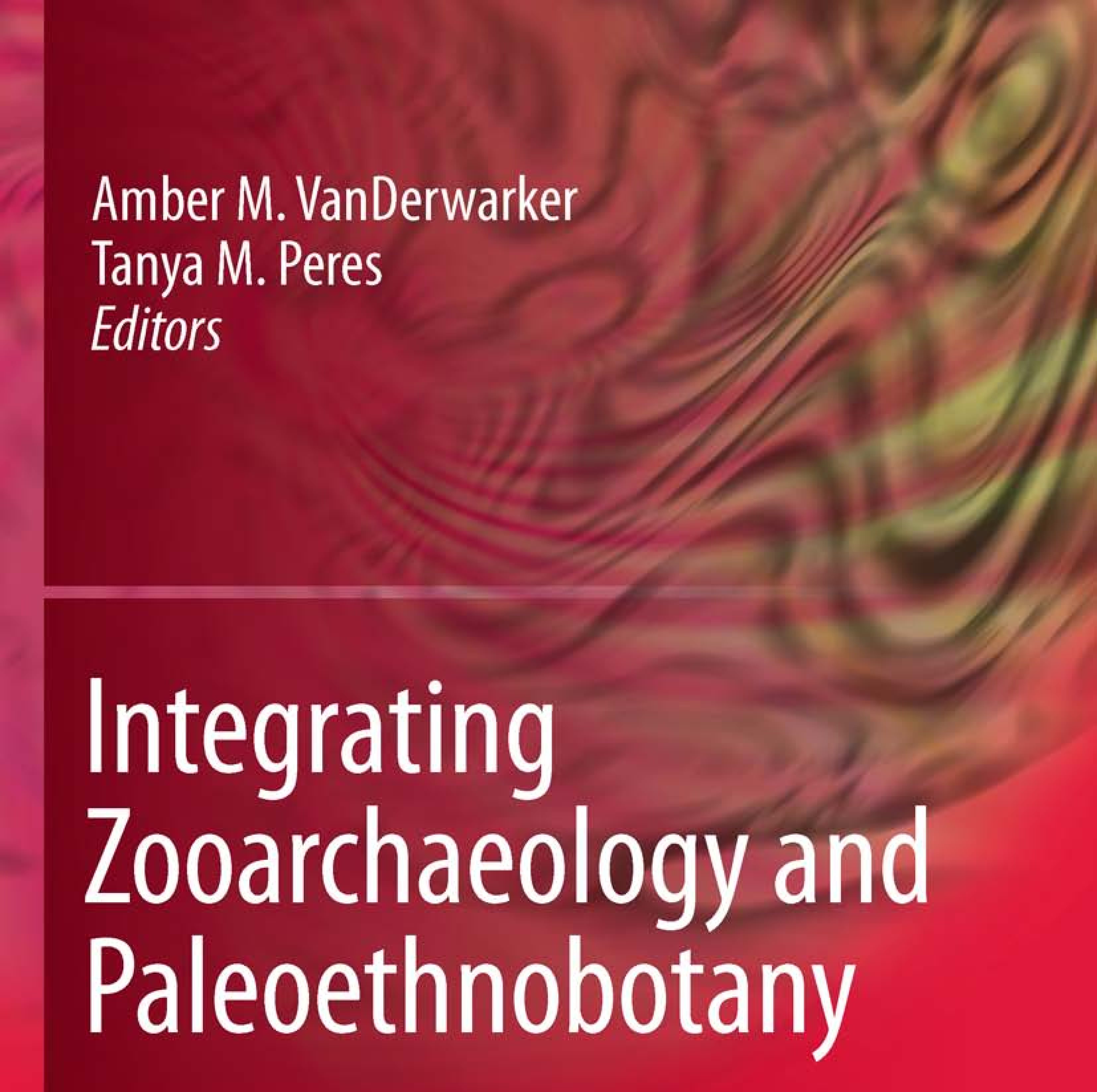

Amber M. VanDerwarker
Tanya M. Peres
Editors

Integrating Zooarchaeology and Paleoethnobotany

A Consideration of Issues, Methods, and Cases

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ISBN 978-1-4419-0934-3 e-ISBN 978-1-4419-0935-0
DOI 10.1007/978-1-4419-0935-0
Springer New York Dordrecht Heidelberg London

