevers in Mexico 1545-1815. *The American Journal of Tropical Medicine and Hygiene* 62(6):733-739.
- Acuna-Soto R, Stahle DW, Cleaveland MK and Therrell 2002. Megadrought and megadeath in 16th century Mexico. *Emerging Infectious Diseases* 8:360-362.
- Achilli, Alessandro, Perego, Ugo A, Bravi, Claudio M, Coble, Michael D, Kong, Qing-Peng, Woodward, Scott R, Salas, Antonio, Torroni, Antonio, Bandelt, Hans-Jürgen. 2008. The Phylogeny of the Four Pan-American MtDNA Haplogroups: Implications for Evolutionary and Disease Studies. *PLoS One* 3(3): e1764.
- Alavez, Raul. 1988. *Toponimia Mixteca*. México: Centro de Investigaciones y Estudios Superiores en Antropología Social.
- Alavez Chávez, Raúl Gabriel. 2006. *Toponimia Mixteca II: Mixteca Alta, comunidades del distrito de Tlaxiaco*. México: Centro de Investigaciones y Estudios Superiores en Antropología Social: Instituto Estatal de Educación Pública de Oaxaca.
- Anderson, RM, Kubacka I, Chinnery, PF, Lightowlders, RN, Turnbull, DM, Howell, N. 1999. *Nature Genetics* 23(22):147.
- Balkansky, AK, Kowalewski, SA, Pérez Rodriguez, V, Pluckhahn, TJ, Smith, CA, Stiver, LR, Beliaev, D, Chamblee, JF, Heredia Espinoza, VY, Santos Pérez, R. 2000. Archaeological survey in the Mixteca Alta of Oaxaca, Mexico. *Journal of Field Archaeology* 27(4): 365-389.
- Beaumont, Pablo de la Purísima Concepción. 1932. *Crónica de Michoacán*, por fr. Pablo Beaumont. México: Talleres Gráficos de la Nación.
- Bell, LS, Lee-Thorp, JA, Dobney K. 2006. Mapping human movement using stable oxygen isotopic ratio mass spectrometry: potential application to forensic science demonstrated by a modern horse-human study. *Canadian Society of Forensic Science Journal* 39(2)47-54.
- Berdan, Frances, Anawalt, Patricia R. 1997. *The essential Codex Mendoza*. Berkley: University of California Press.
- Bert, F, Corella, A, Gene M, Perez-Perez, A, Turbon, D. 2001. Major mitochondrial DNA haplotype heterogeneity in highland and lowland Amerindian populations from Boliva. *Human Biology* 73:1-16.

- Blomster, Jeffrey P. 2004. Etlatongo: social complexity, interaction, and village life in the Mixteca Alta of Oaxaca, Mexico. *Case Studies in Archaeology*. Thomson Wadsworth.
- Boles, TC, Snow, CC, Stover, E. 1995. Forensic DNA testing on skeletal remains from mass graves: a pilot project in Guatemala. *Journal of Forensic Sciences* 40:349-355.
- Borah, Woodrow. 2000. The Indians of Tejuapan want to raise silk on their own: Oaxaca, Mexico 1543. In *Colonial Lives: Documents on Latin American History, 1550-1850*, Richard Boyer and Geoffrey Spurling, eds. Pp. 6-10. New York: Oxford University Press.
- Borah, Woodrow. 1941. The collection of tithes in the bishopric of Oaxaca during the sixteenth century. *Hispanic American Historical Review* 21(3):386-409.
- Borah, Woodrow. 1963. El origen de la sericultura en la Mixteca Alta. *Historial Mexicana* 13(1):1-17.
- Bryant, JD, Koch, PL, Froelich, PN, Showers, WJ, Genna BJ. 1996. Oxygen isotope partitioning between phosphate and carbonate in mammalian apatite. *Geochimica et Cosmochimica Acta* 60(24):5145-5148.
- Buikstra, Jane E, Ubelaker, Douglas, eds. 1994. *Standards for data collection from human skeletal remains*. Fayetteville, AR: Arkansas Archaeological Survey.
- Burgoa, Francisco de. 1934 [1674]. *Geográfica descripción*. México: Publicaciones del Archivo General de la Nación.
- Calderón Galván, E. 1988. *Tepozcolula: breve ensayo monográfico*. Oaxaca de Juárez, Mexico: Secretaría de Desarrollo Económico y Social, Dirección General de Educación, Cultura y Bienestar Social del Gobierno del Estado de Oaxaca.
- Callaway, Carol H. 1993. St. Michael and the Sudarium: a Christian soldier and human sacrifice. *College Literature* 20(3):79-95.
- Carlyle, Shawn W, Parr, Ryan L, Hayes, M Geoffrey, O'Rourke, Dennis H. 2000. Context of maternal lineages in the Greater Southwest. *American Journal of Physical Anthropology* 113:85-101.
- Carlyle, Shawn. 2005. Discerning the origins of the Anasazi with mtDNA haplogroups. In *Biomolecular archaeology: genetic approaches to the past*. Reed DM, ed. Occasional Paper 32. Center for Archaeological Investigations, Southern Illinois University, Carbondale. Pp. 93-127.
- Caso, Alfonso. 1956. La Cruz de Topiltepec, Tepozcolula, Oaxaca. In *Estudios antropológicos publicados en homenaje al doctor Manuel Gamio*. México: Dirección General de Publicaciones. Pp. 171-182.
- Caso, Alfonso. 1965. Lapidary work, goldwork, and copperwork from Oaxaca. In *Handbook of Middle American Indians, Vol. 3, Archaeology of Southern Mesoamerica*. Gordon R. Willey, ed. Pp. 896-930.

- Caso, Alfonso. 1977-1979. *Reyes y reinos de la Mixteca: diccionario biográfico de los señores mixtecos*. México, D.F.: Fondo de Cultura Económica.
- Castro Morales, E, Garcia Moll, R. 1972. Un entierro colectivo en la ciudad de Cholula, Puebla. In *Religion en Mesoamerica, XII mesa redonda*. Jaime Litvak King and Noemi Castillo Tejero, eds. Pp. 381-384. Mexico: Sociedad Mexicana de Antropología.
- Chamberlain, Andrew. 2006. *Demography in archaeology*. New York: Cambridge University Press.
- Chan, Yvonne, Anderson, Christian, Hadly, Elizabeth. 2006. Bayesian estimation of the timing and severity of a population bottleneck from ancient DNA. *PLoS Genetics* 2(4):e59.
- Chance, John K. 1978. *Race and class in colonial Oaxaca*. Stanford: Stanford University Press
- Charleton, Thomas H, Charlton, Cynthia L. Otis, Fournier García, Patricia. 2005. The Basin of Mexico AD 1450-1620. In *The Postclassic to Spanish Era Transition in Mesoamerica: Archaeological Perspectives*, Susan Kepecs and Rani T. Alexander, eds. Pp. 49-64. Albuquerque: University of New Mexico Press.
- Chimalpahin Cuauhtlehuanitzin, DF de SAM. 1997. *Codex Chimalpahin: society and politics in Mexico Tenochtitlan, Tlateloco, Texcoco, Culhuacan, and other Nahuatl altepetl in Central Mexico*. Norman, OK: University of Oklahoma Press.
- Cohen, Mark N, O'Connor, Kathleen, Danforth, Marie, Jacobi, Keith, Armstrong, Carl. 1994. Health and death at Tipu. In *In the Wake of Contact: Biological Responses to Conquest*, Clark Spencer Larsen and George R. Milner, eds. Pp.121-134. New York: Wiley-Liss.
- Cook, ND. 1998. *Born to die*. New York: Cambridge University Press.
- Cook, SF and Borah, W. 1968. *The population of the Mixteca Alta: 1520-1960*. Berkeley, CA: University of California Press.
- Coplen, TB, Kendall, C, Hopple, J. 1983. Comparison of stable isotope reference samples. *302(5905):236-238*.
- Crawford, MH. 1998. *The origin of Native Americans*. New York: Cambridge University Press.
- Crosby, Alfred W. 1976. *Epidemic and peace, 1918*. Westport, CT: Greenwood Press.
- Cuevas, Mariano. 1975. *Documentos inéditos del siglo XVI para la Historia de México*. México: Porrúa.
- Danforth, Marie Elaine, Jacobi, Keith P, and Cohen, Mark Nathan. 1997. Gender and health among the colonial Maya of Tipu, Belize. *Ancient Mesoamerica* 8:13-22.
- De la Cruz, Isabel, Gonzalez-Oliver Angelica, Kemp, Brian M, Roman, Juan A, Smith, David Glenn, Torre-Blanco, Alfonso. 2008. Sex identification of children sacrificed to the ancient Aztec rain gods in Tlateloco. *Current Anthropology* 49(3):519-526.

- DeNiro, Michael 1985. Postmortem preservation and alteration of invivo bone-collagen isotope ratios in relation to paleodietary reconstruction. *Nature* 317(6040):806-809.
- DeWitte, Sharon N, Wood, James W. 2008. Selectivity of Black Death mortality with respect to preexisting health. *PNAS* 105(5):1436-1441.
- Dickinson, Martin F. 1989. Delineating a site through limited research: the mission of San Juan del Puerto (8DU53), Fort George Island, Florida. *The Florida Anthropologist* 42(4):396-409.
- Duncan, WN, Balkansky, AK, Crawford, K, Lapham, HA and Meissner, J. 2008 Human cremation in Mexico 3,000 years ago. *Proceedings of the National Academy of Sciences USA* 105:5315-5320.
- Ehleringer, James R, Bowen, Gabriel J, Chesson, Lesley A, West, Adam G, Podlesak, David W, Cerling, Thure E. 2008. Hydrogen and oxygen isotope ratios in human hair are related to geography. *PNAS* 105(8):2788-2793.
- Eire, Carlos MN. 1995. *From Madrid to Purgatory: the art and craft of dying in sixteenth-century Spain*. New York: Cambridge University Press.
- Farriss, Nancy. 1984. *Maya society under colonial rule: the collective enterprise of survival*. Princeton: Princeton University Press.
- Ferembach, D, Schwidetzky, I, and Stloukal, M. 1979. Recommandations pour déterminer l'âge et le sexe sur le squelette. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 6(XIII):7-45.
- Fields, Sherry Lee. 2008. *Pestilence and headcolds: encountering illness in colonial Mexico*. New York: Columbia University Press.
- Foster, George M. 1960. *Culture and conquest: America's Spanish heritage*. New York: Wenner-Gren Foundation for Anthropological Research.
- Gaxiola González, Margarita. 1984. *Huamelulpan: un centro urbano de la Mixteca Alta*. Colección Científica. Mexico, D.F.: Instituto Nacional de Antropología e Historia.
- Gerhard, Peter. 1977. Congregaciones de Indios en la Nueva España antes de 1570. *Historia Mexicana* 26: 347-395.
- Gerhard, Peter. 1993. *A guide to the historical geography of New Spain*. Norman, OK: University of Oklahoma Press.
- Gilbert, MTP, Bandelt, H-J, Hofreiter, M, Barnes, I. 2005. Assessing ancient DNA studies. *Trends in Ecology and Evolution* 20(10): 541-544.
- González-Oliver, A, Márquez-Morfín, L, Jiménez, JC, Torre-Blanco A. 2001. Founding Amerindian mitochondrial DNA lineages in ancient Maya from Xcaret, Quintana Roo. *American Journal of Physical Anthropology* 116:230-235.
- Gowland, RL, Chamberlain, AT. 2005. Detecting plague: palaeodemographic characterization of a catastrophic death assemblage. *Antiquity* 79:146-157.

- Graham, Elizabeth, Pendergast, David M, and Jones, Grant D. 1989. On the fringes of conquest: Maya-Spanish contact in colonial Belize. *Science* 246(4935):1254-1259.
- Guzmán, Eulalia. 1934. Exploración Arqueología en la Mixteca Alta. *Anales del Museo Nacional de Arqueología, Historia y Etnografía*. Tomo I, X época. México: Talleres Gráficos de la Nación.
- Hodges, DC. 1987. Health and agricultural intensification in the Valley of Oaxaca, Mexico. *American Journal of Physical Anthropology*. 73(3):323-332.
- Hollingsworth, Mary F, Hollingsworth, TH. 1971. Plague mortality rates by age and sex in the parish of St. Boltolph's without Bishopgate. *Population Studies* 25(1):131-146.
- Hoppa, RD, Vaupel, JW, eds. 2002. *Paleodemography: Age Distributions from Skeletal Samples*. Cambridge: Cambridge University Press.
- Humboldt, Alexander F von. 1966. *Ensayo político sobre el reino de la Nueva España*. México: Editorial Porrúa.
- Iacumin, P, Bocherens, H, Mariotti, A, Longinelli A. 1996. An isotopic palaeoenvironmental study of human skeletal remains from the Nile Valley. *Palaeogeography, Palaeoclimatology, Palaeoecology* 126:15-30.
- Jacobi, Keith. 2000. *Last Rites for the Tipu Maya*. Tuscaloosa: University of Alabama Press.
- Jim, S, Ambrose, SH, Evershed, RP. 2004. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: implications for their use in palaeodietary reconstruction. *Geochimica Et Cosmochimica Acta* 68(1):61-72.
- Jimenez Moreno, Wigberto and Mateos Higuera, Salvador. 1940. *Codice de Yanhuitlan*. Mexico, D.F.: Museo Nacional, Secretaria de Educacion Publica, Instituto Nacional de Antropología e Historia.
- Kellner, CM, Schoeninger, MJ. 2007. A simple carbon isotope model for reconstructing prehistoric human diet. *American Journal of Physical Anthropology* 133(4):1112-1127.
- Kemp, Brian M. 2006. *Mesoamerica and Southwest prehistory, and the entrance of humans into the Americas: mitochondrial DNA evidence*. Doctoral dissertation. University of California, Davis, CA.
- Kemp BM, Reséndez A, Román Berrelleze JA, Malhi RS and Smigh DG. 2005. An analysis of ancient Aztec mtDNA from Tlatelolco. In *Biomolecular archaeology: genetic approaches to the past*. Reed DM, ed. Occasional Paper 32. Center for Archaeological Investigations, Southern Illinois University, Carbondale. Pp. 32-46.
- Kemp, Brian, Tung, Tiffani, Summar, Marshall. 2009. Genetic continuity after the collapse of the Wari Empire: mitochondrial DNA profiles from Wari and post-

- Wari populations in the ancient Andes. *American Journal of Physical Anthropology* 140:90-91.
- Kemp, Brian, González-Oliver, Angélica, Malhi, Ripan, Monroe, Cara, Schroeder, Kari, McDonough, John, Rhett, Gillian, Resendéz, Andres, Peñalosa-Espinosa, Rosenda, Buentello-Malo, Leonor, Gorodesky, Clara, Smith, David Glenn. 2010. Evaluating the farming/language dispersal hypothesis with genetic variation exhibited by populations in the Southwest and Mesoamerica. *PNAS* 107(15):6759-6764.
- Kiracofe, James B. 1995. Architectural fusion and indigenous ideology in early colonial Teposcolula: the Casa de la Cacica, a building at the edge of oblivion. *Anales del Instituto de Investigaciones Estéticas* 66: 45-84.
- Kiracofe, James B. 1996. Architectural fusion and indigenous identity in early colonial Mexico: a case study of Teposcolula, Oaxaca, 1535-1580, demonstrating cultural transmission and transformation through negotiation and consent in planning a new urban environment. Virginia Polytechnic Institute and State University, Unpublished Ph.D. dissertation.
- Koch, J. 1983. Mortuary behavior patterning and physical anthropology in colonial St. Augustine. In: *Spanish St. Augustine: the archaeology of a colonial creole community*. Ed., Kathleen Deagan. New York: Academic Press.
- Koch, Paul, Tuross, Noreen, Fogel, Marilyn L. 1997. The effects of sample treatment and diagenesis on the isotopic integrity of carbonate in biogenic hydroxylapatite. *Journal of Archaeological Science* 24:417-429.
- Kolman, C and Tuross, N. 2000. Ancient DNA analysis of human populations. *American Journal of Physical Anthropology* 111:5-23.
- Krogman, WM, Iscan, MY. 1986. *The Human Skeleton in Forensic Medicine*. Springfield, IL: C.C. Thomas Publications.
- Kubler, George. 1948. *Mexican Architecture of the Sixteenth Century*. New Haven: Yale University Press.
- Lalueza Fox, C, Luna Calderón, F, Calafell, F, Morera, B, Bertranpetit, J. 2001. MtDNA from extinct Tainos and the peopling of the Caribbean. *Annals of Human Genetics* 65: 137-151.
- Lalueza Fox, C, Gilbert, MTP, Martínez Fuentes, AJ, Calafell, F, Bertranpetit, J. 2003. Mitochondrial DNA from Pre-Columbian Ciboneys from Cuba and the prehistoric colonization of the Caribbean. *American Journal of Physical Anthropology* 121:97-108.
- Larsen, Clark Spencer, ed. 1990. The archaeology of Mission Santa Catalina de Gaule: 2. biocultural interpretations of a population in transition. *Anthropological Papers of the American Museum of Natural History* 68.
- Larsen, Clark Spencer. 1993. On the frontier of contact: mission bioarchaeology in La Florida. In *The Spanish missions of La Florida*, Bonnie G McEwan, eds. Pp. 322-356. Gainesville: University Press of Florida.

- Larsen, Clark Spencer, Schoeninger, Margaret J, Hutchinson, Dale L, Russell, Katherine F, Ruff, Christopher B. 1990. Beyond demographic collapse: biological adaptation and change in native populations of La Florida. In *Columbian Consequences*, Vol. 2: Archaeological and historical perspectives on the Spanish Borderlands East, David Hurst Thomas, ed. Pp. 409-428. Washington, D.C.: Smithsonian Institution Press.
- LeBlanc, Steven A, Kreisman, Lori S, Cobb, Kemp, Brian M, Smiley, Francis E, Carlyle, Shawn W, Dhody, Anna N, Benjamin, Thomas. 2007. Quids and aprons: ancient DNA from artifacts from the American Southwest. *Journal of Field Archaeology* 32:161-175.
- Lee, Thomas A. 1979a. Coapa, Chiapas: a sixteenth-century Coxoh Maya village on the Camino Real. In *Maya Archaeology and Ethnohistory*, Norman Hammond and Gordon R. Willey, eds. Pp. 208-222. Austin: University of Texas Press.
- Lee, Thomas A. 1979b. Early colonial Coxoh Maya syncretism in Chiapas, Mexico. *Estudios de cultura maya* 12:93-109.
- Lewis, Cecil M, Buikstra, Jane, Stone, Anne. 2007. Ancient DNA and genetic continuity in the south central Andes. *Latin American Antiquity* 18(2):145-160
- Longinelli, Antonio. 1984. Oxygen isotopes in mammal bone phosphate: a new research tool for paleohydrological and paleoclimatological research? *Geochimica et Cosmochimica Acta* 48:385-390.
- Lorenz, Joseph G, Smith, David Glenn. 1996. Distribution of four founding mtDNA haplogroups among native North Americans. *American Journal of Physical Anthropology* 101: 307-323.
- Lovejoy, C Owen, Meindl, Richard S, Pryzbeck, TR, Mensforth, Robert P. 1985. Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. *American Journal of Physical Anthropology* 68:15-28.
- Lovell, G. 1992. Disease and depopulation in early colonial Guatemala. In: *Secret Judgements of God: Old World disease in Colonial Spanish America*, eds. Noble David Cook and W. George Lovell, pp. 49-83.
- Luz, B, Kolodny, Y. 1989. Oxygen isotope variations in bone phosphate. *Applied Geochemistry* 4:317-323.
- MacLeod MJ. 1973. *Spanish Central America: a socioeconomic history, 1520-1720*. Berkeley, CA: University of California Press.
- Malhi, Ripan S, Eshleman, Jason A, Greenberg, Jonathan A, Weiss, Deborah A, Schultz Shook, Beth A, Kaestle, Frederika A, Lorenz, Joseph G, Kemp, Brian M, Johnson, John R, Smith, David Glenn. 2002. The structure of diversity within New World mitochondrial DNA haplogroups: implications for the prehistory of North America. *American Journal of Human Genetics* 70:905-919.
- Malhi, Ripan S, Mortensen, Holly M, Eshleman, Jason A, Kemp, Brian M, Lorenz, Joseph G, Kaestle, Frederika A, Johnson, John R, Gorodezky, Clara, Smith,

- David Glenn. 2003. Native American mtDNA prehistory in the American Southwest. *American Journal of Physical Anthropology* 120:108-124.
- Malvido, Elsa. 1997. Civilizados o salvajes: los ritos al cuerpo humano en la época colonial mexicana. In *El cuerpo humano y su tratamiento mortuorio*, Elsa Malvido, Grégory Pereira, and Vera Tiesler, eds. Pp. 29-49. Serie Antropología Social, Centro Francés de Estudios Mexicanos y Centroamericanos. Mexico, D.F.: Instituto Nacional de Antropología e Historia.
- Malvido, E, Mansilla J, and Pompa JA. 1986. Un cementerio indígena del siglo XVI en Huexotla, Estado de México. *Trace* 10:39-51
- Malvido, E and Viesca C. 1985. La epidemia de cocoliztli de 1576. *Historias* (Mexico, D.F.) 11: 27-33.
- Mansell, EB, Tykot, RH, Friedel, DA, Dahlin, BH and Arden, T. 2006. Early to terminal classic Maya diet in the northern lowlands of the Yucatan (Mexico). In *Histories of Maize*. Staller J, Tykot R and Benz B, eds. Academic Press, pp. 173-185.
- Mansilla, Josefina, Pompa, José. 1992. Un cementerio indígena del siglo XVI en Huexotla. In *Antropología física anuario 1991*, María Teresa Jáen, José Luis Fernández Torres, Antonio Pompa y Padilla, eds. Pp. 93-119. México: Instituto Nacional de Antropología e Historia.
- Mansilla, Josefina, Pijoan, Carmen María, Pompa, José A, Villegas, Delia. 1992. Los entierros primarios del templo de San Jerónimo, ciudad de México (temporada 1976): estudio de los indicadores de las agresiones ambientales. In *Antropología física anuario 1991*, María Teresa Jáen, José Luis Fernández Torres, Antonio Pompa y Padilla, eds. Pp. 121-149. México: Instituto Nacional de Antropología e Historia.
- Margerison, Beverley J and Knüsel, Christopher J. 2002. Paleodemographic comparison of a catastrophic and an attritional death assemblage. *American Journal of Physical Anthropology* 119:134-143.
- Marr, John S, Kiracofe, James B. 2000. Was the huey cocoliztli a haemorrhagic fever? *Medical History* 44:341-362.
- McAndrew, John. 1965. *The open-air churches of sixteenth century Mexico: atrios, posas, open chapels, and other studies*. Cambridge: Harvard University Press.
- McCafferty GG. 2000. The Cholula massacre: factional histories and archaeology of the Spanish conquest. In *The Entangled Past: Integrating History and Archaeology*, M Boyd, JC Erwin and M Hendrickson, eds. Pp. 347-359. Proceedings of the 30th annual Chacmool Conference. Calgary: The Archaeological Association of the University of Calgary, Alberta.
- McClung de Tapia, Emily, Solleiro-Rebolledo, Elizabeth, Gama-Castro, Jorge, Villalpando, José Luis, Sedov, Sergey. 2003. Paleosols in the Teotihuacan valley, Mexico: Evidence for paleoenvironment and human impact. *Revista Mexicana de Ciencias Geológicas* 20(3):270-282.

- Melville Elinor GK. 1994. *A plague of sheep: environmental consequences of the conquest of Mexico*. New York: Cambridge University Press.
- Melton PE, Briceño I, Gómez A, Devor EJ, Bernal JE and Crawford MH. 2007. Biological relationship between Central and South American Chibchan speaking populations: evidence from mtDNA. *American Journal of Physical Anthropology* 133:753-770.
- Mendieta, FJ de. 1945 [c.1574-1596]. *Historia eclesiástica Indiana*. México, D.F.: Editorial Salvador Chávez Hayhoe.
- Merriwether, DA, Rothhammer, F, Ferrell, RE. 1995. Distribution of the four founding lineage haplotypes in Native Americans suggests a single wave of migration for the New World. *American Journal of Physical Anthropology* 98:411-430.
- Merriwether DA, Reed DM and Ferrell RE. 1997. Ancient and contemporary mitochondrial DNA variation in the Maya. In *Bones of the Maya: studies of ancient skeletons*. Whittington SL and Reed DM, eds. Washington, DC: Smithsonian Institution Press.
- Metcalfe, JZ, Longstaffe, FJ, White CD. 2009. Method-dependent variations in stable isotope results for structural carbonate in bone apatite. *Journal of Archaeological Science* 36:110-121.
- Middleton, WD, Feinman, GM, Molina Villegas, Guillermo. Tomb use and reuse in Oaxaca, Mexico. *Ancient Mesoamerica* 1998(9):297-307.
- Miller, Arthur G, Farriss Nancy M. 1979. Religious syncretism in colonial Yucatan: the archaeological and ethnohistorical evidence from Tanchah, Quintana Roo. In *Maya Archaeology and Ethnohistory*, Norman Hammond and Gordon R Willey, eds., pp. 223-240. Austin: University of Texas Press.
- Miranda, José. 1958. Orígenes de la ganadería en la Mixteca. In *Miscellanea*, Paul Rivet octogenario dictata, Vol. 2.
- MITOMAP: A Human Mitochondrial Genome Database. <http://www.mitomap.org>, 2009.
- Moraga, Mauricio, Aspillaga, Eugenio, Santoro, Calogero, Standen, Vivien, Carvallo, Pilar, and Rothhammer, Francisco. 2001. Análisis de ADN mitocondrial en momias del norte de Chile avala hipótesis de origen amazónico de poblaciones andinas. *Revista Chilena de Historia Natural* 74:719-726.
- Moraga, Mauricio, Santoro Calogero, Standen, Vivien, Carvallo, Pilar, Rothhammer, Francisco. 2005. Microevolution in prehistoric Andean populations: chronologic mtDNA variation in the desert valleys of Northern Chile. *American Journal of Physical Anthropology* 127:170-181.
- Motolinía o Benavente, T de. 1971. *Memoriales o libro de las cosas de la Nueva España y de los naturales dello*. México: UNAM.
- Mullen, Robert James. 1975. *Dominican architecture in sixteenth century Oaxaca*. Tempe: Center for Latin American Studies, Arizona State University.

- Newson, L. 1992. Old World epidemics in early colonial Ecuador. In: *Secret Judgments of God: Old World disease in Colonial Spanish America*, eds. Noble David Cook and W. George Lovell, pp. 84-112.
- Ocaña del Río, Bertha. 1985. Estudio del material oseó procedente del convento de San Gabriel, Cholula, Puebla. In *Avances en antropología física. Cuaderno de Trabajo 2*. Pp. 73-80. Mexico, D.F.: Instituto Nacional de Antropología e Historia.
- Orellana SL. 1987. *Indian medicine in Highland Guatemala*. Albuquerque, NM: University of New Mexico Press.
- Oudijk, MR, Restall, M. 2007. Mesoamerican conquistadors in the sixteenth century. In: *Indian conquistadors: indigenous allies in the conquest of Mesoamerica*, eds., Laura E. Matthew and Michel R. Oudijk. Norman, OK: University of Oklahoma Press.
- Paso y Troncoso, F. 1981. *Relaciones geográficas de Oaxaca*. Edit. Innovación, S.A. México.
- Passey, Benjamin H, Robinson, Todd F, Ayliffe, Linda K, Cerling, Thure E, Sponheimer, Matt, Dearing, M. Denise, Roeder, Beverly L, Ehleringer, James R. 2005. *Journal of Archaeological Science* 32:1459-1470.
- Patterson, Jannine K, Lei, Xin Gen, Miller, Denise D. 2008. The pig as an experimental model for elucidating the mechanisms governing dietary influence on mineral absorption. *Experimental Biology and Medicine* 233(6):651-664.
- Pellicer, Sergio Navarrete. 1990. Las transformaciones de la economía indígena en Michoacán: siglo XVI. In *Agricultura indígena: pasado y presente*, Teresa Rojas Rabiela, ed. Ediciones de la Casa Chata 27. Pp. 109-127. Mexico, D.F.: Centro de Investigaciones y Estudios Superiores en Antropología Social.
- Peña, MT de la. 1950. Problemas sociales y económicos de las Mixtecas. *Memorias del Instituto Nacional Indigenista Vol. 2, No. 1*. México, D.F.: Ediciones del Instituto Nacional Indigenista.
- Peñaloza-Espinosa, RI, Arenas-Aranda, D, Cerda-Flores, RM, Buentello-Malo, L, González-Valencia, G, Torres, J, Alvarez, B, Mendoza, I, Flores, M, Sandoval, L, Loeza, F, Ramos, I, Muñoz, L, Salamanca, F. 2007. Characterization of mtDNA haplogroups in 14 Mexican indigenous populations. *Human Biology* 79(3):313-320.
- Pendergast, David M. 1991. The Southern Maya Lowlands contact experience: the view from Lamanai, Belize. In *Columbian Consequences, Vol. 3, The Spanish Borderlands in Pan-American Perspective*, David Hurst Thomas, ed. Pp. 337-354. Washington, D.C.: Smithsonian Institution Press.
- Pérez Ortiz, Alfonso. 2003. *Tierra de Brumas: Conflictos en la Mixteca Alta, 1523-1550*. Mexico, D.F.: Plaza y Valdés.
- Pérez Rodríguez, Veronica. 2006. States and households: the social organization of terrace agriculture in Postclassic Mixteca Alta, Oaxaca, Mexico. *Latin American Antiquity* 17(1):3-22.

- Pérez-Roldán, Gilberto, Fabiola Torres-Estévez, María, and Valadez-Azúa, Raúl. Not dated, a. Primer informe parcial de la fauna descubierta en el "Proyecto Arqueológico Pueblo Viejo de Teposcolula, Yucundaa," Temporada 2004. Universidad Nacional Autónoma de México Instituto de Investigaciones Antropológicas Laboratorio de Paleozoología.
- Pérez-Roldán, Gilberto, Fabiola Torres-Estévez, María, and Valadez-Azúa, Raúl. Not dated, b. Segundo informe parcial de la fauna descubierta en el "Proyecto Arqueológico Pueblo Viejo de Teposcolula, Yucundaa," Temporada 2005. Universidad Nacional Autónoma de México Instituto de Investigaciones Antropológicas Laboratorio de Paleozoología.
- Pita Moreda, María Teresa. 1992. Los predicadores novohispanos del siglo XVI. Salamanca: San Esteban, Editorial.
- Prem, Hans. 1992. Disease outbreaks in Central Mexico during the sixteenth century. In: *Secret Judgments of God: Old World disease in Colonial Spanish America*. Cook ND and WG Lovell, eds. Norman: University of Oklahoma Press, pp. 20-48.
- Price, T Douglas, Burton, James H, Sharer, Robert J, Buikstra, Jane E, Wright, Lori E, Traxler, Loa P, Miller, Katherine A. 2010. Kings and commoners at Copan: isotopic evidence for origins and movement in the Classic Maya period. *Journal of Anthropological Archaeology* 29:15-32.
- Quinn RL, Tucker BD and Krigbaum J. Diet and mobility in Middle Archaic Florida: stable isotopic and faunal evidence from the Harris Creek archaeological site (8Vo24), Tick Island. *J Archaeol Sci* 35(8): 2346-2356.
- Quiñones, Keber Eloise. 1995. *Codex Telleriano-Remensis: ritual, divination, and history in pictorial Aztec manuscript*. Austin: University of Texas Press.
- Restall, Matthew, Sousa, Lisa, Terraciano, Kevin. 2001. *Mesoamerican voices: colonial Mexico, Oaxaca, Yucatan, and Guatemala*. New York: Cambridge University Press.
- Riquer, Jorge Silva. 1990. La agricultura indígena en el Valle de Nochixtlan en el siglo XVI. In *Agricultura indígena: pasado y presente*, Teresa Rojas Rabiela, ed. Ediciones de la Casa Chata 27. Pp. 187-196. Mexico, D.F.: Centro de Investigaciones y Estudios Superiores en Antropología Social.
- Robles García, Nelly. 1988. Las unidades domésticas del preclásico superior en la Mixteca Alta. *BAR International Series* 407.
- Robles García, Nelly, Spores, Ronald. 2004. Pueblo Viejo de Teposcolula Yucundaa, proyecto arqueológico: primera temporada. Cuadernos de Teposcolula 3. Resultados reportados al Consejo de Arqueología del INAH, México.
- Robles García, Nelly, Spores, Ronald. 2005. Pueblo Viejo de Teposcolula Yucundaa, proyecto arqueológico: primera temporada. Resultados reportados al Consejo de Arqueología del INAH, México.

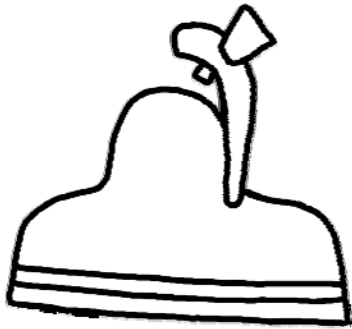
- Robles García, Nelly, Spores, Ronald. 2006. Pueblo Viejo de Teposcolula Yucundaa, proyecto arqueológico: primera temporada.. Resultados reportados al Consejo de Arqueología del INAH, México
- Robles Sierra, Adolfo. 1990. Una aproximación a Domingo de Betanzos: a propósito de su carta de 1540. In Actas del II Congreso Internacional sobre los Dominicos y el Nuevo Mundo, José Barrado, ed. Pp. 227-258. Salamanca: Editorial San Esteban.
- Romano Pacheco, Arturo and Jaén Esquivel, María Teresa. 1985. Proyecto: ex convento de san jeronimo, df. “estudio de una muestra de la población de la Ciudad de Mexico, siglos XVI a XIX. In Avances en antropología física. Cuaderno de Trabajo 2. Pp. 87-93. Mexico, D.F.: Instituto Nacional de Antropología e Historia.
- Romero Frizzi, Maria de los Ángeles. 1990. Economía y vida de los españoles en la Mixteca Alta: 1519-1720. Colección Regiones de México. México, D.F.: Instituto Nacional de Antropología e Historia, Gobierno del Estado de Oaxaca.
- Rothhammer, Francisco, Santoro, Calogero, Poulin, Elie, Arriaza, Bernardo, Moraga, Mauricio, Standen, Vivien. 2009. Archaeological and mtDNA evidence for tropical lowland migrations during the Late Archaic/Formative in Northern Chile. *Revista Chilena de Historia Natural* 82:543-552.
- Rush, Alfred C. 1941. *Death and burial in Christian antiquity*. Washington, D.C.: Catholic University of America Press.
- Sahagún, Bernardino de. 1950-1982. *Florentine Codex: general history of the things of New Spain*. Santa Fe, NM: School of American Research; Salt Lake City, UT; University of Utah.
- Sahagun, Bernardino de. 1956. *Historia General de las cosas de Nueva España*. Vol. 3. Pp. 355-361. Ed. Angel María Garibay K. México: Editorial Porrúa.
- Salas Cuesta, María Elena. 1982. *La población de México Tenochtitlan, Estudio de osteología Antropológica*, Colección Científica-Antropología Física, México.
- Salazar, Gerardo A, García-Mendoza, Abisai. 2009. A new species of *Dichromanthus* (Orchidaceae, Spiranthinae) from Oaxaca, Mexico. *Revista Mexicana de Biodiversidad* 80:23-28.
- Schroeder, Hannes, O’Connell, Tamsin C, Evans, Jane E, Shuler, Kristrina A, Hedges, Robert EM. 2009. Trans-Atlantic slavery: isotopic evidence for forced migration to Barbados. *American Journal of Physical Anthropology* 139:547-557.
- Schurr TG. 2004. The peopling of the New World: perspectives from molecular anthropology. *Annual Review of Anthropology* 33: 551–583.
- Schurr, TG, Ballinger, SW, Gan, YY, Hodge, JA, Merriwether, DA, et al. 1990. Amerindian mitochondrial DNAs have rare Asian mutations at high frequencies, suggesting they derived from four primary maternal lineages. *American Journal of Human Genetics* 46:613–623.
- Scott, GR, Turner II, CG. 1997. *The anthropology of modern human teeth: dental morphology and its variation in recent human populations*. Cambridge: Cambridge University Press.

- Sepúlveda y Herrera, María Teresa. 1994. *Códice de Yanhuítlán: estudio preliminar*. México, D.F.: Benemérita Universidad Autónoma de Puebla, Instituto Nacional de Antropología e Historia.
- Shimada, Izumi, Shinoda, Ken-ichi, Bourget, Steve, Alva, Walter, Uceda, Santiago. 2005. MtDNA analysis of Mochica and Sicán populations of Pre-Hispanic Peru. In *Biomolecular archaeology: genetic approaches to the past*. Reed DM, ed. Occasional Paper 32. Center for Archaeological Investigations, Southern Illinois University, Carbondale. Pp. 61-92.
- Shimada, Izumi, Shinoda, Ken-ichi, Farnum, Julie, Corruccini, Robert, Watanabe, Hirokatsu. 2004. An integrated analysis of Prehispanic mortuary practices: a Middle Sicán case study. *Current Anthropology* 45(3):369-402.
- Shinoda, Ken-ichi, Adachi, Noboru, Guillen, Sonia, Shimada, Izumi. 2006. Mitochondrial DNA analysis of ancient Peruvian highlanders. *American Journal of Physical Anthropology* 131(1):98-107.
- Signoli, Michel. 2006. Etude anthropologique de crises démographiques en contexte épidémique: aspects paléo –et biodémographiques de la peste en Provence. Oxford: Archaeopress.
- Signoli, Michel, Seguy, Isabelle, Biraben, Jean-Noel, Dutour, Olivier, Belle, Paul. 2002. Paleodemography and historical demography in the context of an epidemic plague in Provence in the eighteenth century. *Population* 57(6):829-854.
- Smith, DG, Malhi, RS, Eshleman, J, Lorenz, JG, Kaestle, FA. 1999. Distribution of mtDNA haplogroup X among Native North Americans. *American Journal of Physical Anthropology* 110:271-284.
- Soren, David. 2003. Can archaeologists excavate evidence of malaria? *World Archaeology* 35(2):193-209.
- Spores, Ronald. 1967. *The Mixtec Kings and their Peoples*. Norman: University of Oklahoma Press.
- Spores, Ronald. 1974. Marital alliance in the political integration of Mixtec kingdoms. *American Anthropologist* 76(2):297-311.
- Spores, Ronald. 1984. *The Mixtecs in ancient and colonial times*. Norman: University of Oklahoma Press.
- Spores, Ronald. 1997. Mixteca cacicas: status, wealth, and the political accommodation of native elite women in early colonial Oaxaca. In *Indian Women of Early Mexico*, Susan Schroeder, Stephanie Wood, and Robert Haskett, eds. Norman: University of Oklahoma Press.
- Spores, Ronald and Robles García, Nelly. 2007. A Prehispanic (Postclassic) capital center in colonial transition: excavations at Yucundaa Pueblo Viejo de Teposcolula, Oaxaca, Mexico. 2007. *Latin American Antiquity* 18(3): 333-353.
- Sticker, G. 1932. Die Einschleppung europäischer Krankheiten in Amerika während der Entdeckungszeit; ihr Einfluss auf den Rückgang der Bevölkerung. *Ibero-Amerikanisches Archiv* 6:62-83, 194-224.

- Stiver, Laura. 2001. Prehispanic Mixtec settlement and state in the Teposcolula Valley of Oaxaca, Mexico. Doctoral dissertation. Vanderbilt University, Nashville, TN.
- Taylor, William. 1972. Landlord and peasant in colonial Oaxaca. Stanford: Stanford University Press
- Tejada y Ramiro, Juan. 1855. Colección de canones y de todos los concilios de la Iglesia Española. Madrid.
- Terraciano, Kevin. 2001. The Mixtecs of colonial Oaxaca: Ñudzahui history, sixteenth through eighteenth centuries. Stanford, CA: Stanford University Press.
- Tieszen, LL, Fagre, T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO₂, bone collagen, bioapatite and soft tissues. In Prehistoric Human Bone: archaeology at the molecular level, JB Lambert and G Grupe, eds. Pp. 121-155. Berlin: Springer Verlag.
- Tiesler, V, Cucina, A, Pacheco, AR. 2004. Who was the red queen? Identity of the female Maya dignitary from the sarcophagus tomb of Temple XIII, Palenque, Mexico. *Homo* 55(1-2): 65-76.
- Torre Villar, Ernesto de la, Navarro de Anda, Ramiro. 1991. Instrucciones y memorias de los virreyes novohispanos: estudio preliminar. México, D.F.: Editorial Porrúa.
- Torrioni, Antonio, Schurr, Theodore G, Yang, Chi-Chuan, Szathmary, Emöke JE, Williams, Robert C, Schanfield, Moses S, Troup, Gary A, Knowler, William C, Lawrence, Dale N, Weiss, Kenneth M, Wallace, Douglas. 1992. Native American mitochondrial DNA analysis indicates that the Amerind and the Nadene populations were founded by two independent migrations. *Genetics* 130:153–162.
- Torrioni, A, Schurr, TG, Cabell, MF, Brown, MD, Neel, JV, Larsen, M, Smith, DG, Vullo, CM, Wallace, DC. 1993. Asian affinities and continental radiation of the four founding Native American mtDNAs. *American Journal of Human Genetics* 53(3): 563–590.
- Torrioni, A, Chen, Y-S, Semino, O, Santachiara-Beneceretti, AS, Scott, CR, Lott, MT, Winter, M, and Wallace, DC. 1994. MtDNA and Y-chromosome polymorphisms in four Native American populations from Southern Mexico. *American Journal of Human Genetics* 54: 303-318.
- Toussaint, Manuel. 1939. Paseos Coloniales. Mexico: Imprenta Universitaria.
- Trueman, Clive NG, Behrensmeyer, Anna K, Tuross, Noreen, Weiner, Steve. 2004. Mineralogical and compositional changes in bones exposed on soil surfaces in Amboseli National Park, Kenya: diagenic mechanisms and the role of sediment pore fluids. *Journal of Archaeological Science* 31:721-739.
- Tuross, Noreen, Warinner, Christina, Kirsanow, Karola, Kester, Cynthia. 2008. Organic Oxygen and Hydrogen Isotopes in a Porcine Controlled Dietary Study. *Rapid Communications in Mass Spectrometry* 22(11):1741-1745.
- Ubelaker, Douglas H. 1978. Human Skeletal Remains: excavation, analysis, interpretation. Chicago: Aldine Publishing Company.

- Ubelaker, Douglas H. 1989. *Human Skeletal Remains: excavation, analysis, interpretation*, 2nd edition. Washington, D.C.: Taraxacum.
- Valadés, Diego. 1579. *Rhetorica christiana ad concionandi et orandi vsvm accommodata, vtrivsqve facultatis exemplis svo loco insertis; qvae quidem ex Indorum maximè deprompta svnt historiis. Vnde praeter doctrinam, svma quoqve delectatio comparabitvr. Pervsiae, apud Petrumiacobum Petrutium.*
- Vences Vidal, Magdalena. 2000. *Evangelización y arquitectura dominicana en Coixtlahuaca (Oaxaca) México*. Salamanca: Editorial San Esteban.
- Waldron, HA. 2001. Are plague pits of particular use to palaeoepidemiologists? *International Journal of Epidemiology* 30:104-108.
- Warinner, Christina, Tuross, Noreen. 2009. Alkaline cooking and stable isotope diet-tissue discrimination in swine: archaeological implications. *Journal of Archaeological Science* 36(8):1690-1697.
- Warinner, Christina, Tuross, Noreen. 2010. Tissue isotopic enrichment associated with growth depression in a pig: implications for archaeology and ecology. *American Journal of Physical Anthropology* 141:486-493.
- Weismann, Elizabeth Wilder. 1985. *Art and Time in Mexico*. New York: Harper Row.
- Werner, Roland A, Brand Willi A. 2001. Referencing strategies and techniques in stable isotope ratio analysis. *Rapid Communications in Mass Spectrometry* 15:501-519.
- White, T, Folkens, P. 1991. *Human Osteology*. San Francisco: Academic Press.
- White, Christine D, Price, T Douglas, Longstaffe, FJ. 2007. Residential histories of the human sacrifices at the Moon Pyramid, Teotihuacan: evidence from oxygen and strontium isotopes. *Ancient Mesoamerica* 18:159-172
- White, Christine D, Spence, Michael W. 1998. Oxygen isotopes and the identification of geographical origins: the Valley of Oaxaca versus the Valley of Mexico. *Journal of Archaeological Science* 25:643-655.
- White, Christine D, Spence, Michael W, Longstaffe, Fred J, Law, Kimberley R. 2000. Testing the nature of Teotihuacan imperialism at Kaminaljuyu using phosphate oxygen isotope ratios. *Journal of Anthropological Research* 56(4):535-558.
- White, Christine D, Longstaffe, Fred J, Law, Kimberley R. 2001. Revisiting the Teotihuacan connection at Altun Ha: oxygen isotope analysis of tomb F-8/1. *Ancient Mesoamerica* 12:65-72.
- White, Christine D, Spence, Michael W, Longstaffe, Fred J, Law, Kimberley R. 2004a. Demography and ethnic continuity in the Tlailotlacan enclave of Teotihuacan: the evidence from stable oxygen isotopes. *Journal of Anthropological Science* 23:385-403.
- White, Christine D, Storey, Rebecca, Spence, Michael W, Longstaffe, Fred J. 2004b. Immigration, assimilation and status in the ancient city of Teotihuacan: isotopic evidence from Tlajinga 33. *Latin American Antiquity* 15(2):176-198.

- White, Christine D, Wright, Lori E, Pendergast, David M. 1994. Biological disruption in the early colonial period at Lamanai. In *In the Wake of Contact: Biological Responses to Conquest*, Clark Spencer Larsen and George R. Milner, eds. Pp. 135-146. New York: Wiley-Liss.
- Whittington, Stephen L. 1989. Characteristics of demography and disease in low-status Maya from Classic period Copan, Honduras. Ph.D. Dissertation. Pennsylvania State University.
- Williams Jocelyn S, White, Christine D, Longstaffe, Fred J. 2005. Trophic level and macronutrient shift effects associated with the weaning process in the Postclassic Maya. *American Journal of Physical Anthropology* 128:781-790.
- Wright, Lori E, Schwarcz, Henry P. 1998. Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology* 106:1-18.
- Wright, Lori E, Schwarcz, Henry P. 1999. Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: infant diets at Kaminaljuyú. *Journal of Archaeological Science* 26:1159-1170.
- Yang, Dongya Y, Eng, Barry, Wayne, John S, Dudar, J. Christopher, Saunders, Shelley R. 1998. Improved DNA extraction from ancient bones using silica-based spin columns. *American Journal of Physical Anthropology* 105:539-543.
- Zavala, Silvio. 1982. *Asientos de la gobernación de la Nueva España: periodo del virrey Don Luis de Velasco 1550-1552*. México: Archivo General de la Nación.
- Zinsser, H. 1934. *Rats, lice, and history, being a study in biography, which, after twelve preliminary chapters indispensable for the preparation of the lay reader, deals with the life history of typhus fever*. Boston: Little, Brown.



5.12. Appendices



Appendix 5.A. Selected excerpts from 16th century Spanish documents

Table of Contents:

Appendix 5.A.1: Selected excerpts from a letter written by Provincial Domingo de Betanzos to García de Loaysa, dated December 3, 1540	262
Appendix 5.A.2: Excerpts from the court records relating to the 1544-1546 Inquisition trial against Don Domingo de Guzmán, Don Francisco, and Don Juan of Yanhuitlan on the charges of idolatry, heresy, murder, cannibalism, polygny, and other crimes	265
Appendix 5.A.3: Excerpt of a decision issued in 1548 by Viceroy Antonio de Mendoza regarding the tribute obligations of the Mixtec community Yanhuitlan to Don Domingo, the community's indigenous ruler.....	274
Appendix 5.A.4: Excerpt from a decision issued by Viceroy Antonio de Mendoza in 1550 regarding armed assault and theft committed by the natives of Teposcolula in order to procure building materials for the construction of a new church	275
Appendix 5.A.5: Excerpt of a letter from Viceroy Antonio de Mendoza to his successor Viceroy Luis de Velasco on the subject of the relocation of the Mixtec town of Teposcolula, 1550.....	276
Appendix 5.A.6: Excerpt from Viceroy Luis de Velasco's agenda for May 6, 1551 in which the Corregidor of Teposcolula is ordered to resolve a dispute over damage caused to roads by cattle, and also to investigate the presence of vagabond Spaniards and Mestizos near Tututepeque.....	277
Appendix 5.A.7: Excerpt from Viceroy Luis de Velasco's agenda for February 6, 1552 in which the <i>corregidor</i> , <i>cacique</i> , governor, <i>alcaldes</i> , and indigenous nobles of Teposcolula are ordered to peacefully relocate their town in accordance with the policy of <i>congregación</i>	278
Appendix 5.A.8: Excerpt from a 1563 letter written by Alonso Caballero, resident of Yanhuitlan, to Lic. Valderrama, Visatador de Nueva España, regarding the burdens placed on the peasants of Yanhuitlan in the construction of a Dominican monastery and the support of its friars	279
Appendix 5.A.9: Excerpt from a 1564 report of the goods paid to the Dominican, Augustinian, and Franciscan Orders in support of its monasteries in New Spain from 1553-1563.....	280
Appendix 5.A.10a-d: Excerpts from the 1579-1581 <i>Relaciones Geográficas</i> of Antequera.....	281
Appendix 5.A.11: Account of the three great pestilences to befall Mexico in the 16 th century by Fray Bernardino de Sahagun	288

Appendix 5.A.1. Selected excerpts from a letter written by Provincial Domingo de Betanzos to García de Loaysa, dated December 3, 1540 (Archivo del Convento de Predicadores de Valencia [conventual], number 80, folios 414-415).⁶¹

This letter, written by Domingo de Betanzos in 1540, requests the intervention of a member of the Spanish court on two matters affecting the Mixtec town of Teposcolula: 1) to make Teposcolula a permanent corregimiento, and 2) to free the residents of Teposcolula from providing personal service and food to their corregidor. In this letter, Betanzos identifies Friar Domingo de Santa María as the first Dominican to learn the Mixtec language, and he describes the “miraculous” success with which this friar has converted the Mixtecs of Teposcolula to Christianity. He describes how Friar Domingo de Santa María uses love rather than force, and how through his efforts 600 loads of idols have been destroyed at Teposcolula. Betanzos is careful to emphasize that (in contrast to the practices of the Franciscans) no Mixtecs were baptized until they fully understood the Christian Doctrine, and he suggests that Teposcolula should be used as a model for future evangelization efforts.