Library of Congress Control Number: 2009933116

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Acknowledgments

Numerous individuals and institutions played a part in the life of this volume. Funding for the original research at Tres Zapotes, Veracruz, which brought the co-editors together in the first place, was provided by a National Science Foundation Grant (BCS-0242555) to Dr. Christopher Pool, University of Kentucky. We would like to thank Chris for asking us to both be a part of the Tres Zapotes project and scheduling our brief, but significant, overlap at the TZ lab. We are thankful to our home institutions (University of California, Santa Barbara, and Middle Tennessee State University) for financial and professional support in bringing this volume to fruition.

We thank several anonymous reviewers for their comments and criticisms on both the original volume prospectus and the final set of chapters, in addition to various other colleagues who took the time to provide comments and reviews for the volume chapters, specifically Kate Spielmann, Margie Scarry, and Betsy Reitz. The editorial staff at Springer Press, namely Teresa Krauss and Katie Chabalko, have been extremely helpful and supportive throughout this process. We also acknowledge Dana Bardolph, who spent many hours patiently checking and formatting a dozen bibliographies.

We would be remiss if we did not thank the contributors to the original symposium and to this volume for their dedication, hard work, and endless patience. Finally, none of this would have been possible without the loving support of our families.

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Introduction

Amber M. VanDerwarker and Tanya M. Peres

We first met in 2004, a pivotal time in both our careers. We had both recently finished our PhD work (Peres in 2001 at the University of Florida, VanDerwarker in 2003 at the University of North Carolina), we were both actively searching for academic jobs, and we were both incredibly serious about holistic approaches to food and diet. We began our earnest conversation in the small village of Tres Zapotes, in southern Veracruz, Mexico, in one short week of overlapping travel schedules. We had both been invited to participate in the Tres Zapotes Archaeological Project by Dr. Christopher Pool (University of Kentucky), Tanya as the project zooarchaeologist and Amber as the project paleoethnobotanist. Our one week of overlap began a deep abiding friendship, a productive professional relationship, and laid the groundwork for the development and completion of this volume.

What began as a simple idea for integrating our own plant and animal datasets from Tres Zapotes transformed into a much broader and more varied approach to data integration. After much discussion, we decided to test the waters by organizing a symposium ("Quantitative Integration of Zooarchaeological and Archaeobotanical Data: A Consideration of Methods and Case Studies") for the 2006 Society for American Archaeology meetings in Puerto Rico. We solicited papers from a variety of respected scholars and organized a panel of ten presentations covering cases from around the world and dealing with a variety of methods. The panel was well attended and received a great deal of praise; one colleague stated that it was the most useful panel he attended while at the conference. Many colleagues approached us afterwards, voicing praise and emphasizing the need for more integrative studies. The positive feedback that we received following the presentations in 2006 confirmed our instincts to move forward with publishing this volume. Several of the original contributors are included in this volume, and

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_1,

several additional colleagues agreed to contribute to help round out the geographical and methodological breadth of the volume.

Integrating Zooarchaeology and Paleoethnobotany takes the lead in tackling the important issue of integrating subsistence data by addressing the methodological limitations of data integration, proposing new methods and innovative ways of using established methods, and highlighting case studies that successfully employ these methods to shed new light on ancient foodways. The volume challenges the perception that plant and animal foodways are distinct from one another and contends that the separation of the analysis of archaeological plant and animal remains sets up a false dichotomy between these portions of the diet. In advocating qualitative and quantitative data integration, our volume establishes a clear set of methods for (1) determining the suitability of data integration in any particular case, and (2) carrying out an integrated qualitative or quantitative approach. In addition to a focused methodological approach, *Integrating Zooarchaeology and Paleoethnobotany* transcends the traditional methodological text by presenting a series of case studies that operationalize integrative methods. Ultimately, we hope that this volume will highlight the depth of knowledge possible through integrating plant and animal data, and provide the subsistence-minded archaeologist with the tools to actually perform the integration.