Interestingly, Betanzos describes Teposcolula in this letter as “the most notable and most populous” town in the Mixteca, and also the “first to be converted.” This is not true, strictly speaking. The Mixtec town of Yanhuitlan was the earliest site of Dominican evangelization efforts in the Mixteca, and by many accounts it was larger and more populous than Teposcolula. However, the relationship between the Dominican friars and the Mixtec elite at Yanhuitlan had become strained by 1540, and in 1541 the Dominican friars were forced to give up their mission work at Yanhuitlan and relocate to Teposcolula. In 1544, they initiated an Inquisition trial against the ruling elite of Yanhuitlan on charges of idolatry and heresy, among other crimes (see Appendix 5.A.2).

The present version of this letter survives as a copy made by Father Juan Micó of Valencia in 1542. The copy was mistakenly bound with a series of sermons upon Father Micó’s death in 1555 and was rediscovered by Alonso Getino in 1945.

Muy Magnífico Señor,

La gracia y consolación del Espíritu Sancto sea siempre en su ánima. Porque sé que vuestra merced huelga del bien e provecho de sus vertidas desta Nueva España, maoyrmente en lo que toca al provecho de sus ánimas, le quiero hazer saber que andando y por estas tierras visitando y baptizando los niños que más corren, mayormente por unas sierras y montañas de muy grande aspereza y de muy peligrosos pasos, por donde ninguna bestia puede andar, y aún ay hartos lugares en ellas donde nunca xiano entró, donde por la bondad de Dios se ha hecho no poco fructo y se han remediado no pocas ánimas: pues discurriendo por aquellas montañas vine a descender a una provincia que se llama la Misteca, donde hallé una cosa muy nueva y de mucha consolación, para mi que la deseo yo ver mucho en la conversión destas gentes: e para que vuestra merced tenga esto que quiero decir en mucho, ha de saber que toda la manera de convertir a estas gentes desde el principio hasta agora siempre ha sido más violenta que voluntaria, porque

⁶¹ Source: Robles Sierra 1990:248-251.

siempre han sido más traídos por miedo y castigo que pro amor e voluntad, lo qual todo es contra la doctrina y evangelio de nuestro redempto. y por eso siempre estamos sospechos de la xiandad destes mayores por no ser firmada en ellos la fe por amor: y por esto nunca se an desaraigado de sus ydolos totalmente ni de su voluntad. porque si algunos los an dexado a sido más por fuerça quitándoselos contra su voluntad: esta es una cosa muy universal en toda esta Nueva España: esto presupuessto sabrá vuestra merced que viniendo yo a esta provincia de la Misteca, que tengo dicho, hallé aquí unos religiosos de nuestra Orden entendiendo en la conversión de esta gente que es de otra lengua muy çerrada: al uno de los quales conosçe vuestra merçed que le habió en Castilla, que se llama frai Domingo de Sancta María, que es cierto varón apostólico, el qual aprendió la lengua desta tan bárbara gente, que es cierto que ninguna otra persona hasta oy la aya podido aprender ni saber sino él solo: y dióle Dios tanta gracia con esta gente y fue tan eficaz su predicación que con solo amor los atraxo a que de su propria voluntad todos de un coraçón traxessen todos sus ídolos y ydolatría y con sus propias manos los quemaron detestando tan de coraçónde ellos como si uviera mil años que uvieran resçebido la fee, y nunca hombre dellos fue bautizado hasta que totalmente todos sus ydolos dexaron, y como aún los religiosos no los querían bautizar fueron tantas las lágrimas y lloros que sobre esto lloraron que no oviera coraçón tan duro que no se quebrantara. y reventara con lágrimassi lo viera. fueron los primeros que esto hizieron los de un pueblo y cabeçera, que es la más notable y poblada que ay en la Misteca, que se llama Teposcolula, y a exemplo deste pueblo vinieron todos los pueblos de la Misteca, que son muchos en número, los quales todos un coraçón han dado todos sus ydolos. los quales an sido en tanta cantidad que pasa de seisçientas cargas de ydolos, y de verdad digo poco, porque an sido muchas más en número, porque hubo pueblo donde se traxeron y quemaron sobre quatroçientas cargas de ydolos y idolatrías. y con todo esto nunca los quisieron bautizar hasta que fuesen bien doctrinados y supiesen dar razón de toda la doctrina cristiana: [Fue] tanto el deseo que tovieron del bautismo que pusieron tanta diligencia en aprender toda ladoctrina que mu breve tiempo apenas avía hombre ni muger ni adultos que no la supiesse, y los padres con gran cuidado la esneñavan a sus hijos. [Y] sobre esto antes que fuesen bautizados eran examinados cada uno por sí de la doctrina no solamente si la sabía decir, mas también si la sabía entender: y daban todos tan buena razón de todo, harto mejor que la sabría dar ningún pebeyo de nuestra nación, lo qual es cosa harto de estimar y harto nueva en estas gentes: y con todo este examen han sido enseñados y bautizados todos los pueblos desta Misteca. los quales tienen tan grande amor a la fee de xpo qual nunca se ha visto en estas tierras después que an sido descubiertas: y tienen tan grande amor a los religiosos y dan tanto crédito a sus palabras como si verdaderamente fuesen ángeles del çielo venidos: y todo esto ha venido, porque esta provincia hasta oy no avía sido predicada de nadie, mas la dexavan como a gente bestial: y este padre que tengo dicho con sus compañeros quisieron gastar sus trabajos en ella: y finalmente como este padre apredió su lengua atrájoles por amor en tanta manera que hasta oy no se les a dado un papirote ni se les a quitado ídolo por fuerça mas todo lo que han hecho, an hecho por su propria voluntad: por lo cual, puede vuestra merced creer que es esta la mejor xiandad que ay en toda la Nueva España, y está la fee de xpo en ellos mejor plantada y edificada o predicada por vía derecha conforme al evangelio. qual nunca en estas partes se a hecho, por lo qual es mucha razón que sean estos indios muy favoreçidos y relevados porque se conserve en ellos la fee que con tanto amor han

resçebidos, y aunque con todos se deviera hazer esto, pero mayormente suplico a vuestra merced tenga respecto en esto a este pueblo de Teposcolula el qual a sido el primero que se convirtió: y por su solicitud y diligencia por su exemplo han venido todos los otros pueblos...porque lo que este pueblo pide es muy poco y muy favorable cosa, la qual con todos se debía hazer. y es que suplican a su Magestad que les dé un privilegio que sean siempre de la Corona real: y que agor ni en otro tiempo nunca sean quitados della, porque los pueblos que están en la Corona Real siempre son mejor tratados e más revelados: E lo segundo que piden es que no se les pongan Corregidor a quien ayan de dar servicio personal ni comida: porque estos servicios personales son los que destruyen los pueblos...estas son las dos cosas principales que piden, las quales son harto piadosas y con justa y piadosa razón se les deven ser concedidas: suplico a vuestra merced se muestre quien es en favoresçer a estas pobres gentes, mayormente a estas nuevas plantas que el Señor a traído a su viña...El padre frai Domingo de Sancta María escribirá a vuestra merced más largo como persona que sabe más sus cosas y los tiene a cargo, al qual vuestra merced con mucha razón puede y debe dar tanto crédito como a un apóstol de Dios, el qual verdaderamente así en el exemplo de su personal como en sus predicación a sido otro sant Pablo y le a dado Dios la lengua desta gente quasi milagrosamente, la qual ningo hasta oy a aprendido ni sabido, y pues por mano deste su religioso el Señor a covertido a estas gentes...Desta provincia de la Misteca en la Nueva España, a tres días de deziembre de este año 1540. El siervo y capellán de vuestra merced frai Domingo de Betanzos.

Appendix 5.A.2. Excerpts from the court records relating to the 1544-1546 Inquisition trial against Don Domingo de Guzmán, Don Francisco, and Don Juan of Yanhuitlan on the charges of idolatry, heresy, murder, cannibalism, polygyny, and other crimes (Archivo General de la Nación, Ramo de Inquisición, T. 37, Expedientes 5, 7, 8, 9, and 10).⁶²

From 1544-1546, three indigenous nobles of Yanhuitlan, Don Domingo de Guzmán, Don Francisco, and Don Juan, were tried by the Holy Inquisition on charges of idolatry, heresy, murder, cannibalism, polygyny, and other crimes. The court records from this trial represent a rich source of information about late Postclassic and Early Colonial indigenous religious ritual and practice in the Mixteca Alta. The trial, which was first hosted by Etlantongo in 1544, was transferred to Teposcolula in 1545 and eventually moved to Mexico City in 1546. At the trial, testimony was provided by numerous Mixtec nobles, commoners, and slaves, as well as Dominican friars and secular Spanish residents of Oaxaca. Much of the indigenous testimony was given by nobles from Teposcolula, Etlantongo, and Apoala, three traditionally rival communities of Yanhuitlan. Local indigenous friars served as translators throughout the trial, and much of the indigenous testimony focuses on hearsay about the bad acts committed by the accused, while at the same time emphasizing their own good Christian behavior and reputation. A recurring theme among many of the Dominican testators is the hostile behavior of Yanhuitlan's encomendero, Don Francisoco de Mendoza, toward the mendicant friars, which they claim interfered with their mission work at Yanhuitlan and cultivated an environment where idolatry could thrive. The testimony of the Spanish residents, most notably that of Francisco Gutiérrez, details the ineptitude of the Dominican friars in their mission work. The trial record, with its complex text and subtext, is an exquisite window into the political intrigue of three competing powers in the early colonial Mixteca: the secular government of New Spain and its encomendero and corregidor representatives, the Catholic Church and the mendicant order of St. Dominic, and the indigenous Mixtec nobility.

Among the many interesting things that are recorded in the records are 1) numerous references to bird sacrifice in traditional religious ritual, 2) accounts of indigenous attempts to unbaptize themselves through ritual, 3) varied forms of mockery of Catholic beliefs and practices, 4) a detailed account of child sacrifice to the rain deity, 5) references to traditional funerary rites, and 6) surreptitious attacks on the Dominican friars through secret ritual, body switching, polygamous marriages, and the kidnapping and murder of those Mixtecs favored by the Dominicans. Equally interesting is the testimony provided by Mixtec nobles from other communities in which these nobles claim to be good Christians who have firmly embraced Catholic doctrine. What emerges from these records, in combination with the mortuary evidence excavated at Teposcolula Yucundaa, is clear evidence that this tumultuous period in Mixtec history cannot be characterized in simple terms of spiritual conquest or native resistance, but rather hints at a complicated lived experience fraught with anger, rage, fear, and uncertainty, and characterized by resistance and complicity, cultural persistence and political opportunism.

⁶² Sources: Jimenez Moreno and Mateos Higuera 1940:Appendix 6; Spores 1967:Appendix C.

EXPEDIENTE 5

(Nombramiento de intérprete a favor de Juan Sánchez,
criado del Visitador Maraver, en 15 de octubre 1544)

...El dicho Don Juan, Gobernador de Etlantongo...dijo...que este testigo vido bautizar al dicho Cacique Don Dominog, que lo bautizó el primero flayre que allí vino, que habrá 15 años...e que ha oído decir que están y tienen en el dicho pueblo de Anguitlan y que tienen dos ídolos principales de piedra chuchuy que es figuras de hombre e mujer, que el uno se llama Siquiui, y el otro se nombra Xiv...es publico y notorio que los papas que tienen cargo de los demonios tienen ciertas casas en todos los pueblos y estancias de Anguitlan que tributan e pagan el tributo del demonio cuando es menester e que los papas lo piden e cobran e que comúnmente cada año les piden charchores [sic], palomas, piedras, mantas, plumas para el demonio e copal e otras cosas...e los dichos caciques e gobernadores dicen que tienen dos corazones e que con el uno sirven al diablo e que con el otro no entienden las cosas de Dios e que quieren mal a los frayres e por eso los echaron del pueblo porque no les castigasen e predicasen e no los quieren ver en el dicho pueblo.

El dicho Juan de Naveda...dijo...en otra cueva que estaba en la estancia de Anguitlan que se dice Tataloyotepeque que decían que había un gran sacrificio dentro y llegó con indios...a verlo y entraron tres o cuatro indios a verlo y hallaron dos palomas muertas y mucha sangre e pluma y dos maneras de corazones de hombres ya podridos y este testigo los tuvo por corazones de hombres porque todo lo vió e miró...

El dicho Juanes de Angulo, Vicario del pueblo de Apuala...un indio...le dijo que allí en aquel montecillo sacrificaban los de la dicha estancia de Tlatalotepeque e fueron allá habrá un año y hallaron en un montecillo que llamaon los indios “del Quiav” señales de cómo habían estado los palos voladeros de donde el que es papa se cuelga para pedir agua como los indios dicen y señalan y halló muchas plumas de papagayos y sangre y otras aves y cosas y unos ídolos de piedra llana a manera de altar y otros sacrificios y figuras del demonio...

El dicho Don Martín, principal del pueblo de Teposcolula...dijo que conoce a los dichos Don Francisco y Don Juan gobernadores del pueblo Anguitlan, y a Don Domingo cacique, de muchos años a esta parte desde que se acuerda porque este testigo ha tenido trato con ellos como vecino desde antes que los españoles viniesen a estas partes...que puede haber dos años que un intio que está en Teposcolula dijo a este testigo que el dicho Don Francisco tiene a cargo los demonios de Anguitlan y unas veces los hace llevar a un cerro que está camino de Cuestlabaca junto a unas casas del dicho Don Juan Gobernador y toras veces los hace pasar a otro cerro y...que puede haber un año que estando este testigo en el pueblo de San Juan [a subject ñuu of Teposcolula Yucundaa] un estlavo de Domingo el mercader le dijo a este testigo que el dicho Domingo había hecho ayuntar en su casa todos los papas de Anguitlan 60 días había y les había hecho gran fiesta y consulta en do se hizo muy gran sacrificio al demonio seis días seguidos unos tras otros y habían muerto muchas codornices y pájaros y la última noche todos se emborracharon y sacrificaron y echaron mucho copal al demonio y luego otro día siguiente el dicho Domingo hizo que el Vicario que estaba en el dicho pueblo le dijese misa en su casa en una capilla que tiene y el dicho Vicario la dijo los cuales lo hicieron todo a fin de escarnecer las cosas de nuestra santa fee católica...y cuando los macehuales de

Teposcolula vienen algunas veces al tianguetz de Anguitlan, los naturales de Anguitlan dicen a los de Teposcolula que se vayan de su tianguetz y que no estén allí porque se quieren hacer cristianos como los de Castilla...que el dicho Don Francisco y Don Juan, muerto el cacique [de Yanhuitlan] enviaron un indio que y es muerto a decir a los señores de Teposcolula y a este testigo cómo el dicho cacique de Anguitlan era muerto porque los demonios estaban enojados, y que viniesen a traer cules y copal y plumas y viniesen a sacrificar como era costumbre, y este testigo ni ninguno del dicho pueblo de Teposcolula no vinieron, mas de que oyó decir que le enterraron como era costumbre y que llevaba en el pecho una figura de demonio de charchuy...

El dicho Don Cristóbal Gobernador y alguacil del dicho pueblo de Nochistlán...fue preguntado si sabe que los dichos Don Francisco y Don Juan y Don Domingo son bautizados: dijo que se bautizaron cuando se fundó el monesterio...que en el tiempo de Fray Dionisio ciertos muchachos de la iglesia dijeron al dicho religioso como había diablos en Yanguitlán y que don Francisco, que era el papa mayor, y Domingo el estumeca [oztomécatl] mataron tres mochachos de los de la iglesia en una cueva de demonios...Don Francisco...sacrifica palomas y codornices y que agora cuatro años el dicho Don Francisco mató a un mochacho...y que puede haber cuatro años que andando el padre Fray Domingo de Santa María y Fray Hernando en Anguitlan trabajando porque todas las estancias trujesen sus demonios para los quemar...y que ha oído decir que en el pueblo de Cuzcatepeque está un indio que habla con el demonio y que no está bautizado y que el dicho Don Francisco y Don Juan van a tomar consejo con él para saber como han de servir al demonio y el dicho Don Francisco se casó en haz de la Santa Madre Iglesia con una india su esclava, tenía escondida a su mujer natural que se dice Yyayuxi la cual no es bautizada...y que agora un año cuando no llovía, en una estancia de Anguitlan, que se dice Topiltepec sacrificaron y mataron muchas cules y palomas y para la fiesta fue Don Francisco y Don Juan y Don Domingo y para ello se juntó todo el pueblo y que lo mismo se ha hecho y hace por todas las estancias de Anguitlan por mandado de los dichos Don Francisco y Don Juan, los cuales dicen a los dichos macehuales que no miren a los indios de Teposcolula, Nochistlan, Etlatongo, que entienden las cosas de Dios y son cristianos...y sabe que el dicho Don Francisco ha dicho públicamente a los macehuales que todos vengán a la doctrina, no para la saber y entender sino para conplir con los padres, y que pues están en el patio do eran cues y casas del demonio que es a donde la iglesia edificada, que adoren al diablo y le tengan por dios como él hace y que nadie dé sus diablos como él no da los del pueblo, sino los guarden, si no que al que lo hiciere lo ha de matar...

...fuéle preguntado si cuando murió la mujer del dicho Don Francisco si se hizo sacrificio e si mataron hombres, dijo: que lo que pasa es que muerta la susodicha, los dichos papas cortaron cierta parte de los cabellos de la dicha difunta y los ataron con ciertas piedras e charchines [sic] y los ofrecieron al demonio y sacrificaron muchas palomas y codornices y hicieron una piedra a la figura de la dicha muerta y la dieron al demonio, y después de todo hecho, la llevaron a enterrar, y venidos el dicho Don Francisco y todos los demás a la dicha casa se sacrificaron las orejas, comieron y se emborracharon pero que aunque ésta decía el dicho Don Francisco que era su mujer, que no lo era porque la mujer del dicho Don Francisco está en un pueblo que se llama tula a donde está un árbol grande junto a Anguitlan y que la dicha se llama Cacuene porque no es bautizada, que es mujer de cincuenta años y muchas veces del año los dichos papas que el dicho Don Francisco

tiene en su casa van a la dicha estancia a sacrificar con la dicha Cacuenne, y que puede haber cinco años que el dicho Don Francisco estuvo malo y que por aquella enfermedad hizo matar cinco o seis indios porque así se lo ha dicho su hija? De este testigo y otras estlavas y que en presencia de la hija de este testigo mataron los dos indios en casa del dicho Don Francisco, que eran estlavos, que eran muchachos de hasta diez años y que los otros se sacrificaron en la casa de la dicha su mujer, y que muchas veces el dicho Don Francisco se sacrifica, porque no se le parezca, en la lengua y en sus partes deshonestas...

EXPEDIENTE 7

El pueblo de Tepuzquilula en 22 días del mes de febrero de mil e quinientos e cuarenta y cinco años, el muy Reverendo Señor el Bachiller Gómez Maraver, de la Santa Iglesia de Oaxaca, en presencia de mí Pedro Caballero, Notario Apostólico, dijo: que por cuanto Don Domingo, cacique del pueblo de Yanguitlan e Don Francisco, Gobernador, habían apostatado e cometido muchos pecados exorbitantes contra ley natural, en gran ofensa de Dios Nuestro Señor e menosprecio de nuestra Sancta Fe Católica y que para averiguación de lo susodicho le había sido mandado por el Ilmo. Señor Lic. Francisco Tello de Sandoval, Inquisidor de esta Nueva España y del Supremo Estado de Su Majestad hiciese información, por tanto, que por virtud de la dicha comisión...él quería saber e ser informado cómo y de qué manera pasa e hacer información para la enviar a Su Md. porque en el caso se haga justicia e para ello hizo paracer ante sí a los testigos de yuso presentados e recibidos de oficio...

...Iten, si saben que agora tres años que faltaron las aguas y hambre el dicho Don Francisco renegó del santo bautismo recibido e domatizó haciendo que otras muchas personas hiciesen lo mismo e mandó que todas se emborrachasen, sacrificasen, llamasen al demonio que les diese agua, dándoles a entender que porque eran bautizados no llovía.

...Iten si saben que puede haber seis años que el Padre Fray Domingo de Santa María predicaba en el pueblo de Yanguitlan con intención de destruir las ofensas de Dios, y muchos de los principales a el dicho pueblo sujetos traían sus ídolos para los quemar y destruir, lo cual visto por el dicho Don Francisco como Gobernador del dicho pueblo mandó que todos los recogiesen en su casa a fin y con intención de reñir a los dichos principales como les rinó diciendo [que] por qué querían quemar los dioses de sus padres creyendo las mentiras de los Padres que predicaban las cosas de Dios puesto [costura]... burla sino lo que sus antepasados les habían dicho y que les rogaba guardasen y sirviesen al demonio y el que no lo hiciese que lo había de matar, y para cumplir con el dicho religioso apartó de cada estancia los ídolos que le pareció para que se quemasen y los demás los mandó guardar como están guardados.

...Iten, si saben que siendo el pueblo de Yanguitlan el más poderoso de esta comarca, tiene la más mala iglesia y dotrina de todos los otros, y en todos los pueblos a él sujetos no hay iglesia ni rastro de conversión, digan los testigos cómo pasa y quién es la cuasa...que el Padre Fray Dionisio dijo a este testigo un día y a otros españoles que fuesen con él en casa de Don Domingo porque había sacrificio y no osaba ir solo porque no le levantasen algún testimonio como habían hecho a otros y entrando todos en casa del dicho Don Domingo su mujer e ciertos papas se pusieron en resistencia al dicho fraile e entrados dentro hallaron en cu de altura de dos palmos hecho de todas las masas que ellos comen, y encima de lo llano de él tenía una codorniz o paloma sacrificada e sorrascada y

puesta en pie a manera de cruz y estendidas las alas y enhiesta y a los pies de la dicha codorniz estaba una culebra hecha de pluma e le preguntaron si la dicha codorniz puesta del arte que tiene dicho era por inominia de la pasión de Nuestro Señor, dijo que así le pareció a este testigo...este testigo oyó decir públicamente y así se tiene por cierto que el dicho cacique e principales habían muertos tres muchachos de la dicha iglesia en un día que lo religiosos habían salido a visitar por la comarca...que los frailes se lo dijeron a este testigo que lo tenían por cierto e que tenía noticia de los pueblos de la comarca porque siendo los tres muchachos de la iglesia domésticos e queridos de los religiosos se habían desaparecido y que nunca los frailes ni sus padres nunca más los hallaron...[y este testigo] se dio a buscar los sacrificios que tenían y halló que en la estancia de Tecozaguala, que es subjeta de dicho pueblo Yanhuitlán en la cual estaba renovado un cu, del cual este testigo sacó con los e trece o catorce ollas de sangre y la una era fresca que parecía de tres o cuatro días y una cabeza de un español según que los indios se lo dijeron la cual habían traído del pueblo de Tepetl Tututla, presentada al dicho Don Francisco y como este testigo y los demás españoles sacasen los ídolos la cacica de la dicha estancia y indios se lo resistían por fuerza e por ruegos diciendo que no eran suyos sino de los señores de Yanguitlán e allí los habían traído a guardar por miedo de los frailes e que si se los llevaban que la matarían y este testigo llevó los ídolos a su casa y cada día era muy perseguido de Don Francisco e Don Domingo con mensajeros e presentes para que les diese los dichos ídolos...y después, dende a ciertos días este testigo vió en otra estancia de Yanguitlan y tuvo noticia que hacía un gran sacrificio donde mataban muchos hombres, mujeres e niños y se comió carne humana...y este testigo y el dicho Lara hallaron muchas codornices e palomas sacrificadas y muchos vasos de alabastro e figuras del diablo y en cierto apartamiento halló ciertas ollas grandes puestas en sus braseros y la guía dijo a este testigo que eran las ollas que se cocía carne en ellas de los indios que sacrificaban...es verdad que el más poderoso y grande de esta Mixteca y que en él al presente no hay dotrina más descaecida en todos los otros pueblos con ser el primero donde se fundó monesterio y la gente más predicada y que le parece a este testigo que el dicho Don Francisco ha sido mucha parte, y después las muchas diferencias que Francisco de las Casas ha tenido con todos los religiosos y denuestos y palabras feas que les ha dicho y mandado a los naturales que no les obedeciesen sin su licencia en cosa alguna...

E después de lo susodicho, día mes e año susodicho, Fray Domingo de Santa María, Vicario de esta casa e Monesterio de San Pablo Tepuzzulula...dijo que lo que sabe es que estando él allí por Vicario, entendiendo en la dotrina de los Naturales, trabajó de destruir las idolatrías y puede haber cinco años poco más o menos que le trujeron ciertos ídolos los cuales allí quemó públicamente...dijo que no la sabe porque este testigo no tiene trato con dichos indios por no dejallos el dicho Francisco de las Casas entender libremente en la dotrina ni que los indios los obedezcan, por cuya causa despoblaron la dicha casa e monesterio que tenían en el dicho pueblo de Yanguitlán...dijo que sabe que el pueblo de Yanguitlán es el mayor de todas estas comarcas y que la iglesia no es decente para tan gran pueblo y que no tienen buen retablo ni las otras coasas necesarias para honra del culto divnino ni hay iglesia en esta comarca en los pueblos de mediana posibilidad que no tengan mejor aderezo que no en la iglesia de Yanguitlán...y que estando una vez el dicho Padre Fray Josehp [sic] predicando por un muchacho de la iglesia, intérprete, el dicho Francisco de las Casas no lo consintió ni permitió y que tiene entendido y le parece que

si el dicho Francisco de las Casas no hubiera estado en el dicho pueblo, que hubiera más doctrina y que es contra justicia tenello allí y mucho daño de los Naturales...