1 A Consideration of Subsistence Data Integration

Understanding any subsistence system from an archaeological standpoint requires the integration of as many lines of evidence as possible. In recent years, scholars have emphasized the need for more holistic subsistence analyses, and collaborative publications towards this endeavor have become more numerous in the literature (see below). A survey of the literature, however, reveals relatively few attempts to *qualitatively* integrate zooarchaeological and paleoethnobotanical data, and even fewer attempts to *quantitatively* integrate these two types of subsistence evidence [but see Crane and Carr (1994), Smith and Egan (1990), and Spielmann and Angstadt-Leto (1996)]. Given the vastly different methods used in recovering and quantifying these data, not to mention their different preservational histories, it is no wonder that so few have tackled this problem.

This volume bridges the gap in the literature between zooarchaeological and paleoethnobotanical studies by presenting methods and cases for qualitatively and quantitatively integrating these seemingly disparate types of data. For our purposes, we make a distinction between *qualitative* integration and *quantitative* integration, in which quantitative-integrative measures are those that combine plant and animal data to create a single result. Qualitative-integrative measures, on the other hand, involve separate calculations for each data set, which are then compared in a qualitative fashion. There are many steps involved in arriving at a successful integration of archaeological plant and animal data which can be subsumed into three broad categories: (1) acknowledgement of the different taphonomic and recovery histories; (2) development of methods for integrating data; and (3) testing the interpretive value of any given method by implementing it within the context of a case study.

Before developing methods for integrating the archaeological plant and animal remains, it is imperative to first take stock of the current state of subsistence studies by acknowledging studies that have led the way in integrative research, as well as summarizing the methodological biases unique to paleoethnobotanical and zooarchaeological datasets. The literature review presented in this chapter sets the stage for the chapters that follow and provides a context for considering data integration more closely.

The review of the existing literature in identifying research incorporating both plant (specifically, macrobotanical) and animal data was extensive. The search was limited to published works, and thus site reports were excluded. Although site reports usually include information on both plant and animal remains, they tend to be descriptive, and it is rare that the individual paleoethnobotanical and zooarchaeological analysts attempt to interpret their datasets with respect to the other. Thus, the literature review focuses on problem-oriented research that goes beyond descriptive analysis. Extensive searches were conducted using several library databases and periodical indexes, in addition to consultation with subsistence-oriented colleagues. The final tally of publications which consider both datasets was 25.[1] Six presented plant and animal data as separate lines of evidence without quantitative analysis of either dataset (Bendremer 1999; Cartwright 1998; Martin and Parks 1994; Mbida et al. 2000; VanDerwarker and Detwiler 2000; Wetterstrom 1994); while 16 presented plant and animal data as separate lines of evidence with quantitative analysis of each dataset and a qualitative integration of the two (Bakels et al. 1992; Cooke et al. 1996; Di Lernia 2001; Fischer 1998; Jackson 1989; Kidder and Fritz 1993; Lovis et al. 2001; Moore et al. 1994; Newsom and Wing 2004; Pauketat et al. 2002; Reitz et al. 1985; Scarry and Reitz 2005; Sobolik 1994; VanDerwarker 2006; Walker et al. 2001); and three quantitatively integrated both datasets (Crane and Carr 1994; Smith and Egan 1990; Spielmann and Angstadt-Leto 1996), which are discussed in greater depth in "Simple Measures for Integrating Plant and Animal Remains" (see VanDerwarker, this volume).

1.1 Methodological Issues in the Analysis of Plant and Animal Data

Plant and animal assemblages each have unique preservational and taphonomic histories (see Peres, this volume; Wright, this volume). Although macro-plant remains can be preserved in uncarbonized form in some environmental contexts (see Miksicek 1987), these types of assemblages are rare. Most often paleoethnobotanical analysts deal with carbonized plant remains (but see Wright, this volume for discussion of preservation of microbotanical remains; see also Dickau, this volume). The process of carbonization, thus, serves as a filter which often excludes plant foods that are eaten raw and have fragile structures (e.g., tubers and greens) and under-represents plant foods that have small seeds or do not yield byproducts that can be used as fuel in hearth-fires (Scarry 1986).

In most cases, carbonized plant assemblages are biased towards wood fuel and food-processing by-products used secondarily as fuel [e.g., nutshell, maize (*Zea mays*) cobs/cupules]. Although this may bias our understanding of plant subsistence towards certain taxa, it is still possible to consider changes in the relative use of those taxa that are routinely recovered (Scarry 1986; Yarnell 1982).

Although animal assemblages are not filtered through the process of carbonization in the same way as plant assemblages are, they nevertheless represent biased datasets that do not completely reflect past animal subsistence. Rarely are animal flesh and other soft tissues preserved in archaeological contexts, and thus zooarchaeologists are usually left with assemblages composed entirely of the hard durable parts – bones, teeth, antler, and shell. Thus, whereas plant assemblages *are biased towards* food-processing byproducts, animal assemblages *are composed completely of* food-processing by-products. Moreover, preservation of bone varies both between and within taxonomic classes, often resulting in assemblages skewed towards large mammal remains (Lam et al. 1999; Lyman 1984, 1994; Nicholson 1996; Reitz and Wing 2008). Bones of large mammals are denser and thus preserve better than bones from smaller mammals or from other taxonomic classes; because they are large, large mammal bones also tend to fragment into more pieces than those of smaller animals, resulting in an inflation of their representation in terms of specimen counts (NISP) (Brain 1969; Lyman 1994; Reitz and Wing 2008; Watson 1972). As with plant data then, animal data are also biased towards the representation of certain species. While we cannot extrapolate the absolute representation of different animals in past diets using animal data, we can consider the changes in the relative importance of those species commonly recovered in archaeological samples (Grayson 1979; Reitz and Wing 2008). The challenge, thus, becomes one of getting the most out of what we have.

Our ability to consider differences in the relative contribution of commonly recovered plants and animals in space and/or time is contingent upon our ability to determine whether the plant and animal assemblages from different spaces and/or times have similar preservational histories. It would be problematic to compare two animal assemblages (or two plant assemblages, for that matter) from different contexts if they underwent vastly different taphonomic processes. A determination must first be made as to whether those assemblages are comparable. Zooarchaeology has made more strident advances in the area of taphonomy than has paleoethnobotany (but see Miksicek 1987; Wright 2003), and thus there are many established methods for examining the differential effects of taphonomy on different animal assemblages (e.g., extent of weathering, carnivore/rodent gnawing, and bone fragmentation) (see Andrews 1995; Bonnichsen 1989a, b; Irving et al. 1989; Lam et al. 2003; Lyman 1994; Lyman and Fox 1989; Marean 1991). If two (or more) animal assemblages yield similar rates of weathering, gnawing, and fragmentation, then there is a better basis for making valid comparisons.

Taphonomic issues in paleoethnobotany are restricted to mechanical damage that occurs post-carbonization (see also Wright, this volume). Carbonization effectively transforms plant material from organic matter into carbon, thus eliminating problems of differential preservation with respect to natural decay. Rates of fragmentation, however, increase with exposure to mechanical damage (e.g., trampling, repeated wetting/drying, and freezing/thawing), complicating our ability to identify taxa (Miksicek 1987; Wright 2003). The use of low-powered microscopes (10–40× magnification) in macrobotanical analysis helps to mitigate some problems of identification related to fragmentation. Some paleoethnobotanists deal with these issues by basing their analyses on the presence/absence of data (e.g., ubiquity analysis) (Godwin 1956; Hubbard, 1975, 1976, 1980; Popper 1988; Willcox 1974); others argue that if frequency data are standardized appropriately (e.g., by soil volume or plant weight), then relative comparisons between contexts and assemblages can be made (Miller 1988; Pearsall 2000; Scarry 1986; VanDerwarker 2006).