E después de lo susodicho, día mes y año susodicho, Fray Bernaldo de Sancta María, que reside en esta casa de Tepuzqulula...dijo...que residiendo este testigo en Yanhuitlan procurando la doctrina de los Naturales, un sacristán que se llama Andrés, que está en la dicha iglesia dijo a este testigo que yendo una vez al tianguéz [mercado] de Suchiltepeque había oído a dos indios iban hablando por el camino: “agora no llueve y es año estéril, hamos mandado nuestros principales de Yanguitlan que sacrifiquemos y llamemos al demonio porque llueva” ...

...Diego, indio de la iglesia, natural del pueblo de Yanguitlan...ha oído decir que el dicho Don Francisco y Don Domingo tenían ídolos e papas en sus casas...que siendo este testigo lengua y predicador de los religiosos, estaba muy mal con este testigo y no quería oír las cosas de Dios y le anduvieron acechando por muchas veces para le matar...que muerto un indio que se decía Tuchtli, hermano de Don Francisco, el susodicho tomó por mujer, puede haber 22 años, a la mujer del dicho su hermano, la cual se llama Malinal y en mixteca Cacueñe la cual hasta el día de hoy la tiene por mujer y en ella hubo un hijo que al presente se llama Gonzalo, que será de 20 años y siempre lo ha tenido escondido y encubierto hasta puede haber tres o cuatro años que Francisco de las Casas lo descubrió y se bautizó y la dicha su madre hasta el día de hoy está por bautizar y el dicho Don Francisco la tiene escondida en un pueblo que se llama Tula y por más disimular haciendo burla del sacramento del matrimonio se había casado en haz de la Santa Iglesia con una macehual esclava suya...Que siendo el dicho pueblo de Yanhuitlan tan grande y rico no tiene iglesia que sea tal como conviene y las imágenes son unas mantas viejas y de malas figuras y en todo hay mala doctrina...

...Don Domingo, Gobernador del pueblo Chachuapa...[dijo que] el dicho Don Francisco y Don Juan Gobernadores se habían juntado en la tecpa, que son las casas del cacique y se hablaron que no llovía y los macehuales tenían necesidad, que convenía que llamasen el Zagui que es dios del agua y que le hiciesen su sacrificio, que al dios de los cristianos que ellos no lo conocían ni lo veían por sus aposentos...que ha oído decir públicamente a todos sus esclavos de Don Juan que puede haber cuatro años que se le murió una hija que estaba casada con un principal de dicho pueblo a la cual mandó el dicho Don Juan, siendo bautizada, que la enterrasen en su cueva donde ellos se suelen enterrar y para cumplir con los padres sacrificaron una india y la enterraron en la iglesia y hicieron sus sacrificios como solían...

Juan, indio esclavo que fue del dicho Don Francisco, natural del pueblo Etlatongo...dijo que...a la cuarta pregunta dijo que lo que sabe que como no llovía el dicho Don [costura] mandó a los papas que fuesen al monte e hiciesen carbón y traído, lo molieron y hicieron tinta y el dicho don Francisco se desnudó y se pintó de [manera] de tizne y dijo: “agora ya no soy cristiano sino como antes solía” y luego se sacrificó de las orejas y se hizo sahumar con copal y mandó traer muchas codornices y las sacrificó y llamó al diablo y lo mismo mandó que hiciesen sus amigos y parientes...

E después de lo susodicho día mes e año susodicho, Xaco, indio no cristiano natural del pueblo de Molcaxtepeque...dijo...que son cuatro demonios de piedra chalchuitl y que los dos tienen figura de hombre y los dos de mujer y con los dichos demonios habían otros

demonios y aparatos de pluma y otras cosas que ya están podridas y cada día ordinariamente hacían sus sacrificios de plumas y piedras y palomas y codornices y otras cosas...

...cacique [Don Domingo] tenía un papa que dicho tiene que se llama Cagua...fuele preguntado como se había con su demonio y de que manera le sacrifica[ba], dijo: que cuando no llovía este testigo sacaba su ídolo y lo ponía delante de sí con mucha reverencia, el cual ídolo era de piedra, y luego este testigo se ponía en cuclillas delante del ídolo y le ofrecía copal, plumas, sangre, y decíale que se doliese, que los macegales tenían hambre, que pues era dios del agua que lloviese, que él le prometía de sacrificarle palomas, codornices, perros, papagayos de los grandes y alguna persona conforme la intención que este testigo tenía y tomaba agua en una jícara y derramábala hacia arriba encima de lo que tenía ofrecido al ídolo y tomaba una pelota de esta tierra que se llama vle que es de resina y goma de árboles y la echaba en el suelo que saltase y después quemaba la dicha pelota y con aquella resina untaba al demonio y luego, hecho su sacrificio, hacía llamar al cacique y a Don Francisco para que trujesen todas aquellas cosas y la persona que habían de sacrificar...Fue preguntado a este testigo cuantas personas mató e hizo matar en el tiempo que fue papa y qué los hacían; dijo: que en el tiempo que este testigo fue papa mandó matar y mató cuatro muchachos en veces porque se tardaban las aguas. Fuele preguntado de qué manera lo hacían; dijo: que él se iba a un cerro el más alto que había y llevaba su ídolo y la persona que había de sacrificar y ponía el ídolo en una parte donde le parecía y delante le daba humo de copal y hablaba con el ídolo un rato y después ponía el muchacho delante y lo sacrificaban, y que a este demonio del agua no se le ofrecía personas grandes sino niños y que sacrificado el dicho niño le sacaba el coraz'on por el pecho y lo ponía ante el ídolo y así se estaba dos días o más tiempo, y después quemaba el corazón, y la ceniza la tomaba y ponía con todo lo demás ofrecido al ídolo y lo hacía un envoltorio y lo guardaba. Fuele preguntado qué tantas personas matarían todos los otros papas en este tiempo que este testigo lo fue: dijo que no lo sabe porque cada papa está por sí y tiene cuidado de su ídolo y no da parte ni dice a los otros lo que hace ni ha de hacer...

EXPEDIENTE 8

...VI—Yten, si saben que el dicho Don Francisco fue penitenciado con disciplina y azotes por Fray Domingo de Santa María, Vicario del pueblo de Tapazcolula, por haberse hallado por Martín de la Mezquita en casa del dicho Don Francisco las pajas y plumas con sangre a manera de sacrificio...

...X— ...[Francisco de Melgar, Corregidor of Coyatepeque] Menciona en su declaración a Antonio de Nava, Corregidor de Tapazcolula, ante quien se inició el pleito sobre los esclavos que le habían sido robados a Don Francisco por los indios de Etlantongo.

EXPEDIENTE 9

En 18 de abril de 1545 rinde Don Domingo su declaración y en ella dice que es de edad de 35 años y que le bautizó Fr. Bernaldino en el pueblo de Anguitlán, puede haber 17 años poco más o menos. Preguntado qué tanto tiempo ha que hay monesterio [sic] en el dicho pueblo de Anguitlán, dijo: “que habrá 17 años poco más o menos, que fueron al dicho pueblo los frailes y hicieron en él monesterio y estuvieron un año y se tornaron a ir y después han vuelto en veces y han estado allí algunas temporadas y que al presente

están en Tapazcolula.” En el monasterio aprendió a leer y se le enseñó la doctrina cristiana. Tenía Don Domingo un hermano de su mismo nombre que era cacique de Tliltepec....

EXPEDIENTE 10

En primero de abril de 1546 se inicia la nueva información y en 3 de abril siguiente se nombra intérprete a Fr. Bernardino de Santa María, vicario de Tapazcolula. En el mismo convento residía Fr. Alonso del Espíritu Santo, fraile profeso. Por estar enfermo el Padre Santa María lo suplió en el cargo de intérprete, en varias ocasiones, Fr. Francisco Marín, vicario de Coaixtlahuacan. En las declaraciones siguientes Fr. Bernardino Santa María declara tener 38 años de edad y ser natural de Sevilla, mientras Fr. Francisco Marín dice tener 39 años y ser nativo de Sanlúcar de Barrameda. En estas y otras declaraciones se dice que hacía siete años de la muerte del cacique de Yanhuitlán.

A Don Juan, Gobernador de Yanhuitlán, según su propia declaración, lo habían bautizado hacía 17 años y tenía 55 de edad en 1546. En 6 de abril de este mismo año era vicario de Yanhuitlan Francisco Gómez.

Otros muchos datos contiene este interesantísimo Proceso y entre ellos muchos nombres de “papas” que, por falta de tiempo, no hemos podido utilizar.

EXPEDIENTE 10 [CONTINUED IN ENGLISH, TRANSLATED BY RONALD SPORES]

...In the said pueblo of Yanhuitlán, on April 14, 1546, the said Lord Judge Commissary, for the investigation of that which was stated by Diego, native of Etlantongo, that Don Juan ordered an Indian girl killed and buried in the house of one Juan on the occasion of the death of his mother-in-law, went to the residence houses of the said Juan *indio* where, together with the said Juan *gobernador* and in the presence of myself, the said notary, and the said witnesses named below, in a chamber of the said dwellings he ordered the opening of a grave where the said Don Juan had ordered the said girl to be buried. And it was opened and they removed from it certain skull bones and other bones of the body that appeared to be those of a boy or girl together with certain *piedras azules*, as well as a complete skull with its teeth, jawbones, and hair that appeared to belong to an adult man or woman, and many body bones wrapped in a *petate*, and certain *chalchiuite* beads, and pieces of silver and *esandillas*, and eight complete pots. And the said sepulcher was in the form of a rounded vault and measured what appeared to be two *estados* [3.7 yards] of masonry. And I, the said notary, swear that I saw the aforementioned and that I found present as witnesses Don Gómez de Maraver, Dean of Oaxaca, and Fray Francisco Marín of the Order of Santa Domingo, and Alonso de Aldana...

...On April 15, 1546, the said Lord Judge Commissary went to the pueblo of Tliltepec and, being in the presence of myself, the said notary, and the witnesses mentioned below, he asked Domingo, native of Moxcaltepec, to come and indicate the location of the grave and place where were buried the two children that had been killed and sacrificed by order of Don Domingo, as the witness had testified. Domingo stated that truly he had seen them buried but that it had been so long ago that he did not know or remember where it was.

And after the aforesaid on this day, month, and year, the said Lord Judge Commissary left the pueblo of Tliltepec and went one league from the boundaries of the pueblo and in the presence of myself, the said notary, and the said witnesses, in a place that he was

shown, ordered the opening of a tomb for investigation of the statement of Alonso Xanu that Don Domingo sent a slave, which he purchased from its owners, to the people of Tultepec so they might sacrifice him [on the occasion of] the death of his [Don Domingo's] brother, and that on this spot they had buried the sacrificial victim. And opening the grave they took from it a complete skull with its teeth, hair, and jawbones, and many bones of the body that were wrapped in a petate and the bones appeared to be of an adult man or woman. The grave was located between two fields of maize, one on one side and the other on the other side, and between some magueys and the edge of an arroyo of water and among five hills that circled it, one being very large and the others small. And I, the said notary, swear that I saw the aforesaid as did the witnesses in attendance, the Dean don Gómez Maraver and Fray Francisco Marín and Alonso de Aldana....

Appendix 5.A.3. Excerpt of a decision issued in 1548 by Viceroy Antonio de Mendoza regarding the tribute obligations of the Mixtec community of Yanhuitlan to Don Domingo, the community's hereditary indigenous ruler (Archivo General de la Nación, Ramo de Tierras, T. 985).⁶³

This decision, recorded by Antonio de Turcios, was issued following the 1544-1546 Inquisition trial of Don Domingo and two of Yanhuitlan's governors, Don Francisco and Don Juan, on charges of idolatry, among other things. Don Domingo was acquitted, and his hereditary rights to tribute and labor were reinstated. In addition to labor and traditional forms of tribute, the decision also notes that Don Domingo is entitled to the yield of a large wheat field measuring 300 square brazas.

TASACION A D. DOMINGO, EN 1548, POR D. ANTONIO DE MENDOZA

En la Ciudad de Mexico a veinte y seis días del mes de Octubre, de mil quinientos cincuenta [sic] y ocho años: Ante el Yllmo Sor. Don Antonio de Mendoza, Visorrey, y Gobernador por su Majestad en esta N. E. se tasó la Comida y servicio que los Yndios del Pueblo de Yanhuitlán han de ser obligados a dár á Don Domingo, Governador del dho Pueblo, por razón del cargo é durante el tiempo que lo tuviere. —Primeramente: le han de dár al dho Governador cada día, una Gallina de la Tierra y diez Yndios de servicio. — Yten: le han de dar cada seis meses, dos Jiquipiles de cacao gordo. —Yten: le han de ylar siete Cargas de algodón cada seis meses, y se las texan en mantas. —Yten: le han de hacer una sementera de Trigo de trecientas Brazas, y beneficiarlas, y coger el fruto. — Yten le han de hacer otras quatro sementeras de Mais, que las dos cada una tenga quatrocientas Brazas en quadro y la otra trecientas, y la otra seiscientas. —Y esto que he dicho es, le han de dar, y no otra cosa alguna, ni él lo pida ni lleve, só pena de privación del cargo é que será castigado; sacada del Libro. —Antonio de Turcios

⁶³ Source: Jimenez Moreno and Mateos Higuera 1940:Appendix 5.

Appendix 5.A.4. Excerpt from a decision issued by Viceroy Antonio de Mendoza in 1550 regarding armed assault and theft committed by the natives of Teposcolula in order to procure building materials for the construction of a new church (Archivo General de la Nación, Ramo de Mercedes, T. III, folio 201).⁶⁴

This document substantiates the early chronology for the construction of the valley church at Teposcolula proposed by Mullen (1975) by demonstrating that construction of the church was already underway by 1550. It is noteworthy that, on the heels of the recent Yanhuitlan Inquisition trial, the natives of Teposcolula chose to rob the residents of Yanhuitlan for building materials to construct a new church.

COMISION QUE DIO DON ANTONO DE MENDOZA AL CORREGIDOR DE NOCHISTLAN, PARA QUE AMPARASE A LOS INDIOS YANHUITECOS, ATACADOS POR LOS DE TEPOSCOLULA CUANDO OBTENIAN MATERIALS PARA LA CONSTRUCCION DE SU IGLESIA.

Yo, don Antonio de Mendoza etc. Hago saber a vos el Corregidor de Nochistlan que los indios de Anguitlán se me han venido a quejar de los indios de Tapascolula que yendo a hacer caleras en sus tierras y términos para la obra de la iglesia los del d[ic]ho pu[eb]lo de Tapazcolula vinieron a ellos con mano armada y los maltrataron y tomaron las hachas que tenían para [illegible] leña y dieron de palos y les hicieron otras fuerzas de lo caul han recebido agravio y me pidieron mandavisto, confiando de vos que bien y fielmente haréis lo que os fuere cometido por la presente os mando que veais lo susodicho y hagais información y sepais como e de que manera pasa, y la información y sepais como e de que manera pasa, y la información habida, los que parecieren culpados les prended los cuerpos, y presos, llamadas e oídas las [partes?] breve y sumariamente les haced justicia de manera que la alcancen y ninguno reciba agravio de este [illegible] causa de se venir a quejar para lo cual [que dicho es?] y para llevar vara de justicia os doy poder cumplido. Fecho en México 4 días del mes de Otuble de 1550. Don Antonio de Mendoza. Por mandado, etc., Antonio de Turcios.

⁶⁴ Source: Jimenez Moreno and Mateos Higuera 1940:Appendix 8.

Appendix 5.A.5. Excerpt of a letter from Viceroy Antonio de Mendoza to his successor Viceroy Luis de Velasco on the subject of the relocation of the Mixtec town of Teposcolula, 1550 (Instrucciones que los Virreyes de Nueva España dejaraon a sus sucesores. Añádense algunas que los mismos trajeron de la Corte y otros documentos semejantes a las Instrucciones. México: Imprenta Imperial, 1867).⁶⁵

In 1550, after serving as Viceroy of New Spain for fifteen years, Antonio de Mendoza left Mexico at the behest of King Phillip II of Spain to take up the post of Viceroy of Peru. Luis de Velasco was named as his successor. On his way to Peru, Mendoza passed through the Mixteca Alta and visited Teposcolula in 1550. While at Teposcolula, he was shocked by what he considered the unrestrained style (“de muy ruin mezcla”) and ill-suited location of the new Dominican construction projects. The open-air chapel at Teposcolula contains many innovative architectural details (see McAndrew 1965:555) that may have been the source of Mendoza’s dissatisfaction. He told both the Teposcolulan Mixtecs (presumably through a translator) and the Dominican friars not to proceed with the relocation of the town. This document demonstrates that construction in the valley was well underway by 1550 and supports Mullen’s (1975) early chronology for the construction of the Teposcolula open-air chapel.

RELACIÓN, APUNTAMIENTOS Y AVISOS

QUE POR MANDADO DE S.M. DI AL SR. D. LUIS DE VELASCO, VISORREY Y GOBERNADOR Y
CAPITÁN DENERAL DE ESTA NUEVA ESPAÑA

Para remediar desto, con los religiosos de San Francisco y San Agustín concerté una manera de traza moderada, y conforme a ella se hacen todas las casas. Es necesario que V.S^a haga lo mismo con los de Santo Domingo, porque comienzan agora muchos monesterios, y háñseles de hacer más. V.S^a mande buscar dos o tres personas que sean buenos oficiales, y déles salarios en quitas, y vacaciones y corregimientos para que anden por toda la tierra visitando las obras y enmendado los defectos que son mucho... Y para esto de la Misteca, provea V.S^a luego, porque conviene. En Tepozcolula se labró una casa de muy ruin mezcla y en mal lugar quiren traer los indios a una vega junto al monasterio. Estarán muy mal, porque es húmeda, y ellos tienen sus casas en laderas y sobre peña, y han de adolecer, así por el sitio como por ser casas nuevas; y ocupan la tierra que es de regadío con las casas, y es poca. Estando toda desembarazada, yo dije a los indios que no se mudasen, y a los religiosos que no se lo mandasen. V.S^a no lo permita, que destruirá aquel pueblo. En Yanhuitlan se hace una buena casa y de muy ruin mezcla, habiendo mucha cal y muy buenos materiales, solo por falta de oficiales. ... A la vuelta se lee de otra mano: “Memorial que dejó D. Antonio a D. Luis de Velasco.”

⁶⁵ Source: De la Torre Villar and Navarro de Anda 1991:115-116.

Appendix 5.A.6. Excerpt from Viceroy Luis de Velasco's agenda for May 6, 1551 in which the corregidor of Teposcolula is ordered to resolve a dispute over damage caused to roads by cattle and horses, and also to investigate the presence of vagabond Spaniards and Mestizos near Tututepeque (Archivo General de la Nación, Libros de Velasco, folio 124r).⁶⁶

In this document, the people of Tututepeque have appealed to the viceroy to for remediation regarding the destruction of their roads by the cattle and horses owned by the Spaniard Pero Nieto. The corregidor of Teposcolula is ordered to force Pero Nieto to pay for the repair the roads. Teposcolula's corregidor is also ordered to investigate reports that vagabond Spaniards and Mestizos are harassing and abusing the Mixtecs of Tututepeque and to banish any such offending individuals if encountered.

En México, a 6 de mayo de 1551, el virrey Velasco hace saber a Juan Fernandez Verdejo, teniente de corregidor en el pueblo Tapazcolula, que así por él [Velasco] como por el virrey Mendoza está proveído que Pero Nieto saque cierto ganado mayor de vacas y yeguas que trae en término de la provincia de Tutupeqque [in margin, Tututepeque] y sus sujetos, y de los naturales de Xicayan, por el daño que reciben los indios de dichos pueblos; y porque para haber de sacar el camino, porque de otra manera diz que no puede salir, por la presente le manda que con vara de justicia vaya a lo susodicho y entienda en la ejeución de lo que está mandado, y para que haya efecto en sacar el ganado, entienda en que los indios comarcanos abran y aderecen el camino y pasos malos que en él hubieren, de manera que en ello no reciban agravio, y dará orden cómo el dicho Pero Nieto pague a los dichos indios su trabajo lo que fuere justo; y el teniente de corregido se ocupe en lo susodicho ocho días y lleve de salario cada un día un peso de oro común para ayuda de costa y mantenimiento; y por quanto el vierrey es informado que en la provincia de Tututepeque y su sujeto andan algunos españoles y mestizos vagamundos tratando y contratando con los indios y haciendo fuerzas y agravios y otras vejaciones, de lo cual redundan gran perjuicio a los indios, por la presente le manda que con vara de justicia vaya a la provincia de Tutupeqque y se informe si andan en ella algunos españoles o mestizos con perjuicio de los naturales, y hallando ser así, les mande con pena que se salgan dentro del término que le señalare y no vualvan en ella ni tengan tratos ni contrataciones con los indios, para lo cual todo que dicho es le da poder cumplido.

⁶⁶ Source: Zavala 1982:79.

Appendix 5.A.7. Excerpt from Viceroy Luis de Velasco's agenda for February 6, 1552 in which the *corregidor*, *cacique*, governor, *alcaldes*, and indigenous nobles of Teposcolula are ordered to peacefully relocate their town in accordance with the policy of *congregación* (Archivo General de la Nación, Libros de Velasco, folios 405v and 406r).⁶⁷

In this document, Viceroy Luis de Velasco orders that it is necessary, for both the good of the people of Teposcolula and in order that they may be watched and effectively instructed in the Catholic faith, that the people of Teposcolula move their community to the abundant lands adjacent to the newly built monastery. He states that he has communicated this order to the corregidor of Teposcolula, as well as to the cacique, governor, alcaldes, and nobles of the town. He also instructs that no force or other maltreatment be used during the relocation. Finally, he entrusts the Dominican friars with the responsibility of persuading the people to relocate by demonstrating the many spiritual and temporal benefits that will result from the move.

...mandamiento que da el virrey Velasco en México, a 6 de febrero de 1552, fols. 405v y 406r., en el cual dice ser informado que al bien y conservación de los naturales del pueblo de Tapascolula conviene y es necesario, para que vivan en policía y sean industriados en las coasas de la fe católica, que se junten a vivir y morar a la parte y lugar que les está señalado cerca del monasterio del dicho pueblo, por haber como hay gran cantidad de tierra y disposición de todo lo demás necesario para su sustentación y población; atento lo cual, manda el virrey al corregidor en ese pueblo y al cacique, gobernador, alcaldes y principales de él, [que] buenamente den orden cómo a los naturales del dicho pueblo, sin les hacer fuerza ni otro mal tratamiento, vengan a vivir y morar cerca del monasterio y se junten en congregación y policía de la tal parte que les está señalada; y encarga a los religiosos del dicho monasterio que les per[suadan] a ello, dándoles a entender el pro y utilidad que de ello se les seguirá, así en lo espirtual como en lo temporal, y cómo solamente se procura lo susodicho para su buen tratamiento y conversión y salvación y que mejor sean industriados en la doctrina cristiana sin les hacer, como dicho es, fuerza alguna.

⁶⁷ Source: Zavala 1982:316.

Appendix 5.A.8. Excerpt from a letter dated 1563 written by Alonso Caballero, resident of Yanhuitlan, to Lic. Valderrama, Visatador de Nueva España, regarding the heavy burdens placed on the peasants of Yanhuitlan in the construction of the Dominican monastery and the support of its friars (Archivo General de las Indias, Audencia de México, #2564, Seville).⁶⁸

In this letter, Alonso Caballero describes how peasant labor at Yanhuitlan is allocated to the construction of the Dominican monastery and the support of its friars, and also to the construction of an elaborate house for the cacique of Yanhuitlan. This letter provides a unique window into the costs of evangelization and the new financial burdens levied upon peasants during the early colonial period in the Mixteca Alta.

...Los frailes de Yanhuitlán persuadieron a Don Gabriel, cacique del dicho pueblo a que se hiciese una casa muy suntuosa a fin de detener la obra del monasterio, porque si se acaba perderán los intereses que llevan a los indios y las sobras de tributos que les son mandadas dar. Y de hacer casa el cacique se sigue gran daño a los frailes les pobres porque se alarga la obra del monasterio, y si hay lugar de que los frailes les lleven más tiempo, lo que les llevan, y ellos no tengan lugar a labrar sus tierras, ni a ganar para pagar los tributos al encomendero, porque le cabe a cada uno cuatro semanas cada año ir a la obra de la iglesia; dos a sacar piedra a la cantera; y dos a hacer cal; y una al monte a cortar madera; y otra a traer la cal al monasterio; y otra a coger zacate para los frailes y la comunidad y servicios de frailes, caciques y comunidad; y seis a hacer las milpas del cacique hasta que se lo dan encerrado en su casa; y otras seis a los frailes en la milpa que siembran de trigo y de maíz. Pues, si sobre lo que está ya diocho han de dar otras cuatro semanas a la casa del cacique, que no les queda a ellos tiempo para hacer y labrar sus milpas, y esta causa padecen necesidad muy grande los pobres. Y de todo estos tequios y obras no les dan paga ninguna a los indios más de como se lo mandan los frailes y el cacique, y así lo hacen porque no hay por la parte de los pobres quien responda...

⁶⁸ Source: Pita Moreda 1992:249. I'd like to thank James Kiracofe for drawing my attention to this letter.

Appendix 5.A.9. Excerpt from a 1564 report of the goods paid to the Dominican, Augustinian, and Franciscan Orders in support of its monasteries in New Spain from 1553-1563 (Archivo General de las Indias, 2-2-313).⁶⁹

This report, prepared by Don Fernando de Portugal in 1564, details the expenditures of the Crown for the support of its mendicant orders in New Spain from 1553-1563. Below is the section that describes the expenditures relating to the Dominican Order.

MEMORIA DE LO PAGADO A LAS ÓRDENES DE SANTO DOMINGO, SAN AGUSTÍN Y SAN FRANCISCO, DESDE EL EL 11 DE MARZO DE 1553 HASTA EL ÚLTIMO DE DICIEMBRE DE 1563.
—26 DE FEBRERO DE 1564.

...

SANTO DOMINGO

Desde el dicho tiempo, once de marzo de mil e quinientos y cincuenta y tres años, hasta fin de diciembre de sesenta y tres, he dado y pagado a los monesterios de señor Santo Domingo, de esta Nueva España, setenta y dos mil y setecientos y cincuenta y nueve pesos y un tomín de oro de minas, de cuatrocientos y cincuenta maravedíes cada peso, para obras y vino y aceite y pescado, trigo y maíz, y cálices y campanas y ornamentos, y comida y otras coasas, en el dicho tiempo.

⁶⁹ Source: Cuevas 1975:277-279.

Appendix 5.A.10a-d. Excerpts from the *Relaciones Geográficas* of Antequera

The Relaciones Geográficas are a compilation of responses to a questionnaire circulated by King Philip II of Spain between 1578 and 1579 (Acuña 1984:11-17). The purpose of the questionnaire was to collect basic information about the Spanish held territories in the Americas. One hundred ninety-one communities responded to the questionnaire between 1578 and 1586, and the present location of 167 responses is known. Among those that have been lost is the response of Tepocolula. The known surviving Relaciones Geográficas are held in the Benson Latin American Collection of the University of Texas at Austin, the Archivo General de Indias in Seville, and the Real Academia de la Historia in Madrid. (see <http://www.lib.utexas.edu/benson/rg/> for a description of the collections).

The following excerpts were collected from the Relaciones of Mixtec communities neighboring Teposcolula.

Appendix 5.A.10a. Excerpts from the Relación Geográfica of Nochistlan, 1581.⁷⁰

The following excerpts describe the location of Nochistlan, the Spanish conquest of the community, and the climate and agricultural fertility of Nochistlan. There is also a discussion of population decline and disease since the Spanish conquest and a description of the orderly arrangement of the community's church and streets. Finally, the document details information about the cultivation of Spanish crops at Nochistlan, which include wheat and barley, and the raising of Spanish livestock, such as chickens, pigs, sheep, and goats. Regular contact with Teposcolula is implied by a statement that salt is procured from there.

N^o 38. NOCHIZTLAN. MIXTECA. OBISPADO DE ANTEQUERA. NUEVA ESPAÑA. CÉSPEDES.

En el pu[eb]lo de Nochiztlan, que es en la Mixteca Alta desta Nueva España, en nueve días del mes de abril de mil y qui[n]ientos y ochenta y un años, el il[ust]re señor Rodrigo Pacho, Correg[ido]r por su Maj[es]tad en este d[ic]ho pu[eb]lo, presentes Ju[an] González de la Borbolla, Correg[ido]r que ansí mismo fue dél, y yo, Luis Gutiérrez del Cast[ill]o, su escribano nombrado, y Don Antonio de Velasco, cacique y gobernador, Domingo de Villegas y Jusepe López, alcaldes, y Tomás Pérez y Luis de Maya, regidores, y Jusepe García y J[ua]n Pérez, indios principales y los más antiguos, todos naturales y principales deste d[ic]ho pu[eb]lo, gobernado en esta Nueva España el muy ex[celen]te señor Don Lorenzo Suárez de Mendoza, Conde de [la] Coruña, Visorrey y Gobernador y Capitán General en ella por su Maj[es]tad, mandó hacer e hizo en su presencia del d[ic]ho señor Correg[ido]r la descripción del estalaje, temple y otras coasas deste d[ic]ho pu[eb]lo, según y como lo manda su Maj[es]tad por una Instrucción a su m[er]ced enviada de capítulos, cuyo tenor de todo ello es lo que se sigue:

1. Primeram[en]te, en lo que toca al primer capítulo, este pu[eb]lo de Nochiztlan está poblado en la provi[n]cia que llaman la Mixteca Alta, y está en la comarca del pu[eb]lo de Yanguitlan, [a] dos leguas dél, y del pu[eb]lo de Guautla, [a] tres leguas, y del d[ic]ho pu[eb]lo de Etlatongo, [a] una legua. Llámase este pu[eb]lo en la lengua que los naturales

⁷⁰ Source: Acuña 1984:365-372

dél hablan, que es mixteca, Atuco, que en mexicano quiere decir Nochiztlan, y en la lengua castellana quiere decir “lugar de grana.”

2. En el segundo capítulo: Se descubrió y ganó este pu[eb]lo en la conquista que hizo el Marqués del Valle, Don Her[nan]do Cortés, general de toda esta Nueva España, que ha sesenta años, poco más o m[en]os.

3. En el t[er]ce[ro] capítulo: Este d[ic]ho pu[eb]lo y provincia de la Mixteca es tierra de muy bien temple, de suerte que es más fría que caliente: y este pu[eb]lo es muy húmedo, y las aguas en él acuden de ordinario en el tiempo dellas, que es los seis meses del año, y, en él, no corren vientos ningunos.

4. En el cuarto capítulo: ... Y [es] falto de ríos y fuentes, porque los naturales beben de aguas de pozos; y tiene pocos pastos, y es fértil, ansí de maíz como de frutos de la tierra y de Cast[ill]a.

5. En el quinto capítulo: Este pu[eb]lo tiene muy pocos indios, porq[ue] no tiene mas de setecientos y veinte tributarios enteros, que cada uno es marido y mujer, sin los hijos. En tiempo de su gentilidad, y al t[ie]m[po] que se gano y conquisto, tenia, según declaraon los naturales, mucha suma de indios, y se han muerto, en veces, de enfermedades que ha habido generales en esta Nueva Espana...

10. En el décimo capítulo: Este pu[eb]lo está en alto, en tierra más llana que doblada, con once calles largas [que van] de oriente a poniente y, de norte a sur, doce calles mas cortas; y, en medio del, esta la plaza e iglesia...

15. En el quinceno capítulo: [Los de] este pu[eb]lo antiguamente...vivían más sanos que ahora, [pero] la causa dello no se sabe...

17. En el diez y siete capítulos: Este d[ic]hop u[eb]lo esta asentado en tierra mas enferma que sana, y es muy humeda. Y la enfermedad que ha de ordinario es, entre los muchachos, de viruelas y sarna, de que mueren muchos. Y el remedio que para ello tienen es la dieta y no otra cosa, según s averiguo.

23. En el veinte y tres capítulos: En este d[ic]ho pueblo se dan muy bien, y en cantidad, mucha pera y albaricoque, durazno, membrillo y manzanas, e higos y uvas y olivos (con la hoja del moral crian seda); y se da, ansi mismo, mucha cereza, y otras frutas de la tierra.

25. En el veinte y cinco capítulos: En este d[ic]ho pu[eb]lo se da muy bien el trigo y cebada, y se da, y criase mucha cantidad de perejil, culantro, yerbabuena, nabo, y mostaza y berenjenas, y se da muy bien el trigo y cebada y seda, y criase mucha cantidad de seda fina. Grana cogen alguna, aunque muy poca, porque no se dan a ella, sino a criar seda.

27. En el veinte y siete capítulos: En este d[ic]ho pu[eb]lo se crian muy bien las aves de Castilla, gallinas y puercos en mucha cantidad, y ovejas y cabras; y ansi mismo, se crian gallinas de la tierra, que son mayores que las de Cast[ill]a.

30. En el treinta capítulos: En este d[ic]hop u[eb]lo no hay salinas. Provéense los naturales dél sal, de Tepozcolula, que es [a] cinco leguas de aquí...

Appendix 5.A.10b. Excerpts from the Relación Geográfica of Tilantongo, 1579.⁷¹

The following excerpts pertain to the powerful Mixtec community of Tilantongo and two of its subject communities, Mitlantongo and Tamazola.

According to the text, answers to the questions posed in the questionnaire were obtained through interviews with Mixtec elders and through an examination of native documents. The political organization of Tilantongo is discussed, as well as the presence of resident Dominican friars at the site, and a statement is included that although the yya toniñe at the time of Spanish conquest remained unbaptized until his death, his son was baptized and given a Christian name. The subject communities of Tilantongo are provided, and the distance from Tilantongo to Teposcolula is specifically noted. There is an account of Tilantongo's importance in Prehispanic times, and a statement that Tilantongo once controlled many territories in the Mixteca Alta, including Teposcolula (a fact that became important in a court case in the 1560s over the contested inheritance of the Teposcolula aniñe). Reflecting on the past, the elders of the community claim that people were healthier in antiquity before being afflicted with the plagues and pestilences of the Spanish, and finally, it is noted that wheat and barley are currently grown in great quantity at Tilantongo, along with many other Spanish crops.

The excerpts regarding Mitlantongo describe how the Mitlantongo nobles consume a rich diet that includes wheat bread, beef, and pork, and that wheat and barley are cultivated at Mitlantongo. They also note that three major epidemics have struck the Mixteca since the arrival of the Spanish, and they include a short description of each one.

The excerpts regarding Tamazola describe the three epidemics suffered by the community since the Spanish conquest. The text notes that no cures were known to be effective against any of the epidemics and that as a result many people died.

N^o 32. N[UEV]A ESP[AÑA]A. TILA[N]TONGO. MIXTECA ALTA. CÉSPEDES.

...En el pueblo de Tilantongo, en cinco días del mes de noviembre de mil y quinientos y setenta y nueve años, el il[ustr]e Ju[an] de Bazán, corregidor por su Maj[esta]d deste d[ic]ho pueblo, y por ante mí, Ju[an] Alonso Rodríguez, escribano de su juzgado, dijo que, por cuanto el muy [e]x[celen]te señor Don Martín Enríquez, visorrey desta Nueva España, le ha enviado una copia de una Memoria de ciertos capítulos que, por ella, parece haberle enviado su Maj[esta]d del rey Don Felipe nuestro señor desde España, para que desta tierra se le haga relación de las coasas en ella contenidas, la cual d[ic]ha copia es la que atrás va puesta y por que su merced, acerca de lo en ella contenido, ha hecho la diligencia y pesquisa y averiguación que le ha sido posible, en presencia de mí, el d[ic]ho escribano, y del muy r[everen]do padre Fray Pedro de las Eras, vicario del monasterio de Santiago de la Orden de Santo Domingo, que en este dicho pueblo está fundado. Y lo que ha podido saber y averiguar con los naturales deste pueblo, viejos y ancianos, y con otras personas de quien se ha informado, y por las pinturas que los d[ic]hos indios tienen, es lo siguiente:

⁷¹ Source: Acuña 1984:227-248.

XI. El pueblo de Tilantongo es cabecera y jurisdicción deste corregimiento; está fundado en él un monasterio del señor Santiago de la Orden del Señor Santo Domingo, [en] el cual de ordinario residen tres religiosos, que administran la doctrina a los naturales dél.

Tiene por sujetas ocho estancias, ...y la otra estancia la vocación dél se dice San Pedro, que en mixteca se dice Ñuyagua y, en mexicano, Tamazola y, en castellano, “lugar de ranas”...

...Del pueblo de Teposcolula, a éste de Tilantongo, hay siete leguas de mal camino y áspero, por ser toda esta provincia serranías...

XIII. A los catorce capítulos: ...Y deste señor, por línea recta, era señor, cuando el Marqués vino a la conquista desta Nueva España, [el] que en mixteca se llamaba Ya q[h] Quaa y, en mexicano, Nahui Maza[t]zi, que en castellano quiere decir “cuatro venados.” Y este señor no fue bautizado, porque murió luego. Y el hijo mayor deste señor fue bautizado, y llamado Don Juan de Mendoza.

Daban de tributo, en tiempo de su gentilidad, a su señor... Y el señorío que este señor tuvo fue muy grande, porque fue de los mayores señores que en toda la provincia hubo. Y tuvo en señorío toda la provincia de Teposcolula, y la provincia de Tlaxiaco y Atoyaquillo y Teozaqualco, pueblos de los más principals de toda la Mixteca...

XV. A los quince capítulos: ...Y que antiguamente vivían más que ahora y vivían más sanos, porque, ahora, dicen que les han sucedido muchas enfermedades y pestilencias, y que, antiguamente no las tenían.

XXIII. A los veinticuatro capítulos: Se dan en esta tierra trigo, cebada en cantidad, y de todas las hortalizas las cuales vinieron de España, como rábano, lechuga, coles, mostaza, cardos, nabos, hinojo, orégano, habas, garbanzo, lenteja, y todas las demás semillas de España...

[MITLANTONGO]

En doce días del mes de noviembre de mil y quinientos y setenta y nueve años, el señor corregidor vino a este pueblo de Mitlantongo [a] hacer y averiguar los capítulos e Instrucción que u Maj[esta]d, y su Exclencia en su real nombre, [mandaron se] hiciese...

XV. A los quince capítulos: ...Y la comida y mantenimiento que antiguamente usaban era yerbas y tortillas de maíz, y hojas de tuna y frijoles y chile, y por gran regalo para sus señores, salían a caza de ratones del campo y codornices, las cuales no osaban otros comerlas si no era el señor... Y el bastimento de que ahora usan y comen son tortillas recién hechas y pan de Castilla, y chile y frijol y calabazas, y venados y vacas y carnero y puerco, y todas las demás carnes...

XVII. A los diecisiete capítulos: Es tierra sana y lo ha sido, que si no han sido tres cocolistles o pestilencias que [ha] habido en esta tierra generales, que el primero habrá cincuenta años, recién ganada la tierra, y otra enfermedad que habrá treinta años, que fue a manera de viruelas, y otra de pujamiento de sangre, que habrá tres años que dio esta enfermedad generalmente en todas las Indias, no ha [ha]bido otro género de enfermedad; de las cuales enfermedades murió, de cuatro partes, las tres de la gente que solía haber antiguamente. Y, así, es tierra muy sana, y [dicen] que la gente que falleció [fue], toda la más, por no tener remedios con que atajar las enfermedades.

XXV. A los veinticinco capítulos: Se dan en este pueblo las semillas que de España trujeron, como es trigo y cebada, y se cria gran cantidad seda, porque es su trato, y contrato y granjería, destos naturales de toda esta provincia mixteca.

[TAMAZOLA]

En dieciséis días del mes de noviembre de mil y quinientos y setenta y nueve años, el señor corregidor, Ju[an] de Bazán, vino a este pueblo de Tamazola [a] hacer y averiguar los capítulos e Instrucción que su Maj[esta]d, y su Excelencia en su real nombre [mandaron se] hiciese...

XII. A los doce capítulos: Confina este pueblo de Tamazola con un pueblo llamado Mitlatongo...y hay, de Mitlatongo a este d[ic]ho pueblo, dos leguas y m[edi]a de muy mal camino....

XVII. A los diecisiete capítulos: Es tierra sana por ser tierra fría , más que cuantas en esta provincia hay, y dicen que nunca han tenido género [alguno] de enfermedad, si no han sido tres pestes generales que [ha] habido desde que la tierra se ganó. Y [dicen] que las dos pestes primeras fue a manera de viruelas y, esotra, pujamiento de sangre, y que no han tenido otra enfermedad; y que no entienden ni saben curarse y, a esta causa, cuando las pestilencias dio, murió mucha cantidad de gente.

5.A.10c. Excerpts from the Relación Geográfica of Teozacualco, 1580.⁷²

The following excerpts pertain to the Mixtec community of Teozacualco and one of its subject communities, Amoltepeque.

The excerpts relating to Teozacualco state that there was once a very large and healthy population at Teozacualco, but that today the lands are depopulated. The community's climate and common diseases are discussed, and it is noted that wheat is grown in the community.

The excerpts regarding Amoltepeque include a description of the general unhealthiness of the community and a statement that wheat is not grown at the site because the climate is too warm.

Nº 34. OB[IS]PADO DE GUAXACA. N[UEV]A ESPAÑA. CÉSPEDES. TEOZACUALCO.

AQUÍ HABLA DE TUTUTEPEQUE. AMOLTEPEQUE. MIXTECA.

Éstas son las relaciones, y descripción que se hizo, de los pueblos de Teozacualco y Amoltepeque, por mandado de su Maj[esta]d y del muy ex[celen]te señor Don Martín Enríquez, Visorrey desta Nueva España en su real nombre. Todo lo cual aquí contenido pasó ante Her[nan]do de Cervantes, Corregidor por su Maj[esta]d que es al presente de los dichos pueblos. Año de 158[0].

15. ...Y [dicen] que, antiguamente, vivían más sanos que ahora, porque los más morían de muy viejos, y porque toda la tierra estaba llena de gente y, ahora, está despoblada; y que esto es lo que entienden acerca desto.

17. Es tierra de buen temple, más cálida que fría, y sana; aunque acuden, a tiempos, algunas enfermedades de calenturas y postemas que se engendran dentro en los cuerpos, de que mueren. No usan remedio ninguno para estas enfermedades.

25. Dase en este pu[eb]lo, y en partes de sus términos, trigo;...

[RELACIÓN DEL PUEBLO DE AMOLTEPEQUE]

11. El pu[eb]lo de Amoltepeque, que es sujeto a este corregimiento de Teozacualco, dista deste dicho pu[eb]lo catorce leguas; está sujeto a la diócesis de la ciudad de Antequera; tiene cincuenta vecinos, poco más o menos; no tiene estancia ninguna sujeto.

17. El sitio deste pu[eb]lo es enfermo, por las malas aguas que tiene. Las enfermedades comunes son calenturas, y postemas y empeines en cantidad...

25. No se da trigo en este pueblo, por ser tierra cálida...

⁷² Source: Acuña 1984:141-151.

5.A.10d. Excerpts from the Relación Geográfica of Justlahuaca, 1580.⁷³

The following excerpts pertain to the Mixtec communities of Justlahuaca and Tecomaxtlahuaca. The text asserts that the population of the communities was much larger in the past, but that mortality was severe during the three epidemics that afflicted the towns following the arrival of the Spanish. Regarding agriculture, there is a statement that wheat grows very well in these communities (except when it hails), but that the local natives don't plant it in great quantity they don't consider it as nutritious as maize.

N^o 35. JUSTLAHUACA, OB[IS]P[A]DO DE GUAXACA. MIXTECA BAJA, N[UEV]A ESPAÑA.
CÉSPEDES. INSTRUCCIÓN DE SU MAJ[ESTA]D PARA LA DESCRIPCIÓN DE LAS INDIAS.

NOMBRAMI[EN]TO DE ESCRI[BAN]O.

En el pu[eb]lo de justlahuaca, que es en la provincia de la Mixteca de la Nueva España, en tres días del mes de enero de mil y quinientos y ochenta años...

Relación del pu[eb]lo de Justlahuaca, que está puesto en Corregimiento con la jurisdicción del pu[eb]lo de Tecomaxtlahuaca.

[10-11] Estos pueblos de Justlahuaca y Tecomaxtlahuaca, que es donde el Corregidor siempre reside...Son doctrinados por los religiosos de la orden del señor Santo Domingo, que residen en estos d[ic]hos pu[eb]los de Justlahuaca y Tecomaxtlahuaca. ...

[15] Averiguado es que, antiguamente, vivieron más sanos que ahora y hubo más indios, y la causa no se sabe, mas de que los naturales dicen que, con tres pestilencias que ha habido después que los españoles vinieron, se han consumido. Tiene ahora este pu[eb]lo de Justlahuaca, con sus sujetos, trescientos y setenta y siete tributarios, y solía tener muchos más. Hallóse, en la última cu[en]ta que se hizo habrá poco más de un año, los d[ic]hos trescientos y sesenta y siete tribu[tari]os. Y en el de Tecomaxtlahuaca, que está, como d[ic]ho es, [a] un tiro de piedra del monasterio deste d[ic]hop u[eb]lo, se hallaron , en la última cu[en]ta que se le hizo habrá poco más de año y medio, con sus sujetos, quinientos y veinte y cinco tributarios. ...

[17] El puesto destos dos pu[eb]los parece sano, porque está asentado en buena parte y no es húmedo; y es tierra de buen temple, más frío que caliente, y corre todos los días desta vida, desde las dos de la tarde hasta las seis de la noche, una marea muy recia, que es tenuta por sana. Las enfermedades que los indios destos d[ic]hos dos pu[eb]los padecen son calenturas y cámaras de sangre, y dolores de cuerpo y de cabeza...

[24-25] Tienen trigo de España, el cual se da muy bien en estos d[ic]hos pu[eb]los, salvo algunas veces se hiela. No se siembran en cantidad, porque los indios se dan más al beneficio del maíz por serles más provechosos...

⁷³ Source: Acuña 1984: 281-324.

Appendix 5.A.11. Account of the three great pestilences to befall Mexico in the 16th century by Fray Bernardino de Sahagún (Historia General de las Cosas de Nueva España. Libro Undecimo, Capítulos XII-XIII).⁷⁴

In this excerpt, the great Franciscan scholar-friar Bernardino de Sahagún unexpectedly provides a sensitive description of the three major 16th century epidemics to afflict Mexico within two chapters on the “quality of roads” and “the maintenance of everything.” In his account, Sahagún describes with anguish the massive mortality of the 1545 epidemic and claims to have personally supervised the burial of more than 10,000 dead. Apparently writing thirty years later during the devastating 1576 matlazahuatl epidemic, Sahagún speculates with despair on the future of the native population of the Indies.

CAPITULO XII: DE LAS DIVERSIDADES DE LAS AGUAS Y DIVERSAS

CALIDADES DE LA DISPOSICIÓN DE LA TIERRA

Nº 7: DE LAS CALIDADES DE LOS CAMINOS.

...Paréceme que poco tiempo podrá perseverar la Fe Católica en estas partes, lo uno es porque las gentes se van acabando con gran prisa, no tanto por los malos tratamientos que se les hacen, como por las pestilencias que Dios les envía. Después que esta tierra se descubrió ha habido tres pestilencias muy universales y grandes, allende de otras no tan grandes, ni universales; la primera fue el año de 1520 cuando echaron de México por guerra a los españoles, y ellos se recogieron a Tlaxcalla, [que] hubo una pestilencia de viruelas donde murió casi infinita gente; después de esta, y de haber ganado los españoles esta Nueva España, y teniéndola ya pacífica y que la Predicación del Evangelio se ejercitaba con mucha prosperidad, el año de 1545, hubo una pestilencia grandísima y universal, donde en toda esta Nueva España, murió la mayor parte de la gente que en ella había. Yo me hallé en el tiempo de esta pestilencia en esta ciudad de México, en la parte de Tlatiluco, y enterré más de diez mil cuerpos, y al cabo de la pestilencia dióme a mí la enfermedad y estuve muy al cabo.

5. Después de esto procediendo las cosas de la Fe pacíficamente, por espacio de 30 años poco más o menos, se tornó a reformar la gente. Ahora, este año de 1576, en el mes de agosto comenzó una pestilencia universal y grande, la cual ha ya tres meses que corre y ha muerto much agente, y muere y va muriendo cada día más, y no sé qué tanto durará ni qué tanto mal hará. Yo estoy ahora en esta ciudad de México en la parte del Tlatiluco, y veo que desde el tiempo que comenz’o hasta hoy, que son ocho de noviembre, siempre ha ido creciendo el número de los difuntos desde diez, veinte, treinta, cuarenta, cincuenta, a sesenta y ochenta, y de aquí adelante no sé lo que será en esta pestilencia; como también en la otra arriba dicha, muchos murieron de hambre, y de no tener quién los cuidase, ni los diese lo necesario; aconteció y acontece en muchas casas caer todos los de la casa enfermos, sin haber quién los pudiese dar un jarro de agua; y para administrarlos los sacramentos en muchas partes, ni había quien los llevase a la Iglesia ni quien dijese

⁷⁴ Source: Sahagun 1956, Vol. 3:355-361.

que estaban enfermos, y conocido esto andan los religiosos de casa en casa confesándolos y consolándolos.

6. Cuando comenzó esta pestilencia de hogaño, el señor visorrey Don Martín Enríquez puso mucho calor en que fuesen favorecidos los indios, así de comida como de los Sacramentos, y por persuasión, muchos españoles anduvieron muchos días por las casas de los indios dándoles comida, y sangradores sangrándolos, y médicos curándolos, y lerigos y religiosos, así de San Francisco como de Santo Domingo, como de San Agustín, como teatinos, andaban por sus casas para confesarlos y consolarlos, y esto duró por obra de dos meses, y luego cesó todo, porque unos se cansaron, otros enfermaron, otros se ocupan en sus hacienda; ahora ya faltan muchos de los sacerdotes ya dichos, que ayudaban y ya no ayudan. En este pueblo del Tlatiluco solos los religiosos de San Francisco andaban por sus casas confesándolos y consolándolos, y dándoles pan de Castilla que coman, comprado de las propias limosnas; y todo se va ya acabando, que el pan vale muy caro, y no se puede haber, y los religiosos van enfermando y cansando, por lo cual hay gran tribulación y aflicción; pero con todo esto, el señor visorrey y el señor Arzobispo no cesan de hacer lo que pueden. Plega a nuestro Señor de remediar esta tan gran plaga, porque a durar mucho todo se acabará.