Plant and animal assemblages also differ in terms of recovery methods. Because of the (often) microscopic nature of plant remains, the only way to ensure adequate recovery is through the use of flotation techniques (Moeller 1982; C.E. Smith 1985; S.A. Smith 1977; Struever 1966; Wagner 1982; Watson 1976). Given the time constraints of most archaeological projects and the labor-intensive flotation methods used to recover plant remains, most archaeologists choose to take standard-sized samples of soil from features and contexts rather than attempt to float all excavated soil (see Pearsall 2000). Recovery of animal remains, on the other hand, is often restricted to materials recovered by screening soil through ¼-in. mesh, although zooarchaeologists are increasingly advocating the use of finer mesh sizes to ensure recovery of bones from smaller animals and elements (Gordon 1993; James 1997; Shaffer 1992; see also Peres, this volume). Zooarchaeologists are also increasingly incorporating animal remains from the heavy fraction component of flotation samples into their analyses as a means to assess size bias in screened samples (see Prevec 1985; Stahl 1996; VanDerwarker 2006). The decision whether to collect all animal remains from an excavation or to sample selected contexts, however, is more variable. It is often more feasible to screen all the soil from an excavation than to float it, so in many cases we end up with animal assemblages that represent nearly 100% recovery (minus what falls through the screen) and plant assemblages that represent less than a fraction of that. Thus, animal and plant assemblages have different levels of "representativeness" with respect to what was actually deposited and what is archaeologically recoverable.

Differences between plant and animal data in terms of preservation, recovery, and representation also structure the ways in which paleoethnobotanists and zooarchaeologists quantify their assemblages (please refer to chapters "On Methodological Issues in Zooarchaeology" and "On Methodological Issues in Paleoethnobotany" for a more complete discussion of quantitative measures). A consideration of quantitative issues with respect to these datasets is absolutely critical to any endeavor that seeks to integrate archaeological plants and animals. Common to both datasets is the tabulation of specimen counts and weights. This basic information, however, is used very differently in the calculation of secondary measures for animal and plant data. Zooarchaeologists use specimen counts (NISP) as the basis for estimating the minimum number of individuals (MNI) (see Reitz and Wing 2008; see also Peres, this volume). Both of these measures can be used to assess relative representation of different species or groups of species, although researchers differ in terms of their preferences for NISP or MNI (Bobrowsky 1982; Chaplin 1971; Grayson 1973, 1984; Perkins 1973; Ringrose 1993; Watson 1972). There is no MNI equivalent in paleoethnobotany as most carbonized plant remains do not lend themselves to this type of reconstruction. For example, it is difficult to estimate the minimum number of hickory (*Carya* spp.) nuts from a collection of different-sized shell fragments that lack diagnostic features. Instead, paleoethnobotanists measure the relative presence and abundance of plant species by calculating ubiquity measures and/or standardizing specimen counts against soil volume or plant weight (Godwin 1956; Hubbard 1975, 1976, 1980; Miller 1988; Pearsall 2000; Popper 1988; Scarry 1986; VanDerwarker 2006; Willcox 1974). Thus, the ultimate measures sought by zooarchaeologists and paleoethnobotanists produce quite different results and can hardly be considered comparable in any direct quantitative way.

So how are we to integrate these seemingly disparate types of data, each with its unique preservational history, recovery procedure, and quantitative methods? First, there must be some independent standard against which to compare integrated data to determine if the results of quantitative integration are meaningful. Thus, animal and plant datasets must be assessed and interpreted separately with respect to one another; this essentially represents the first step of integrating data, that of qualitative integration. In some cases, it is not feasible to move beyond this step. If the nature of the two datasets allows for quantitative integration (e.g., in terms of methodological comparability), then quantitative integration can be attempted. Once the datasets are combined, the analytic results can be compared to the independent analyses to determine the correspondence between the integrative results and the independent results (see also "Correspondence Analysis and Principal Components Analysis as Methods for Integrating Archaeological Plant and Animal Remains," VanDerwarker, this volume).

Secondly, issues of preservation and recovery must be thoroughly explored in the independent analyses of the data. For example, the animal assemblage must be assessed in terms of taphonomic bias. If comparing different spatial loci or time periods, are the different sub-assemblages comparable in terms of weathering, fragmentation, gnawing? If they are, then the analyst is fortunate indeed. If they are not, then the analyst's interpretive potential is more limited. Thus, the integration of plant and animal datasets is only as good as the independent analysis of each respective dataset. In other words, a successful integration of these data requires the same steps and caution as any independent analysis.

Thirdly, any *quantitative* integration should use measures that are feasible to both zooarchaeological and paleoethnobotanical analysis. In addition, data should be quantified in the same manner. For example, it would be inappropriate to combine an MNI measure with a ubiquity measure. Rather, quantitative integration should focus on more basic statistics collected by both analysts, such as specimen counts, weights, and presence/absence.