CAPITULO XIII

DE TODOS LOS MANTENIMIENTOS

...Cuando los españoles llegaron a esta tierra estaba llena de gente innumerable, y cuando por vía de guerra echaron de esta ciudad de México los indios a los españoles, y se fueron a Tlaxcala, dióles la pestilencia de viruelas que queda dicha, donde murieron sin cuento, y después en la guerra, en los trabajos con que fueron afligidos después de la guerra, murieron gran cantidad de gente en las minas, haciéndolos esclavos y llevándolos cautivos fuera de su tierra, y fatigándolos con grandes trabajos en edificios y minas; y después que estas vejaciones se remediaron con haber clamado los religiosos al emperador Carlos V, en el año de 1545, vino la otra segunda pestilencia dicha atrás, donde toda la gente quedó muy menguada; muy grandes pueblos quedaron despoblados, los cuales después nunca se tornaron a poblar. Treinta años después de ésta sucedió la pestilencia que ahora actualmente reina, donde se han despoblado muchos pueblos, y el negocio va muy adelante, y si tres o cuatro meses dura, como ahora va, no quedará nadie. Y la profecía que atrás hice mención dice, que antes de sesenta años después que fueron conquistados, no ha de quedar hombre de ellos. Y aunque a esta profecía yo no le doy crédito, pero las cosas que suceden y han sucedido parece que van enderezadas a hacerla verdadera; no es de creer empero que esta gente se acabe en tan breve tiempo como la profecía dice, porque si así fuese la tierra quedaría yerma, porque hay pocos españoles en ella, y aun ellos se vendrían a acabar, y la tierra se henchiría de bestias fieras y de árboles silvestres, de manera que no se podría habitar.

8. Lo que más se me asienta en este negocio es que con brevedad esta pestilencia presente cesará, y que todavía quedará mucha gente hasta que los españoles se vaya más multiplicando y poblando, de manera que faltado la una generación, quede poblada esta tierra de la otra generación que es la española; y aun tengo para mí que siempre habrá cantidad de indios en estas tierras.



Appendix 5.B. Selected details from 16th-18th century pictorial documents, maps, and paintings

Table of Contents:

Appendix 5.B.1: Detail of Plate XIX of the Codex Yanhuitlan depicting Mixtec nobles 7 Deer and 10 Monkey conversing with a Dominican friar at Teposcolula Yucundaa.....291

Appendix 5.B.2: Detail of the Yanhuitlan church from Plate XX of the Codex Yanhuitlan.....292

Appendix 5.B.3: Detail of the church and cacique of Teposcolula from Plate XVIII of the Codex Yanhuitlan.....293

Appendix 5.B.4: Undated wall mural inside the *Casa de la Cacica* depicting the church-monastery complex at San Pedro y San Pablo Teposcolula....294

Appendix 5.B.5: Detail from a series of images depicting Spaniards forcing the Mixtecs to pan for gold from Plate IX of the Codex Yanhuitlan.....295

Appendix 5.B.6: Probable depiction of wheat tribute from Plate X of the Codex Yanhuitlan.295

Appendix 5.B.7a-d: Details from the *Relaciones Geográficas* of Antequera, 1579-1581, depicting indigenous communities relocated and rebuilt according to a Spanish model.296

Appendix 5.B.8a-c: Details from the *Relaciones Geográficas* of Antequera, 1579-1581 depicting large, walled churchyards associated with churches at Macuilsuchil and Cuahuitlan.297

Appendix 5.B.9: Late 18th century depiction of a cemetery located within a walled churchyard.....297

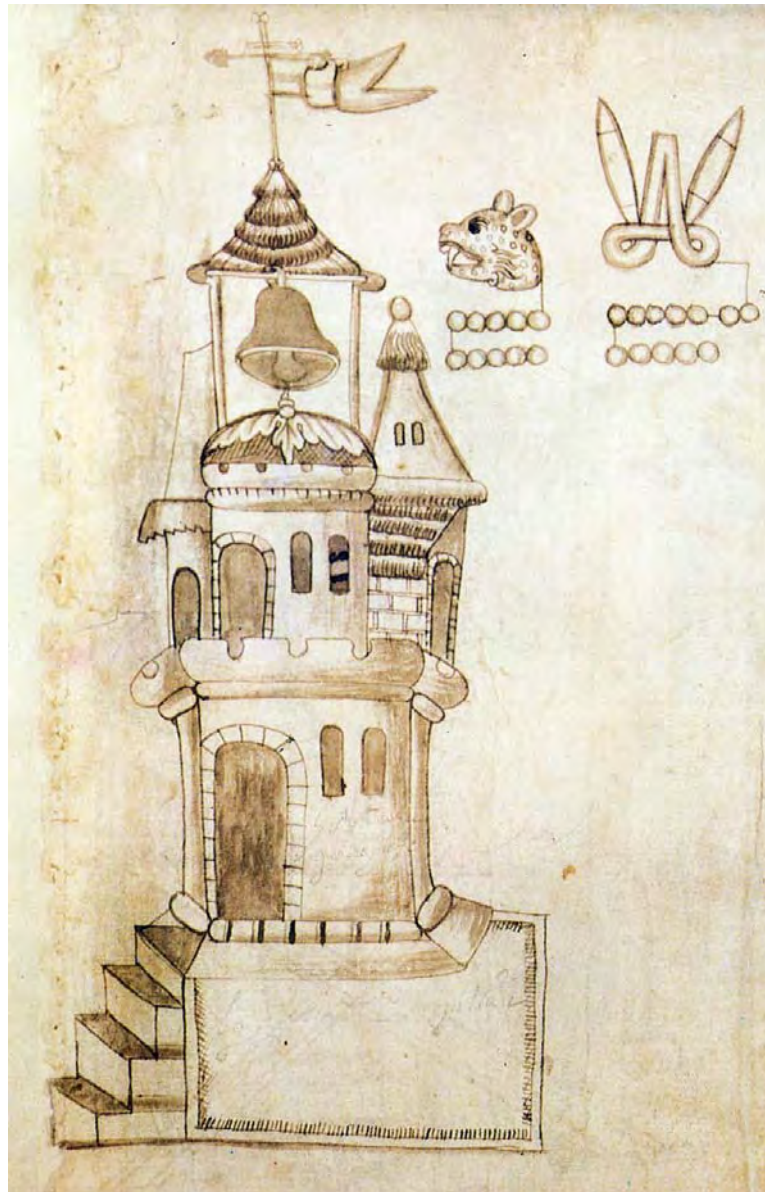
Appendix 5.B.10: Engraving from the *Rhetorica Cristiana* (1579) illustrating the functions of a churchyard in New Spain.....298

Appendix 5.B.11a-c: Painting dated 1746 depicting the Virgin, with the assistance of angels, distributing rosaries to the people of Teposcolula.....299

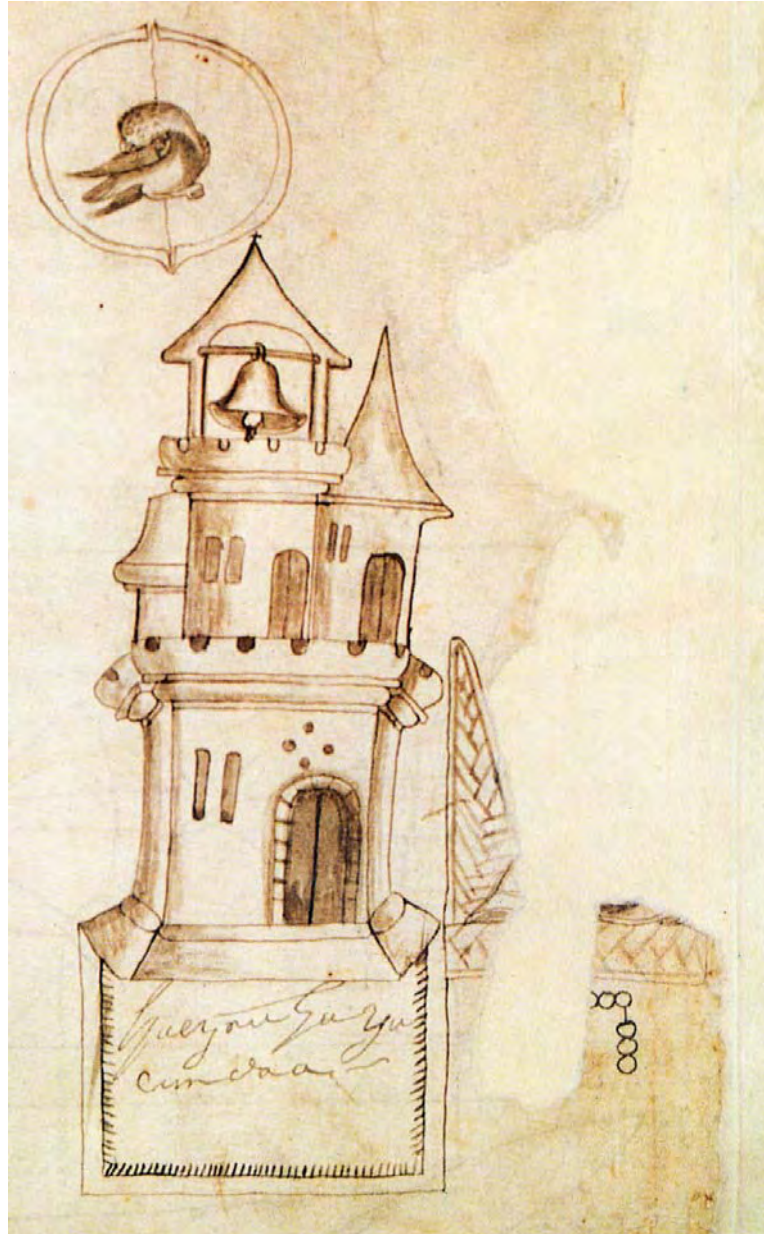


Appendix 5.B.1. Detail of Plate XIX of the Codex Yanhuitlan depicting Mixtec nobles 7 Deer and 10 Monkey conversing with a Dominican friar at Teposcolula Yucundaa. The friar depicted may be Friar Domingo de Santa María. The clothing of 7 Deer and 10 Monkey indicate that they belong to the noble class. This scene may be related to the 1544-1546 Inquisition trial of Don Domingo of Yanhuitlan. The Inquisition trial was briefly hosted by Teposcolula in 1545 and several Teposcolula nobles provided testimony.⁷⁵ The glyph in the lower left corner depicting a coper axe affixed to a stylized representation of a hill is the toponym for Teposcolula (Jimenez Moreno and Mateos Higuera 1940; Spores 1984). Image adapted from Jimenez Moreno and Mateos Higuera (1940).

⁷⁵ Those who testified include: Don Cristóbal, *alcalde* of Teposcolulooa; Don Domingo, *gobernador* of Teposcolula, and Don Martín, a *principal*, or noble, of Teposcolula.



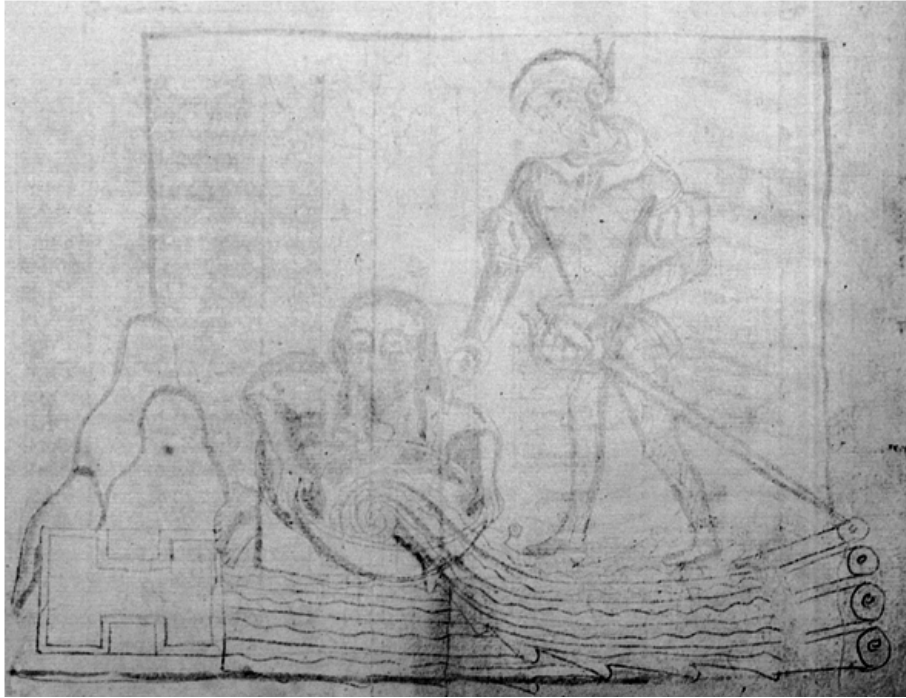
Appendix 5.B.2. Detail of the Yanhuitlan church from Plate XX of the Codex Yanhuitlan. The Mixtec glyphs in the upper right corner record the date 10 Jaguar 12 Flint, which corresponds to either 1544 in the Mixtec calendar (Jimenez Moreno and Mateos Higuera 1941) or 1556 in the Aztec calendar (Sepúlveda y Herrera 1994). The illustrations of the Yanhuitlan and Teposcolula churches are stylistically very similar, and were likely drawn by the same hand over a very short period of time. In 1544, the year in which the Yanhuitlan Inquisition trial began, there were only two monasteries in existence in the Mixteca: one at Yanhuitlan, and the other at Pueblo Viejo Teposcolula. The Yanhuitlan monastery had been abandoned by the Dominicans in 1541 and was only intermittently occupied by secular clergy from 1541-1546. The church was rebuilt in the 1550s and 1560s. These drawings may be meant to depict the churches as they appeared during the Yanhuitlan Inquisition trial of 1544-1546, or later after the reconstruction of both churches by the Dominicans in the 1550s. Image adapted from Jimenez Moreno and Mateos Higuera (1940).



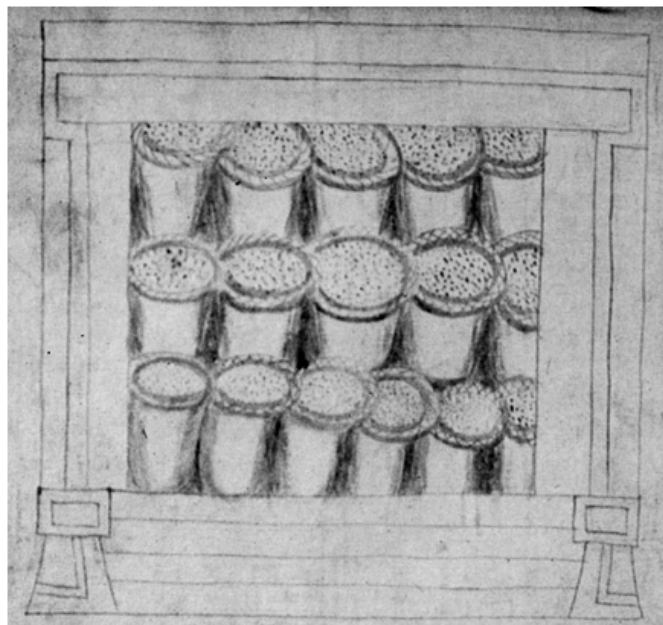
Appendix 5.B.3. Detail the church and cacique of Teposcolula from Plate XVIII of the Codex Yanhuitlan. This image may depict the original church and monastery constructed at Teposcolula c. 1538-1540 or the new church and monastery constructed in the valley c. 1549-1555. Next to the church is an oversized depiction of a reed mat and a partial indigenous name glyph for the *yya toniñe* of Teposcolula. The baptized name of the Teposcolula *yya toniñe* at this time was Pedro de Osorio (Caso 1977-1979; Spores 1997; Spores *pers. comm.* 2010). The bilingual gloss in the churchyard reads *Huey nuhu Yucundaa*, or “Great House of Yucundaa” in a Nahuatl and Mixtec. Throughout the colonial period in the Mixteca, a church was referred to as a *huey ñuhu*, or “great house”; the Spanish loanword for church, *iglesia*, does not appear in native documents of the Mixteca (Terreciano 2001:287). The plaza depicted in front of the church represents the churchyard. Image adapted from Jimenez Moreno and Mateos Higuera (1940).



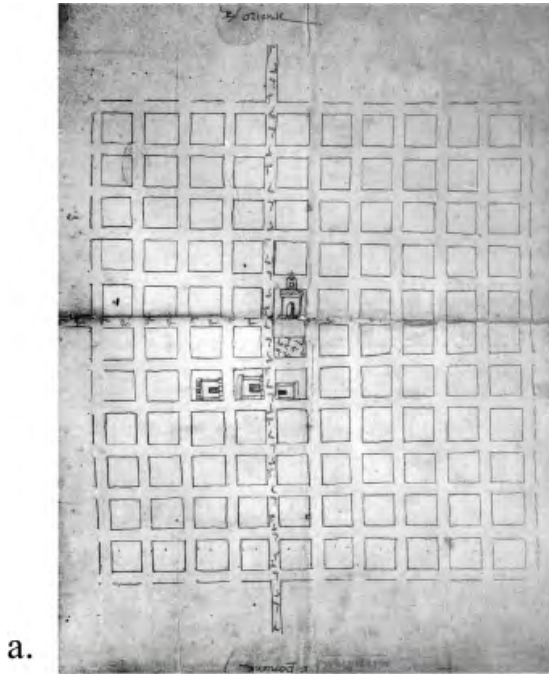
Appendix 5.B.4. Undated wall mural within the *Casa de la Cacica* depicting the church-monastery complex at San Pedro y San Pablo Teposcolula. Photograph taken by the author in 2006.



Appendix 5.B.5. Detail from a series of images depicting Spaniards forcing the Mixtecs to pan for gold from Plate IX of the Codex Yanhuitlan. Image adapted from Jimenez Moreno and Mateos Higuera (1940).



Appendix 5.B.6. Probable depiction of wheat tribute from Plate X of the Codex Yanhuitlan. Image adapted from from Jimenez Moreno and Mateos Higuera (1940).



a.



b.

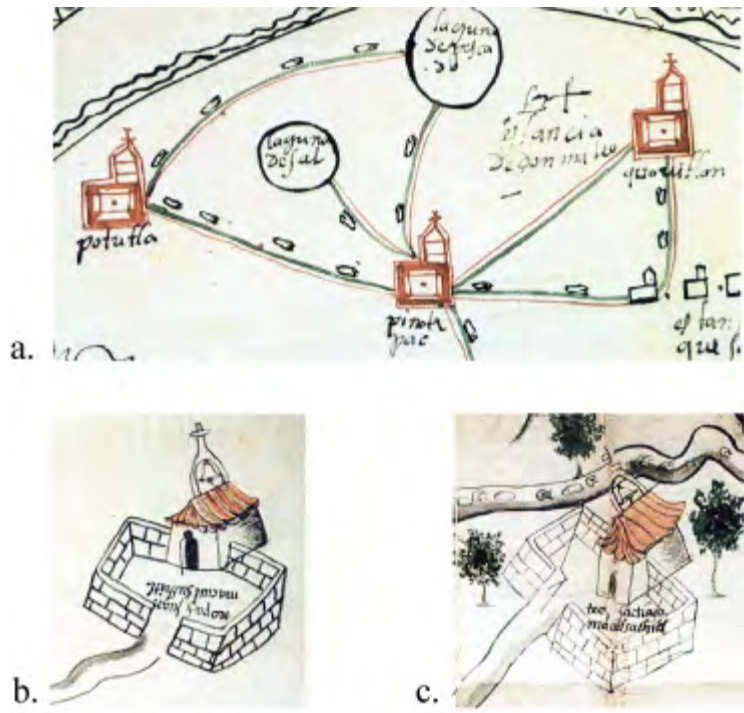


c.



d.

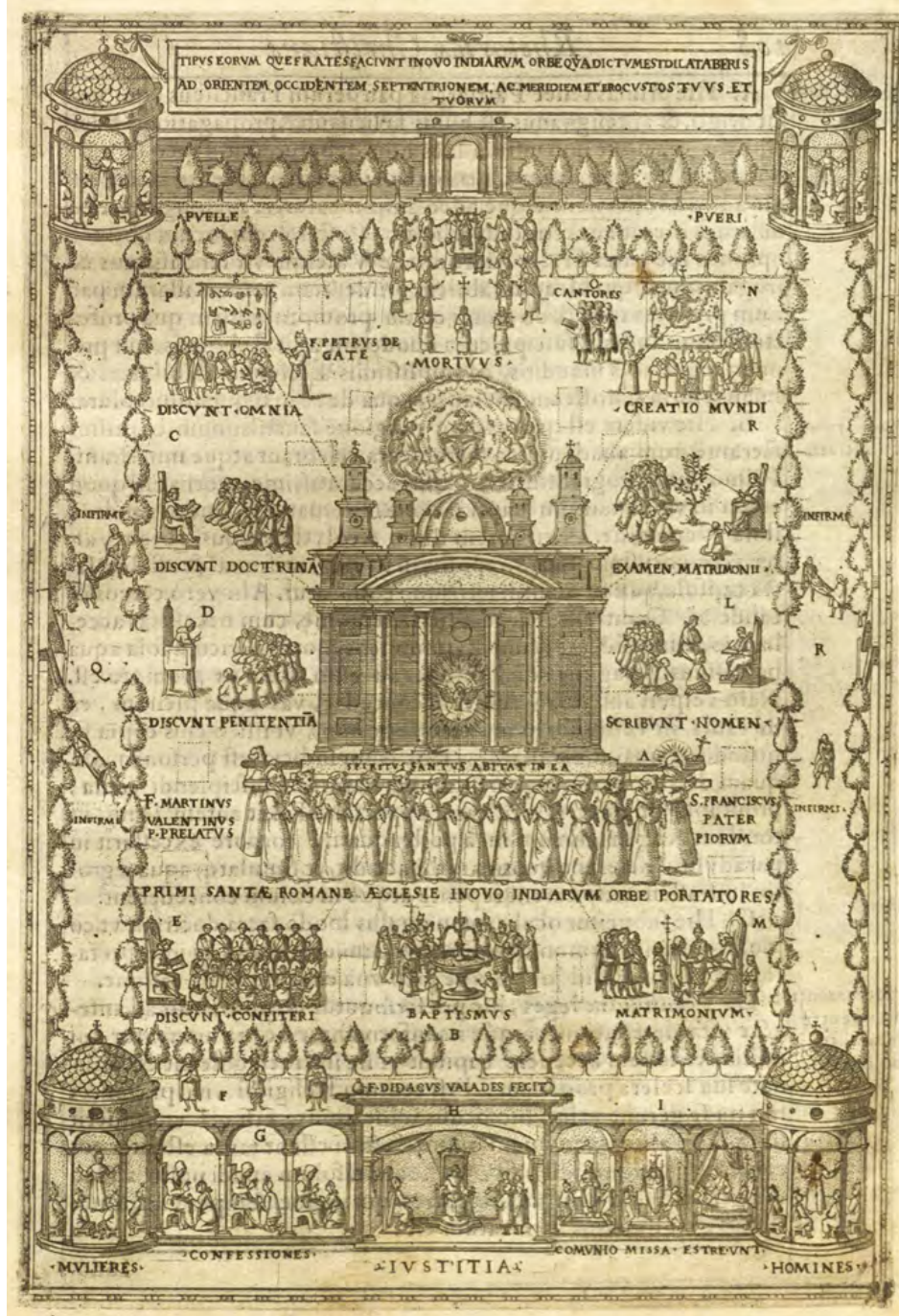
Appendix 5.B.7a-d. Details from the *Relaciones Geográficas* of Antequera, 1579-1581 (Acuña 1984) depicting indigenous communities relocated and rebuilt according to a Spanish model. Note the prominent, central location of the church-monastery-churchyard complex and the gridded layout of the streets. The communities include a) Nochistlan (Mixtec), b) Texupa (Mixtec), c) Iztepehic (Mixtec), and d) Teguantepec (Zapotec). The former mountaintop locations of Iztepehic and Teguantepec are elaborately illustrated.



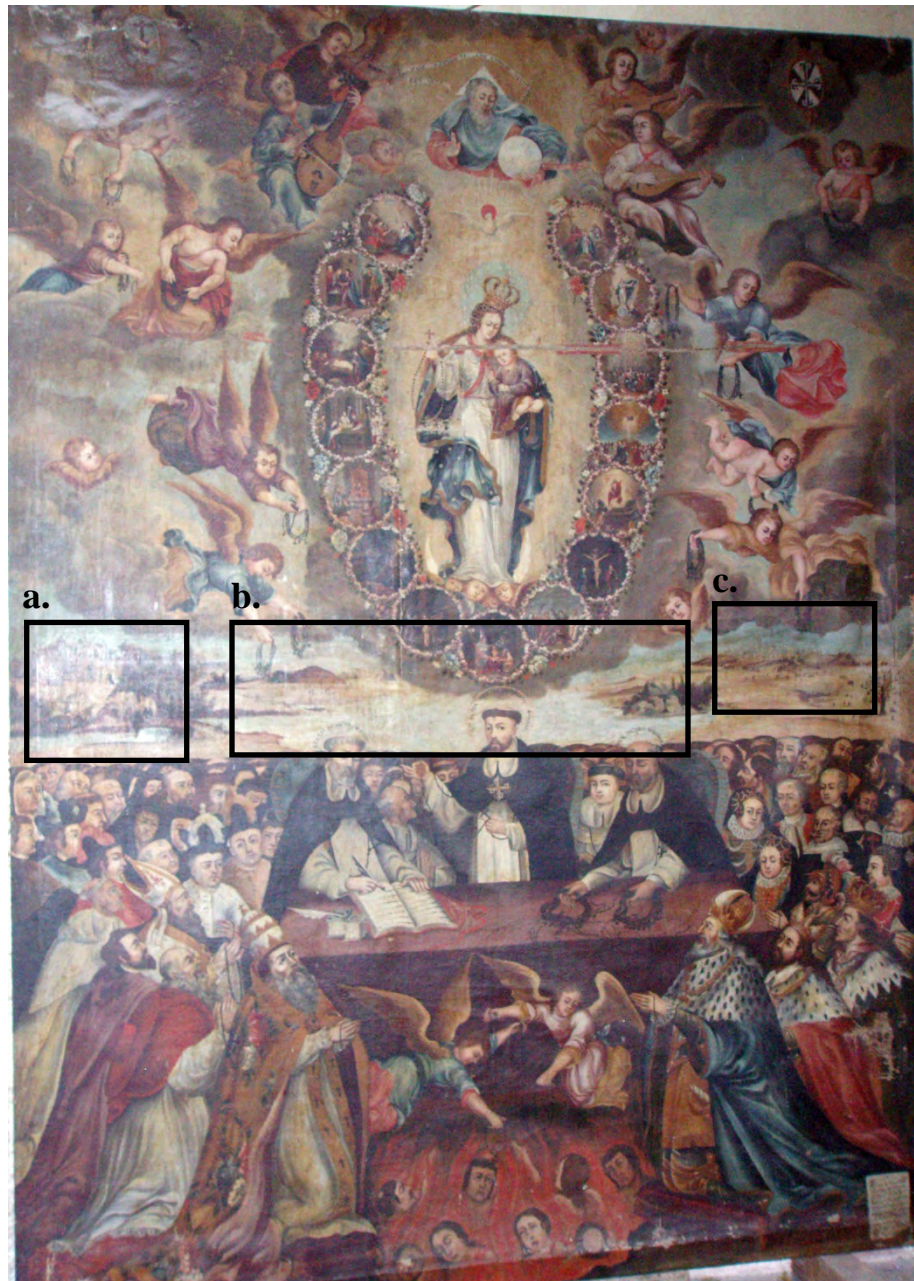
Appendix 5.B.8a-c. Details from the *Relaciones Geográficas* of Antequera, 1579-1581 (Acuña 1984) depicting large, walled churchyards associated with churches at a) Macuilsuchil and b), c) Cuahuítlan. The central dots within the Macuilsuchil churchyards likely represent central cemetery crosses.