Finally, we should also consider what these two types of data have in common – both animal and plant remains represent byproducts of food preparation and consumption, as opposed to portions of food that were actually consumed by people. While these two datasets manifest some key differences, it is important that we also remember their fundamental similarities.

2 Organization of the Volume

We organize the volume into two main sections. The first major section consists of four chapters that deal with methodological issues surrounding the analysis of plant and animal data. The first two chapters discuss methodological issues of independent analyses of zooarchaeological ("On Methodological Issues in Zooarchaeology") and paleoethnobotanical ("On Methodological Issues in Paleoethnobotany") data, respectively; the first provides the zooarchaeological perspective, and the second provides the paleoethnobotanical perspective. Both chapters deal with issues of preservation, taphonomy, field recovery techniques, laboratory procedures, and basic quantification. The goal of these two chapters is to give the reader an overview of the analytical terms and method necessary to understand the case studies presented in Section II of this volume. Chapters "Simple Measures for Integrating Plant and Animal Remains" and "Correspondence Analysis and Principal Components Analysis as Methods for Integrating Archaelogical Plant and Animal Remains" present different methods for integrating zooarchaeological and paleoethnobotanical data; some of these techniques are qualitative and some are quantitative. Both chapters present case studies in order to demonstrate the effectiveness of the methods they propose, but the cases themselves are secondary to the methods under consideration.

The second section is composed entirely of case studies. Section II differs from the previous section in that the cases themselves are the primary interest; each case study employs a method of integration, but the method is embedded within the broader topical issues addressed within the case study. We feel that the distinction between Sections I and II, while subtle, is of utmost importance: Section I outlines the use of integrative methods and demonstrates how to use them in a particular case and Section II highlights the broader interpretive value of using integrative methods to address broader archaeological issues. This section begins with two chapters that use different lines of evidence to integrate subsistence data in new ways. "Microbotanical and Macrobotanical Evidence of Plant Use and the Transition to Agriculture in Panama" integrates both the macro- and microbotanical data from western and central Panama to investigate questions of plant use and the transition to agriculture. In "*Waitui Kei Vanua*: Interpreting Sea and Land Based Foodways in Fiji," Jones and Quinn use data derived from ethnoarchaeological, zooarchaeological, and stable isotope analyses to understand the social meaning of foodways in Fiji.

In "Integrated Contextual Approaches to Understanding Past Activities Using Plant and Animal Remains from Kala Uyuni, Lake Titicaca, Bolivia," Moore et al. use animal and plant remains from flotation samples recovered from Formative sites in Bolivia to study ritual and domestic contexts. They use ubiquity, volume density, and ranked scales of the intensity of burning in addition to experimental and ethnoarchaeological observations to link food remains with known behaviors. These data are then used to describe food processing activities in both the domestic and ritual spheres.

Taphonomic studies of two shell middens located on the western coast of Scotland, United Kingdom are the focus of "A Tale of Two Shell Middens:

The Natural Versus Cultural in 'Obanian' Deposits at Carding Mill Bay, Oban, Western Scotland." Through their study of zooarchaeological and paleoethnobotanical remains from these two sites, the authors are able to reconstruct the local envirionment, and discern selective use of resources such as firewood and large mammalian game animals.

In "Documenting Subsistence Change During the Pleistocene/Holocene Transition: Investigations of Paleoethnobotanical and Zooarchaeological Data from Dust Cave, Alabama," Hollenbach and Walker employ principal components analysis of plant and animal data to understand the subsistence shifts that correspond with major environmental changes. Their case study site is Dust Cave, Alabama, USA, and they focus on the period of the Pleistocene/Holocene transition. Using subsistence data from securely dated cave deposits affords Hollenbach and Walker the opportunity to explore changing subsistence strategies as practiced by foraging groups and how these strategies were influenced by a rapidly changing environment.

Ethnicity and everyday diet are two issues explored in Tóth, et al.'s case study from Hungary ("Plant and Animal Remains from an Ottoman Turkish Period Deposit in 16–17th Century Buda, Hungary"). The authors integrate data derived from zooarchaeological, paleoethnobotanical, artifactual, and textual sources to better understand the daily diet of an urban population living in the Ottoman Period city of Buda – the former capital of Hungary.

"The Farmed and the Hunted: Integrating Floral and Faunal Data from Tres Zapotes, Veracruz" addresses issues of differential access to foodstuffs based on status from the Formative site of Tres Zapotes, Veracruz, Mexico. Using principal components analysis to integrate the zooarchaeological and paleoethnobotanical data from distinct temporal and spatial contexts, the authors are able to highlight patterns in the integrated data that are not seen in the independent analyses.

The contributions in this volume use new and interesting methods to integrate zooarchaeological and paleoethnobotanical datasets, and thus allow us to gain a more holistic insight into subsistence strategies, customs, and processing techniques at various temporal, spatial, and social scales. While not every possible method or technique for quantitatively and qualitatively integrating plant and animal data sets are covered in this volume, the ones that are presented, tested, and showcased prove that moving beyond independent analyses of subsistence data allows for a more robust understanding of the past.

3 NOTES

1. There are undoubtedly more publications that integrate plant and animal data since the time of this writing, as well as some in non-English language books and journals.

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Part I
Issues and Methods for Integrating Data

Methodological Issues in Zooarchaeology

Tanya M. Peres

The main goal of zooarchaeology, as a specialty within archaeology, is to interpret human and environment interactions based primarily on the animal remains recovered from archaeological sites. This chapter is not meant to be a comprehensive text on zooarchaeology; rather it is a guide to some of the analytical methods and terminology that are used commonly by practitioners of zooarchaeology. While each researcher has her/his own way of analyzing and interpreting animal remains, some methods, terms, and analytical tools are considered standard. The purpose of this chapter is to give the reader an overview of basic methodological issues and applications within zooarchaeology. I acknowledge that not all the faunal remains recovered from archaeological sites are related to subsistence activities; however, as the chapters included in this volume are centered on discerning subsistence behaviors through the integration of multiple datasets, I focus more on subsistence practices here. This chapter addresses taphonomic and recovery issues as well as sampling and analytical methods to enable the reader to understand the case studies included in this volume (for a similar treatment of paleoethnobotanical remains, see Wright, this volume).

1 Why Study Zooarchaeology?

Animal remains can be used to inform us about a variety of issues in the study of societies, such as environment, seasonality, subsistence, hunting practices, political and social organization, settlement patterns, and resource-use. As a discipline, zooarchaeology has grown exponentially over the past three decades to include specialists working in dozens of countries on all aspects and time periods of human history (Hesse and Wapnish 1985). The formation and growth of the International Council

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_2,

for Archaeozoology (ICAZ), and the growing bibliography of papers, journals, textbooks, manuals, and CD-ROMs that deal with this topic attest to the strength and importance of this discipline. Zooarchaeology (and paleoethnobotany) is one of the few disciplines that crosscuts all cultural and temporal periods in the study of the human condition.

Knowledge of a group's subsistence is key to understanding the relationships between people and their environments, the technologies they create and use to exploit and modify their environments, as well as social and economic relationships amongst the people themselves. Different subsistence strategies reflect a variety of responses to human/environment interactions and human/human interactions. The animals that are represented in the archaeological record have been termed the "fossil assemblage" by Klein and Cruz-Uribe (1984:3), but those that are actually recovered during excavations are a sample of that, and are thus termed the "sample assemblage" (Klein and Cruz-Uribe 1984:3). The larger the sample assemblage recovered, the more robust the interpretation of human activities and choices.

The suite of taxa that are represented in the archaeological record can inform us about habitat exploitation, both in numerical terms (the number of habitats exploited) and in geographical terms (how far people traveled to obtain their food). This is not a straightforward issue, being closely related to the complexity of the human society and also to the ecological and geological history of the area under study. Which ecological niches are favored, and which are ignored? It is fundamental to determine the locations and social complexity of archaeological sites, which can aid in interpreting the importance of resources to human populations. For example, sites located immediately adjacent to rivers and estuaries are better positioned for the inhabitants to exploit these resources than groups located at a distance from the same habitats.