Appendix 5.B.9. Late 18th century depiction of a cemetery located within a walled churchyard in New Spain (Beaumont 1934, Vol. 3, Map 5).



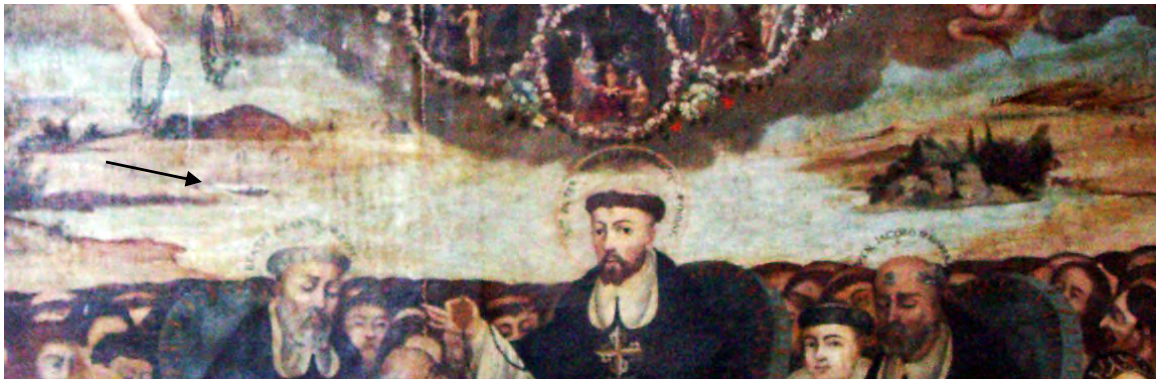
Appendix 5.B.10. Engraving from the *Rhetorica Christiana* (1579) illustrating the functions of a churchyard in New Spain. A funeral is depicted at the top of the engraving, and Kubler (1948) identifies the fourteen dotted rectangles throughout the churchyard as probable burial locations. Although the cardinal directions are not indicated in the illustration, it is interesting to note that not all burial plots exhibit the same orientation. Photograph taken by the author from a first edition print located at Harvard University's Tozzer Library.



Appendix 5.B.11. Painting dated 1746 depicting the Virgin, with the assistance of angels, distributing rosaries to the people of Teposcolula. In the background, one can see a) the modern town of San Pedro y San Pablo Teposcolula, b) a large lake, and c) the ruins of Pueblo Viejo Teposcolula Yucundaa. Photograph taken by the author in 2006.



Appendix 5.B.11a. Detail of the open-air chapel, church, and monastery at San Pedro y San Pablo Teposcolula. Photograph by James Kiracofe; reproduced with permission.



Appendix 5.B.11b. Detail of the lake depicted in the center of the Teposcolula Valley. A canoe (indicated with an arrow) is visible along the left shore. Photograph taken by the author in 2006.



Appendix 5.B.11c. Detail of the ruins of Pueblo Viejo Teposcolula Yucundaa. Note that a standing tower, possibly a bell tower, and a domed structure (indicated with arrows) are visible in the center of the ruins. Photograph taken by the author in 2006.



**Appendix 5.C. Photographs of Pueblo Viejo Teposcolula
Yucundaa and San Pedro y San Pablo Teposcolula**

Table of Contents:

Appendix 5.C.1: Eroded mountain slopes in the Mixteca Alta	303
Appendix 5.C.2: Typical maize field grown by a small-scale Mixtec farming family ...	304
Appendix 5.C.3: Sheep grazing amid the ruins of Pueblo Viejo Teposcolula Yucundaa	305
Appendix 5.C.4: View of upland agricultural terraces and modern farms in the Teposcolula Valley	306
Appendix 5.C.5: View of the fertile fields in the valley from a former agricultural terrace on the western slope of Pueblo Viejo Teposcolula Yucundaa	307
Appendix 5.C.6: The Teposcolula Grand Plaza cemetery, as it appeared before excavation	308
Appendix 5.C.7: The Teposcolula Churchyard cemetery, as it appeared before excavation	308
Appendix 5.C.8: View from above of the southern wall of the Pueblo Viejo Teposcolula Yucundaa Churchyard cemetery looking west.....	309
Appendix 5.C.9: Tarp structure erected to protect the burials from the elements during excavation	310
Appendix 5.C.10: Excavation of burial 18 in progress.....	311
Appendix 5.C.11: View of the town of San Pedro y San Pablo Teposcolula.....	312
Appendix 5.C.12: Restored open-air chapel dedicated St. John the Baptist at San Pedro y San Pablo Teposcolula.....	313
Appendix 5.C.13: Stone cross and platform at the center of the San Pedro y San Pablo Teposcolula Churchyard cemetery	314
Appendix 5.C.14: San Pedro y San Pablo Teposcolula's 16 th century <i>Casa de la Cacica</i>	315



Appendix 5.C.1. Eroded mountain slopes in the Mixteca Alta. Photograph taken by the author in 2006.



Appendix 5.C.2. Typical maize field (polycropped with squash) grown by a small-scale Mixtec farming family. A large agave plant can be seen in the background. Just out of frame are a turkey pen and a pig pen, as well as several large nopal cacti. Chickens (and occasionally turkeys) range freely in the fields. This field, located on the southern slope of Pueblo Viejo Teposcolula Yucundaa, was tilled by oxen and fertilized with oxen and donkey manure.⁷⁶ Photograph taken by the author in the summer of 2006. The maize crop was poor this year because of low rainfall.

⁷⁶ Many subsistence Mixtec farmers in the Teposcolula district do not use mechanized farming equipment and synthetic fertilizers and pesticides. Cost concerns and daily public service announcements broadcast by a popular radio station (XETLA-AM, “La Voz de la Mixteca”) educating farmers about the the benefits of using organic farming techniques are important factors.



Appendix 5.C.3. Sheep grazing amid the ruins of Pueblo Viejo Teposcolula Yucundaa. Photograph taken by the author in 2006.



Appendix 5.C.4. View of upland agricultural terraces and modern farms in the Teposcolula Valley. Photograph taken by the author from the western slope of Pueblo Viejo Teposcolula in 2006.



Appendix 5.C.5. View of the fertile fields in the Teposcolula valley. A small river runs through the middle of the valley. Photograph taken by the author from a former agricultural terrace on the western slope of Pueblo Viejo Teposcolula Yucundaa in 2006.



Appendix 5.C.6. The Teposcolula Grand Plaza cemetery, as it appeared before excavation. Small trees and dense vegetation filled the entire plaza. Photograph taken by the author in 2006.



Appendix 5.C.7. The Teposcolula Yucundaa Churchyard cemetery, as it appeared before excavation. Taller and denser vegetation mark the partially buried walls of the churchyard. View from the church looking south. Composite image compiled from photographs taken by the author in 2006.



Appendix 5.C.8. View of the southern wall of the Pueblo Viejo Teposcolula Yucundaa Churchyard cemetery looking west. Image taken by the author in 2006.



Appendix 5.C.9. Tarp structure erected to protect the burials from the elements during excavation. Physical anthropologist Laura Roldán is seated in the foreground.



Appendix 5.C.10. Excavation of burial 18 in progress. Modern vegetation and soil were removed to reveal the surface of the colonial plaza. Excavation proceeded only within the *rompimiento* (burial cut). Because of the depth of the interment, boards were installed in the burial to assist with excavation.



Appendix 5.C.11. View of the town of San Pedro y San Pablo Teposcolula from a western agricultural terrace of Pueblo Viejo Teposcolula Yucundaa. Photograph taken by the author in 2006.



Appendix 5.C.12. Restored open-air chapel dedicated to St. John the Baptist at San Pedro y San Pablo Teposcolula. In the foreground is part of the spacious walled *atrio*, or churchyard. In the 16th century, such walled spaces were called *patios* (McAndrew 1965:234). The open-air chapel was originally constructed c. 1549-1555. Photograph taken by the author in 2006.



Appendix 5.C.13. Stone cross and platform at the center of the San Pedro y San Pablo Teposcolula Churchyard cemetery. The churchyard walls and main gate can be seen in the background. Although the present stone cross was installed in the last few decades, it was likely preceded by earlier versions. The ruins of older churchyard cross foundation were visible in the 1960s, when John McAndrew (1965:549) conducted his architectural study of the Teposcolula open-air chapel. Photograph taken by the author in 2006.



Appendix 5.C.14. San Pedro y San Pablo Teposcolula's 16th century *Casa de la Cacica*, or "house of the *yya dzehe toniñe*," under restoration in 2006. The *yya dzehe toniñe* in question may be Doña Catalina de Peralta, who inherited the *aniñe* of Teposcolula in 1569 after a lengthy court battle with Don Felipe of Austria from Tilantongo (Spores 1997:189-190). Upon receiving the *aniñe*, Doña Catalina and her husband Don Diego de Mendoza, the *yya toniñe* of Tamazulapan, performed a possession ceremony in this house (Restall et al. 2001:81-86). Photograph taken by the autor.



Appendix 5.D. Exacavation data from Pueblo Viejo
Teposcolula Yucundaa

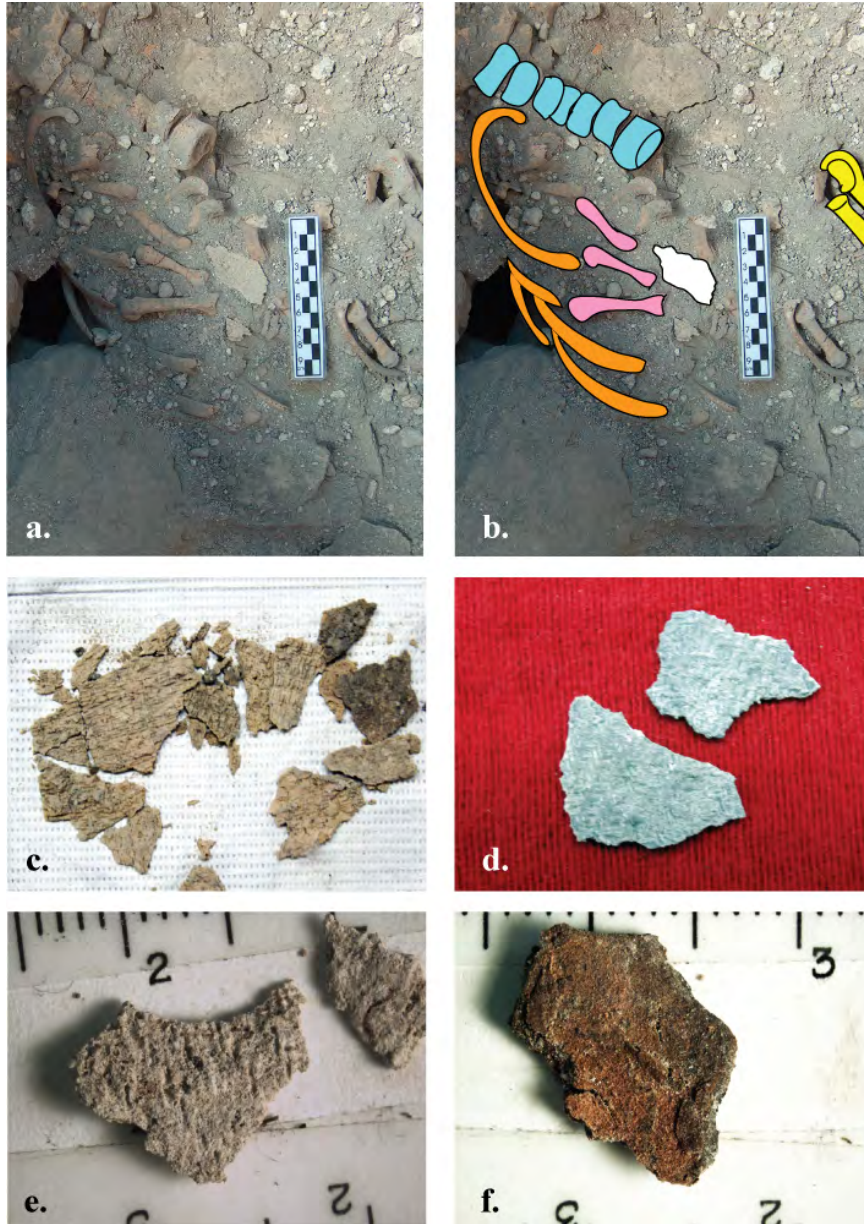
Table of Contents:

Appendix 5.D.1: Fish vertebrae recovered from excavations at Pueblo Viejo
Teposcolula Yucundaa.....317

Appendix 5.D.2a-f: Clothing fragments found in Teposcolula Grand Plaza cemetery
burials.....318



Appendix 5.D.1. Fish vertebrae recovered from excavations at Pueblo Viejo Teposcolula Yucundaa. Photograph by the author.



Appendix 5.D.2a-f. Clothing fragments found in Teposcolula Grand Plaza cemetery burials. Images include a) photograph of a textile impression *in situ* in burial 21; b) illustration of the same photograph with details highlighted: textile impression (white), vertebrae (blue), ribs (orange), metacarpals (pink), and radius and ulna (yellow); c) more burial 21 textile impressions of at least two different weaves, including a basket weave (lower right); d) textile impressions of a twill weave from burial 20, e) damaged textile impressions recovered during soil sieving of burial 19, and f) a fragment of skin or leather recovered during soil sieving of burial 19. Photograph (a) by Laura Roldán (Robles García and Spores 2006); photographs c-f by the author.



Appendix 5.E. Genetic data collected from the Teposcolula Grand Plaza and Churchyard cemeteries, as well as outlying residential terraces.

Table of Contents:

Appendix 5.E.1: Ancient DNA laboratory procedures	320
Appendix 5.E.2: Summary of Teposcolula mitochondrial coding region polymorphisms	323
Appendix 5.E.3: DNA sequences for primer pair NMF-10363/NMR-10480	325
Appendix 5.E.4: DNA sequences for primer pair AF-00635/AR-00745	327
Appendix 5.E.5: DNA sequences for primer pair BF-08196/BR-08316.....	329
Appendix 5.E.6: DNA sequences for primer pair CF-13239/CR-13366.....	331
Appendix 5.E.7: DNA sequences for primer pair DF-05150/DR-05274	333

Appendix 5.E.1. Ancient DNA laboratory procedures

Rigorous ancient DNA laboratory procedures were followed throughout this study to mitigate the risk of modern DNA contamination. All sample extractions and PCR set-up procedures were conducted in a dedicated ancient DNA clean room facility that has never been used to analyze modern human DNA. The ancient DNA clean room is operated under positive pressure and has a dedicated HEPA air filtration system. PCR and post-PCR analyses were conducted in separate, non-contiguous facilities, and unidirectional work flow patterns were established in which daily movement proceeded from the clean room to the PCR facilities, but not the reverse.

Ancient DNA clean room

Within the ancient DNA clean room, dedicated clean room scrubs were worn underneath full-body Tyvek suits (complete with booties and hood), and dedicated clean room synthetic rubber shoes, “shower caps,” face masks, and protective eyewear were worn at all times. Two pairs of latex examination gloves were worn, and the external pair was repeatedly wiped with 6% sodium hypochlorite solution (full strength commercial bleach) before and after handling of supplies, reagents, and samples. All surfaces and pipettors were wiped with 6% sodium hypochlorite solution both prior to and following any work performed in the clean room. All PCR set-up was conducted within an AirClean Systems HEPA-filtered laminar flow hood, which was also UV-irradiated for 30 minutes before use.

All extractions and pre-PCR reactions were performed using certified DNA-free and/or sterile tubes and aerosol pipet tips. Negative extraction controls were run in parallel with each extraction group and repeatedly tested for contamination before

proceeding to archaeological sample PCR amplification. PCR blanks were additionally included with every batch of sample amplifications, with a minimum of one PCR blank for every seven samples. All PCR reactions were prepared as master mixes which were aliquoted into PCR reaction vessels, and 1-2 μ L of sample extract was then added to each reaction vessel. If any negative extraction controls or PCR blanks exhibited contamination, the entire amplification group made from the same master mix was discarded and repeated.

The clean room laboratory was kept locked at all times, and access was restricted. The ancient DNA analyst (Christina Warinner) and all laboratory members with access to the laboratory facilities in which the ancient DNA laboratory is housed were haplotyped and found to belong to haplogroups U, H, K, J, and L3, which are characteristic of European and African descendent populations. No one with access to the laboratory belonged to haplogroups A, B, C, D, or X, which are found among Native American populations.

Field precautions

In addition to laboratory procedures, general precautions were also taken in the field to mitigate ancient DNA damage and contamination. Beginning in 2006 (when the author joined the project), protective shades were erected during burial excavation to limit exposure of the remains to direct sunlight (see Appendix 5.C.9), and gloves were worn during the handling of skeletal remains. Excavated remains were wrapped in tissue paper, cotton, and foil, and stored in coolers until transport to the on-site field laboratory. At the field laboratory, physical handling of the remains by physical anthropologists and other analysts was limited and restricted to basic osteological analysis. Following

examination, the remains were stored in a cool and dark location until sampling. During sampling, they were mechanically cleaned of soil debris (no water or other chemicals were used) and the author collected bone samples from the tibia and/or femur of each individual using a Dremmel Multi-Pro hand-held drill. Latex gloves and masks were worn during sampling. Bone samples were stored in sterile plastic 50mL conical tubes and kept frozen until transport to the United States. The samples were transported on ice to Harvard University and subsequently kept frozen at -20°C in a non-defrosting freezer until analysis.

Appendix 5.E.2. Summary of Teposcolula mitochondrial coding region polymorphisms

Individual	MHgN 10398	MHgM 10400	HgA 663	HgB 8281-8289	HgC 13263	HgD 5178	Consensus Hg
<i>rCRS^a</i>	C	A	A	NO DEL	A	C	H
2	C	A	G‡	NO DEL	A	n.a.	A
3	C	A	G	NO DEL	A	n.a.	A
6	C	A	G‡	NO DEL	n.a.	C	A
8	C	A	G	NO DEL	A	n.a.	A
9	C	A	G	NO DEL	A	n.a.	A
10	C	A	G	NO DEL	A	n.a.	A
13	C	A	G	NO DEL	A†	n.a.	A
19	C	A	G	NO DEL†	A	n.a.	A
20	C	A	G	NO DEL	A†	n.a.	A
23	C	A	G	NO DEL	A	C†	A
24	C	A	G	NO DEL	A†	C‡	A
26	C	A	G	NO DEL	A	C	A
28	C	A	G	NO DEL	A†	C	A
29	C	A	G	NO DEL	A†	C	A
30	C	A	G	NO DEL	A	C	A
31	C	A	G	NO DEL	A	C	A
35	C	A	G	NO DEL	A	C	A
36	C	A	G	NO DEL	A	C	A
38	C	A	G	NO DEL	A	C	A
40	C	A	G†	NO DEL	A	C	A
41	C	A	G†	NO DEL	A	C	A
42	C	A	G†	NO DEL	A	C	A
43	C	A	G†	NO DEL	A	C	A
44	C	A	G†	NO DEL	A	C	A
46	C	A	G	NO DEL	A	n.a.	A
47	C	A	G	NO DEL	A	C	A
48	C	A	G	NO DEL	A	C	A
5	C	A	A	DEL	A	C	B
7	C	A	A	DEL	A	C	B
14	C	A	A	DEL	n.a.	C	B
15	C	A	A	DEL	n.a.	C	B
16	C†	A†	A	DEL	n.a.	C†	B
17	C	A	A	DEL	A	C†	B
18	C†	A†	A	DEL†	A	C	B
33	C	A	A	DEL	A	C	B
34	C	A	A	DEL	A	C	B
37	C	A	A	DEL	A	C	B
45	C	A	A†	DEL	A	C	B

Appendix 5.E.2. continued

Individual	MHgN 10398	MHgM 10400	HgA 663	HgB 8281-8289	HgC 13263	HgD 5178	Consensus Hg
1	T†	G†	A	NO DEL	G‡	C	C
4	T	G	A	NO DEL	G	C	C
11	T	G	A	NO DEL	G	C	C
12	T	G	A	NO DEL	G	C	C
21	T	G	A	NO DEL†	G	C	C
22	T*	G*	A	NO DEL†	G	C	C
27	T	G	A	NO DEL	G	C†	C
25	T	G	A	NO DEL	A	A	D
32	T	G	A	NO DEL†	A	A	D
39	T	G	A†	NO DEL	A	A	D

Notes:

Polymorphisms are reported relative to the forward strand of the rCRS (revised Cambridge Reference Sequence). Note that this differs from Appendices 5.E.3-4 and 5.E.6-7, which report polymorphisms relative to the reverse strand. Target regions that were not amplified are denoted n.a.

†Two independent amplifications yielded identical sequence results.

‡The first amplification yielded an inconclusive sequence at the SNP of interest (mixed base). A second amplification was performed that yielded an unambiguous sequence at the SNP of interest.

*This sample was amplified and sequenced three times. The first amplification yielded a sequence with the nonsensical SNP combination of a C and a G at nucleotide positions 10398 and 10400. The sample was reamplified twice more and the subsequent two sequence chromatograms clearly showed a T and a G at nucleotide positions 10398 and 10400, which is consistent with macrohaplogroup M.

Appendix 5.E.3. DNA sequences for primer pair NMF-10363/NMR-10480

	10390	10400	10410	10420	10430	10440	10450
Ind.	TTTCCTAATCTGACT	TGGCTTAACCATATATCAAATTTGTTTTGCTTACTAAAGCTGAGTAATTTAATACTATTAG					
1	C.A.	.....	.....	.....	.....	.....
1	C.A.	.....	.....	.....	.....	.....
2
3
4	C.A.	.....	.....	.....	.....	.....
5	..T.....	.....	.....	.....	..T.....	.....	.....
6
7	***
8T.....	.....	.....	.....	.....
9	***	**
10	***	**
11	C.A.	.....	.....	.....	***	.....
12	C.A.	.....	.....	.....	***	**
13	***	**
14	***	**
15	***	**
16A.....	.....	.....
16
17
18	..TT...T..T..	.....	..NN...	.....	.....	.....	.....
18Y.....	..YY.....	.....	.....	.....	.....
19
20	***
21	C.A.	.....	.....	.....	***	.....
22A.....	.....	.....	.....	.....	.....
22	..Y.....	..Y..C.A.	.....	.....	.....	.....	.....
22	C.A.	.....	.....	.....	.....	.....
23	***
24
25	C.A.	.....	.....	.....	.....	.....
26	***
27	C.A.	.....	.....	.....	.....	.....
28
29

Appendix 5.E.3. continued

	10390	10400	10410	10420	10430	10440	10450
Ind.	TTTCCTAATCTGACTTGGCTTAACCATATATCAAATTTGTTTTGCTTACTAAAGCTGAGTAATTTAATACTATTAG						
30	***
31	***
32	C.A	.....	.....	.....	***	.....
33	***
34	***
35	***
36	***
37	***
38	***
39	C.A	.....	.....	.....	***	.....
40	***
41	***
42	***
43	***
44	***
45	***
46
47	***
48	***

Notes:

Reverse strand sequence of amplified PCR products shown with primer sequences trimmed. Base calls are given as the majority base present in the electropherogram. Dots indicate identity to the revised Cambridge Reference Sequence (rCRS) given at the top of the alignment. Blank spaces indicate nucleotide positions for which base calls could not be performed because of background noise and/or primer dimers at the beginning of the sequence. "Ns" indicate base call ambiguity and/or regions of poor sequence resolution. Nucleotide positions 10433-10435 and 10443-10444 consistently appear as a wide, undifferentiated adenine peak in the electropherograms; the inferred number of adenines represented by the peak are indicated by stars (*). This primer pair amplifies a region with two AIMS, outlined by black boxes. The first, nucleotide position 10398, is characterized by a C→T transition (G→A in forward strand) SNP among members of macrohaplogroup N, which includes haplogroups A, B, and H (the haplogroup of the rCRS). The second, nucleotide position 10400, is characterized by an G→A transition (C→T in forward strand) among members of macrohaplogroup M, which includes haplogroups C and D.

Appendix 5.E.4. DNA sequences for primer pair AF-00635/AR-00745

	650	660	670	680	690	700
Ind.	AGGAT	CGGAAAGATAAT	CGAGAATCATTCTA	TGTGTACGTT	CGTAGGGGCAAGG	TCCTCAAGTG
1
2	Y.....	.....	.....	.....	.....
2	C.....	.....	.....	.....	.....
3	C.....	.....	.....	.....	.....
4
5
6	Y.....	.....	.....	.....	.....
6	R.C.R.....	.....	.....	.....	.....
7
8	C.....	.....	.....	.....	.....
9	C.....	.....	.....	.....	.....
10	C.....	.....	.....	.....	.....
11
12
13	C.....	.....	.....	.....	**.....
14
15
16
17
18
19	C.....	A.A.....	.....	.....	.....
20	C.....	.....	.....	.....	.....
21
22	N.....	.....	.....
23	C.....	.....	.....	.....	.....
24	C.....	.....	.....	.....	.....
25
26	C.....	***.....	.....	.....	**.....
27	**.....
28	C.....	.....	.....	.....	.....
29	C.....	.....	.....	.....	.....
30	C.....	.....	.....	.....	**.....
31	C.....	.....	.....	.....	**.....
32	**.....
33	**.....
34	**.....
35	C.....	.....	.....	.....	**.....
36	C.....	.....	.....	.....	**.....
37	**.....
38	C.....	.....	.....	.....	.....
39
39	**.....
40	C.....	.....	.....	.....	**.....
40	C.....	.....	.....	.....	**.....
41	C.....	.....	.....	.....	**.....
41	C.....	.....	.....	.....	**.....
42	C.....	.....	.....	.....	**.....
42	C.....	.....	.....	.....	.....
43	C.....	.....	.....	.....	.....
43	C.....	.....	.....	.....	.....
44	C.....	.....	.....	.....	**.....
44	C.....	.....	.....	.....	.....
45	**.....

Appendix 5.E.4. continued

	650	660	670	680	690	700
Ind.	AGGAT	CGGAAAGATAAT	CGAGAATCATTCTAAT	GTGTACGTT	CGTAGGGGCAAGGTC	CACTCAAGTG
45**.
46	C.....	.....	.....	.....	.....
47	C.....	.....	.....	.....	.....
48	C.....	.....	.....	.....	.....**.....

Notes:

Reverse strand sequence of amplified PCR products shown with primer sequences trimmed. Sequences have been reversed for ease of reading. Base calls are given as the majority base present in the electropherogram. Dots indicate identity to the revised Cambridge Reference Sequence (rCRS) given at the top of the alignment. Blank spaces indicate nucleotide positions for which base calls could not be performed because of background noise and/or primer dimers at the beginning of the sequence. “Ns” indicate base call ambiguity and/or regions of poor sequence resolution. Nucleotide positions 00669-00670 consistently appear as a wide, undifferentiated adenine peak in the electropherograms; the inferred number of adenines represented by the peak are indicated by stars (*). Nucleotide position 00663, which among members of haplogroup A contains a T→C (A→G in forward strand) SNP, is outlined by a black box.

Appendix 5.E.5. DNA sequences for primer pair BF-08196/BR-08316

Ind.	8220	8230	8240	8250	8260	8270	8280	8290
	CTAGAATTAATTCCCCTAAAAATCTTTGAAATAGGGCCCGTATTTACCTATAGCACCCCCTCTAC	CCCCTCTAGAGCCCA						
1								
2								A
3				R	R	Y	R	Y
4								T
5								
6								
7			***					
8								Y
9			***					
10			***					
11			***					
12			***					
13			***					
14			***					
15			***					
16				A				T
17			***					
18				T	T	T	T	T
18						R		Y
18			***					
19								
19								
20			***					
21							T	T
21			***			R		
22			***	T	T	T	TTT	
22						Y		Y
22								
23			***					T
24			***					
25								
26								
27								
28								

Appendix 5.E.5. continued

	8220	8230	8240	8250	8260	8270	8280	8290
Ind.	CTAGAATTAAT	TCCCC	TAAAAATC	TTTGAAATAG	GGCCCGTAT	TTTACCCTAT	AGCACCCCTCTA	CCCCCTCTAGAGCCCA
29								
30								
31								
32								
32								
33								
34								
35								
36								
37								
38								
39								
40								
41								
42								
43								
44								
45								
46								
47								
48								

Notes:

Forward strand sequence of amplified PCR products shown with primer sequences trimmed. Sequences have been reversed for ease of reading. Base calls are given as the majority base present in the electropherogram. Dots indicate identity to the revised Cambridge Reference Sequence (rCRS) given at the top of the alignment. Dashes (-) indicate deleted bases. Underlined bases are followed by an insertion of the same base (not shown), likely resulting from Taq slippage in poly-C regions. Blank spaces indicate nucleotide positions for which base calls could not be performed because of background noise and/or primer dimers at the beginning of the sequence. Nucleotide positions 8281-8289, which among members of haplogroup B are deleted, are outlined by a black box.

Appendix 5.E.6. DNA sequences for primer pair CF-13239/CR-13366

	13270	13280	13290	13300	13310	13320	13330	13340
Ind.	GTT	GATCCTGAGTATTATCAATGTTAGCCGTAGTTGGTGGTGTGGATCGTAAGGACGTGTAGACATGGGTGCCGAAGAAGTT						
1	.Y	.....Y	.....				
1	.Y	.Y	.....Y	.....			
1	.C	.....					
2	.	.....				
3	.	.....				
4	.C	.....				**	....
5	.	.....	.T	.....	R	.....	
7	.	.....				
8	.	.....	R	.....			
9	.	.....				
10	.	.....				
11	.C	.....					
12	.C	.....					
13	.	.....				
13	.	.....				
17	.	.....				
18	.	.....				
19	.	.....				
20	.	.....				
20	.	.....				
21	.C	.....					
22	.C	.....					
23	.	.....				
24	.	.Y	.....				
24	.	.....				
25	.	.....				
26	.	.....				
27	.C	.....					
28	.	.....				
28	.	.....				
29	.	.....			R	.....	
29	.	.....				
30	.	.....				**	....
31	.	.....				

Appendix 5.E.6. continued

	13270	13280	13290	13300	13310	13320	13330	13340
Ind.	GTTGATCCTGAGTATTATCAATGTTAGCCGTAGTTGGTTGGTGTGGATCGTAAGGACGTGTAGACATGGGTGCGGAAGAAGTT							
32	.....						
33	.....						
34	.....						
35 **							
36	..... R							
37	.....						
38 **							
39	.....						
40	.....						
41	.....						
42	.....						
43	.....						
44 **							
45	.....						
46	..... Y TY							
47	.....						
48	..... N							

Notes:

Reverse strand sequence of amplified PCR products shown with primer sequences trimmed. Sequences have been reversed for ease of reading. Base calls are given as the majority base present in the electropherogram. Dots indicate identity to the revised Cambridge Reference Sequence (rCRS) given at the top of the alignment. Blank spaces indicate nucleotide positions for which base calls could not be performed because of background noise and/or primer dimers at the beginning of the sequence. Nucleotide positions 13312-13313 occasionally appear as a wide, undifferentiated adenine peak in the electropherograms; the inferred number of adenines represented by the peak are indicated by stars (*). "Ns" indicate base call ambiguity and/or regions of poor sequence resolution. Nucleotide position 13263, which among members of haplogroup C contains a T→C (A→G in forward strand) SNP, is outlined by a black box.

Appendix 5.E.7. DNA sequences for primer pair DF-05150/DR-05274

Ind.	rCRS	5180	5190	5200	5210	5220	5230	5240	5250
	TTTGTTCG	GATTGTACTG	GATTGTGGGAATTA	AAGGTAGGT	GGGAGGAGAGGGG	ATCCTCCGGAC	CGGGGCGATT	TGGCCGAAAAAC	
1	A.....	NNN.....	N.....	.....	.....	.....
4	NNN.....	.....	.....	.....	.....	.....
5
6	A.....	.....	.....	.....	.....	.....
7	N.....	N.....	N.....	A.....	N.....	.....	.....	.....
11
12
14	R.....	.....	.....	.....	.....	.....
15	N.....	R.....	.....	.....	.....	.....
16
16
17
17
18
21
22	Y.....	.....	.....	.....	.....	.....
23
23
24	R.....	.....	.....	.....	.....	.....	.....	.....
24
25	T.....	.....	.....	.....	.....	.....	.....	.....
26
27	A.....	N.....	.....	.....	.....	.....
27
28
29
30
31
32	T.....	.....	.....	.....	.....	.....	.....	.....
33
34
35
36
37

Appendix 5.E.7. continued

	rCRS	5180	5190	5200	5210	5220	5230	5240	5250
Ind.	TTTGTTC	G TATTG	TACTGATTGT	GTTGGGAATTA	AAGGTAGGT	GGGAGGAGAG	GGGATCCTCC	CGGACGGGGG	CGATTGGCCGAAAAAC
38
39	T.....	.....	.....	.....	.....	.....	.....	.....
40
41
42
43
44
45
46
47	A.....	.....	N.....	.....	.....
48

Notes:

Reverse strand sequence of amplified PCR products shown with primer sequences trimmed. Sequences have been reversed for ease of reading. Base calls are given as the majority base present in the electropherogram. Dots indicate identity to the revised Cambridge Reference Sequence (rCRS) given at the top of the alignment. "Ns" indicate base call ambiguity and/or regions of poor sequence resolution. Blank spaces indicate nucleotide positions for which base calls could not be performed because of background noise and/or primer dimers at the beginning of the sequence. Nucleotide position 05178, which among members of haplogroup D contains a G->T (C->A in forward strand) SNP, is outlined by a black box.



Appendix 5.F. Stable isotope data from the Teposcolula
Grand Plaza and Churchyard cemeteries,
as well as outlying residential terraces.

Table of Contents:

Appendix 5.F.1: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of Teposcolula bone collagen	336
Appendix 5.F.2: Measured $\delta^{18}\text{O}$ and δD of Teposcolula bone collagen	338
Appendix 5.F.3: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of Teposcolula M3 enamel apatite without treatment	340
Appendix 5.F.4: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of Teposcolula M3 enamel apatite with treatment	340
Appendix 5.F.5: Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of environmental carbonate	341

Appendix 5.F.1. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of Teposcolula bone collagen

Individual	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N
1	-7.6	8.3	3.3
2	-9.4	6.9	3.4
3	-8.9	9.5	3.3
4	-9.9	7.6	3.4
5	-8.3	8.1	3.3
6	-7.8	8.7	3.4
7	-8.1	8.6	3.4
8	-8.0	8.2	3.3
9	-7.8	7.8	3.3
10	-7.9	9.3	3.4
11	-7.8	7.3	3.4
12	-7.5	9.0	3.4
13	-7.8	8.1	3.3
14	-8.9	6.8	3.4
15	-9.4	8.6	3.3
16	-7.5	8.8	3.4
17	-8.1	9.2	3.3
18	-8.7	8.2	3.3
19	-8.7	8.7	3.4
20	-8.5	7.7	3.3
21	-7.7	8.9	3.3
22	-7.7	8.7	3.4
23	-8.5	8.9	3.4
24	-7.8	8.3	3.4
25	-8.4	9.1	3.3
26	-8.4	9.1	3.4
27	-8.8	9.4	3.5
28*	-5.2	11.5	3.4
29*	-6.1	12.0	3.2
30	-8.1	9.1	3.1
31	-8.8	9.7	3.3
32	-8.6	8.5	3.5
33	-7.7	7.8	3.3
34	-8.6	7.5	3.5
35	-8.6	8.3	3.3
36	-8.2	8.0	3.4
37	-8.4	8.7	3.4
38	-8.1	9.2	3.2
39	-8.1	8.3	3.3
40	-7.8	8.5	3.4
41	-8.6	7.8	3.3

Appendix 5.F.1. Continued

Individual	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{15}\text{N}_{\text{AIR}}$	C/N
42	-6.6	10.3	3.5
43	-8.2	8.4	3.1
44	-8.0	7.6	3.5
45	-8.2	7.3	3.5
46	-8.4	8.6	3.6
47	-8.1	7.0	3.5
48	-8.3	8.3	3.5

Notes: Starred (*) individuals were recovered from outlying residential terraces.

Appendix 5.F.2. Measured $\delta^{18}\text{O}$ and δD of Teposcolula bone collagen

Individual	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
1	8.8	-34
2	9.2	-45
3	9.6	-28
3	10.2	-32
4	8.9	-36
5	9.2	-35
6	8.2	-36
7	9.2	-36
8	8.2	-35
9	8.7	-39
10	8.1	-36
10	8.2	-38
11	7.7	-44
12	8.0	-44
13	7.9	-38
14	8.7	-37
15	8.6	-34
15	8.8	-33
16	7.6	-41
17	7.9	-36
18	8.4	-38
19	8.8	-38
20	8.6	-35
20	9.0	-29
21	7.8	-35
22	7.6	-40
23	8.6	-38
24	7.8	-38
25	8.0	-37
25	8.4	-35
26	7.7	-38
27	8.4	-33
28*	7.8	-51
28*	7.8	-53
29*	9.0	-59
29*	7.8	-54
30	8.7	-30
31	9.6	-34
32	10.1	-36
33	9.4	-36
34	9.0	-37
35	8.6	-41
35	8.8	-39
36	9.0	-38

Appendix 5.F.2. continued

Individual	$\delta^{18}\text{O}_{\text{VSMOW}}$	$\delta\text{D}_{\text{VSMOW}}$
37	8.5	-34
38	7.9	-36
39	7.6	-41
40	7.8	-40
40	7.5	-42
41	8.1	-41
42	8.4	-28
43	7.5	-41
44	7.6	-33
45	7.2	-30
45	7.4	-29
46	6.4	-38
47	7.1	-43
48	6.8	-33
48	7.0	-35

Notes: Starred (*) individuals were recovered from outlying residential terraces.

Appendix 5.F.3. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of
Teposcolula M3 enamel apatite without treatment

Individual	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
1	-0.9	21.4
4	-0.7	21.5
5	-0.5	21.2
6	-1.2	21.8
8	-0.8	19.8
10	-0.6	20.1
17	-1.0	21.1
20	-1.3	21.8
21	-1.2	20.3
22	-0.9	20.7
25	-1.9	20.6
30	-0.6	21.2
37	-0.7	20.9
41	-1.1	22.1
45	-1.1	20.5
48	-0.7	21.7

Notes: Although mechanically cleaned to remove soil and dental plaque, the enamel was not chemically pretreated before analysis.

Appendix 5.F.4. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of Teposcolula
M3 enamel apatite with treatment

Individual	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
1	-1.4	20.7
4	-0.6	21.5
5	-0.7	21.9
6	-1.3	19.7
8	-1.1	20.1
10	-0.6	20.4
17	-0.1	19.0
20	-1.0	20.5
21	-1.3	22.0
22	-1.5	22.4
25	-1.2	20.6
30	-1.5	21.2
37	-2.0	21.7
41	-0.8	19.2
45	-0.6	20.3
48	-0.9	20.9

Notes: Chemical pre-treatment consisted of soaking the enamel powder for 50 minutes in a 0.1M acetic acid solution to remove loosely bound carbonates.

Appendix 5.F.5. Measured $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of environmental carbonate

Context	Sample	$\delta^{13}\text{C}_{\text{VPDB}}$	$\delta^{18}\text{O}_{\text{VSMOW}}$
GRAND PLAZA PLASTER FLOOR			
Burial 18	1	-7.3	23.1
Burial 18	2	-8.0	22.6
Burial 18	3	-3.0	23.5
Burial 19	1	-5.0	23.1
Burial 20	1	-5.4	22.6
Burial 21	1	-6.7	23.6
COOKING LIME			
Oaxacan market	1	-10.6	12.4



Appendix 5.G. Appendix 5.G. Stable isotope data and photographic collections for non-native crops sold in Mesoamerican markets

Table of Contents:

Appendix 5.G1: Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of non-native crops sold in contemporary Mexican markets	343
Appendix 5.G.2: Photographs of non-native crops analyzed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$	345

Appendix 5.G.1. Measured $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ of non-native crops sold in contemporary Mexican outdoor markets












Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%N	Reference
<i>Allium sepa</i>	Onion	Oaxaca	Bulb	-23.7	2.4	0.9	This study, WO87
<i>Allium sepa</i>	Onion	Oaxaca	Bulb	-24.0	-	-	This study, WO87
<i>Allium sepa</i>	Onion	Oaxaca	Bulb	-	2.4	-	This study, WO87
<i>Allium sepa</i>	Onion	Gulf Lowlands	Bulb	-26.9	0.9	1.3	This study, SV21
<i>Avena sativa</i>	Oats	Oaxaca	Seed	-25.1	0.4	1.9	This study, WO58
<i>Averrhoa carambola</i>	Starfruit	Gulf Lowlands	Fruit	-26.6	-2.7	0.9	This study, SV4
<i>Averrhoa carambola</i>	Starfruit	Gulf Lowlands	Fruit	-26.6	-	-	This study, SV4
<i>Brassica nigra</i>	Black mustard	Oaxaca	Seed	-26.4	1.6	3.2	This study, WO67
<i>Brassica nigra</i>	Black mustard	Oaxaca	Seed	-28.9	6.0	3.8	This study, WO67
<i>Cassia fistula</i>	Canafistula	Gulf Lowlands	Fruit	-27.7	11.6	1.7	This study, SV16
<i>Castanea sp.</i>	Chestnut	Gulf Lowlands	Seed	-27.9	8.8	2.5	This study, SV72
<i>Cicer arietinum</i>	Garbanzo bean	Oaxaca	Seed	-24.4	1.5	5.0	This study, WO30
<i>Cicer arietinum</i>	Garbanzo bean	Oaxaca	Seed	-27.6	0.7	4.1	This study, WO65
<i>Cinnamomum verum</i>	Cinnamon	Gulf Lowlands	Leaf	-28.8	7.1	2.2	This study, SV36
<i>Coffea arabica</i>	Coffee	Oaxaca	Seed	-26.8	1.7	2.3	This study, WO55
<i>Coriandrum sativum</i>	Coriander	Gulf Lowlands	Seed	-27.5	5.8	4.1	This study, SV49
<i>Cucumis sativus</i>	Cucumber	Oaxaca	Fruit	-26.4	3.0	3.7	This study, WO32
<i>Cucumis sativus</i>	Cucumber	Gulf Lowlands	Fruit	-23.4	5.9	2.5	This study, SV12
<i>Cucumis sativus</i>	Cucumber	Gulf Lowlands	Fruit	-27.9	1.6	3.3	This study, SV20
<i>Cucumis sativus</i>	Cucumber	Gulf Lowlands	Fruit	-27.9	2.9	4.5	This study, SV20
<i>Cuminum cyminum</i>	Cumin	Oaxaca	Seed	-27.5	-1.0	3.2	This study, WO96
<i>Cuminum cyminum</i>	Cumin	Gulf Lowlands	Seed	-26.1	0.1	3.7	This study, SV50
<i>Cydonia oblonga</i>	Quince	Oaxaca	Fruit	-27.3	-1.6	-	This study, SO27
<i>Cydonia oblonga</i>	Quince	Oaxaca	Fruit	-28.2	-	-	This study, SO27
<i>Hibiscus sabdariffa</i>	Hibiscus (tea)	Oaxaca	Flower	-25.9	0.3	1.1	This study, WO85
<i>Hordeum vulgare</i>	Barley (pearled)	Gulf Lowlands	Seed	-25.2	6.2	1.7	This study, SV48
<i>Matricaria recutita</i>	Chamomile	Oaxaca	Flower	-28.6	2.5	4.3	This study, WO9

Appendix 5.G.1. Continued

Taxa ^b	Common name ^c	Location collected	Botanical part ^d	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	%N	Reference
<i>Morinda citrifolia</i>	Noni	Gulf Lowlands	Fruit	-28.0	-	-	This study, SV27
<i>Morinda citrifolia</i>	Noni	Gulf Lowlands	Fruit	-28.9	-	-	This study, SV27
<i>Morinda citrifolia</i>	Noni	Gulf Lowlands	Fruit	-28.3	12.4	0.8	This study, SV27
<i>Myristica fragrans</i>	Nutmeg	Gulf Lowlands	Nut	-25.3	5.6	1.0	This study, SV52
<i>Myristica fragrans</i>	Nutmeg	Gulf Lowlands	Nut	-25.3	-	-	This study, SV52
<i>Nasturtium officinale</i>	Watercress	Oaxaca	Leaf	-27.5	13.3	6.9	This study, WO28
<i>Panicum miliaceum</i>	Proso millet	Gulf Lowlands	Seed	-13.1	4.1	1.9	This study, SV54
<i>Petroselinum crispum</i>	Parsley	Gulf Lowlands	Leaf	-27.9	5.6	3.9	This study, SV33
<i>Petroselinum crispum</i>	Parsley	Gulf Lowlands	Leaf	-30.6	2.3	3.9	This study, SV63
<i>Petroselinum crispum</i>	Parsley	Gulf Lowlands	Leaf	-27.8	-	-	This study, SV63
<i>Phalaris canariensis</i>	Canary grass	Oaxaca	Seed	-27.3	3.0	2.3	This study, SV63
<i>Phalaris canariensis</i>	Canary grass	Oaxaca	Seed	-26.9	4.7	2.4	This study, WO61
<i>Phalaris canariensis</i>	Canary grass	Gulf Lowlands	Seed	-25.2	1.2	3.0	This study, WO61
<i>Prunus dulcis</i>	Almond	Gulf Lowlands	Nut	-26.3	2.1	4.0	This study, SV41
<i>Rosmarinus officinalis</i>	Rosemary	Gulf Lowlands	Leaf	-26.7	5.2	-	This study, SV43
<i>Ruta sp.</i>	Rue	Gulf Lowlands	Leaf	-29.5	1.3	3.4	This study, SV35
<i>Sesamum indicum</i>	Sesame	Oaxaca	Seed	-28.9	5.2	3.7	This study, WO59
<i>Syzygium aromaticum</i>	Cloves	Oaxaca	Seed	-26.9	1.1	1.6	This study, WO95
<i>Syzygium aromaticum</i>	Cloves	Oaxaca	Seed	-28.2	-	-	This study, WO95
<i>Tamarindus indica</i>	Tamarind	Oaxaca	Fruit	-27.2	-	-	This study, WO21
<i>Tamarindus indica</i>	Tamarind	Oaxaca	Fruit pod	-28.0	-	-	This study, WO21
<i>Tilia sp.</i>	Flor de titla	Gulf Lowlands	Seed	-26.9	-0.4	3.1	This study, SV51
<i>Triticum sp.</i>	Wheat	Oaxaca	Seed	-25.1	3.4	1.9	This study, WO56
<i>Triticum sp.</i>	Wheat	Oaxaca	Seed	-25.3	4.2	2.5	This study, WO56
<i>Vicia faba</i>	Fava bean	Oaxaca	Seed	-26.5	1.1	4.1	This study, WO57
<i>Vicia faba</i>	Fava bean	Oaxaca	Seed	-22.5	0.8	5.9	This study, WO64

Appendix 5.12. Photographs of non-native crops analyzed for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$

January 2006, Valley of Oaxaca market collection

No photo available		No photo available	
WO9. <i>Matricaria recutita</i> , chamomile	WO21. <i>Tamarindus indica</i> , tamarind†	WO30. <i>Cicer arietinum</i> , garbanzo beans	WO32. <i>Cucumis sativus</i> , cucumber
			
WO55. <i>Coffea arabica</i> , coffee	WO56. <i>Triticum</i> sp., wheat†	WO57. <i>Vicia faba</i> , fava bean	WO58. <i>Avena sativa</i> , oats
			
WO59. <i>Sesamum indicum</i> , sesame seeds	WO61. <i>Phalaris canariensis</i> , canary grass seed†	WO64. <i>Vicia faba</i> , fava bean	WO65. <i>Cicer arietinum</i> , garbanzo bean
	No photo available	No photo available	No photo available
WO67. <i>Brassica nigra</i> , black mustard†	WO85. <i>Hibiscus sabdariffa</i> , hibiscus flower	WO87. <i>Allium sepa</i> , onion†	WO95. <i>Syzygium aromaticum</i> , cloves†
No photo available		July 2006, Valley of Oaxaca market collection	
WO96. <i>Cuminum cyminum</i> , cumin			SO27. <i>Cydonia oblonga</i> , quince†

Appendix 5.12. continued

July 2006, Villahermosa market collection



SV4. *Averrhoa carambola*, starfruit†



SV12. *Cucumis sativus*, white cucumber



SV16. *Cassia fistula*, canafistula



SV20. *Cucumis sativus*, cucumber†



SV21. *Allium sepa*, onion



SV27. *Morinda citrifolia*, noni†



SV33. *Petroselinum crispum*, parsley†



SV34. *Rosmarinus officinalis*, rosemary



SV35. *Ruta* sp., rue



SV36. *Cinnamomum verum*, cinnamon



SV41. *Phalaris canariensis*, canary grass



SV43. *Prunus dulcis*, almond



SV48. *Hordeum vulgare*, barley (pearled)



SV49. *Coriandrum sativum*, coriander



SV50. *Cuminum cyminum*, cumin



SV51. *Tilia* sp., flor de titla



SV52. *Myristica fragrans*, nutmeg†



SV54. *Panicum miliaceum*, red proso millet



SV72. *Castanea* sp., chestnut

†Multiple samples from this specimen were measured.