With regard to social complexity, we must take into account that not all citizens of a community procured food for themselves, but would have received foodstuffs via specialist producers, markets, exchange/trade, reciprocity, etc. Gumerman (1994:80) suggests that in more complex societies, such as the Chimu and Wanka of Peru and the Aztecs of Mexico, procurement is directly related to "the context of specialization, the intensity of production, and the personnel involved in production." A number of studies have shown that through analysis of data gathered at the household level, we can understand the differences in diet due to ethnicity, status, gender, or age (Crabtree 1990; Lyman 1987a; McKee 1987; Otto 1980; Peres 2008; Poe 1999, 2001; Reitz 1986, 1987; Reitz and Honerkamp 1983; Reitz et al. 2006; Reitz and Scarry 1985; Schulz and Gust 1983; Scott 2001; see also Peres et al., this volume).

The represented taxa, site location, and duration of occupation can further inform about the scheduling of seasonal resources (e.g., Russo 1991; Russo and Quitmyer 1996; Weinand et al. 2000; see also Bartosiewicz et al., Tóth et al., Hollenbach and R. Walker, all this volume). Procurement technologies such as fishing tackle, digging sticks, and storage items, may be inferred not only from the artifacts found in archaeological contexts, but also from the animal resources (represented taxa, quantity, and size) that were exploited (Kozuch 1993; K. Walker 2000; R. Walker et al. 2001). The presence of small animals in a zooarchaeological assemblage can, through the use of ethnographic analogy, inform us about the types of technologies needed to capture these animals (Cooke and Ranere 1999; Reitz and Wing 2008; Voorhies 2004; Zohar and Cooke 1997). Ethnographic analogy, coupled with archaeological data, also allows us to interpret food processing and food waste disposal behaviors (see also Jones and Quinn, Moore et al., both this volume).

Zooarchaeological remains aid in the interpretations of ancient resource choices, technological adaptations, cultural continuity, and settlement patterns. Thorough studies of human use of past environments must use multiple lines of evidence, the basis of environmental archaeology. Through the study of zooarchaeological data, specialized and utilitarian artifact assemblages, site locations and catchment areas, soils and topography, and stable isotope analysis of human skeletal remains, additional information can be obtained to strengthen or alter these interpretations. For instance, the use of stable isotope analysis of human bone collagen allows for the determination of the environmental origin of the protein resources eaten by an archaeological population. This type of analysis can also give information about continuity and variation in consumed resources through time, between populations, and within a population (Norr 1990; Pate 1992; Scarry and Reitz 2005; Schoeninger 1986; Schoeninger and Moore 1992; Schwarcz 1991; Tieszen 1991; van der Merwe 1989; see also Jones and Quinn, this volume). The study of seasonal-growth increments in the teeth of prey species (especially mammals) (Hillson 1986; Pike-Tay 1991; Pike-Tay and Knecht 1993; Weinand 2000), fish otoliths (Wheeler and Jones 1989), and invertebrates (Quitmyer et al. 1985; Quitmyer and Jones 1992; Quitmyer et al. 1997; Russo and Quitmyer 1996) can give us information about the season when a site was occupied, the scheduling of resource-use, and the age classes targeted.

2 Deposition and Preservation of Animal Remains

When analyzing and interpreting past human behaviors based on zooarchaeological samples, researchers must remember that sample size and preservation quality ultimately influence the outcome. Reitz and Wing (2008:157) state "all primary data are influenced by sample size...[the significance of which] is too frequently" overlooked "by generations of researchers." They, and others, warn that small sample size not only affects the range of taxa identified, but also negatively affects any secondary data derived from the identifications (Cannon 1999; Reitz and Wing 2008). Thus, analysts should do everything they can to ensure the study of large sample sizes, and project directors need to include zooarchaeologists at the earliest stages of planning the research design. Of course, there are samples that were previously excavated and are less than ideal in size, but can still be of value, especially if the site no longer exists and the collection is the only record we have of a group's presence on the planet. As researchers, we need to approach these samples with appropriate research questions, data collection methods, and an understanding of the biases affecting the samples, all of which affect the interpretations based on these samples.

2.1 Potential Sources of Bias in the Zooarchaeological Record

As researchers we must identify possible sources of bias to our scientific studies in order to best interpret past human behaviors. There are three types of biases common to zooarchaeological samples: (1) those resulting from socio-cultural beliefs and practices; (2) those introduced as a result of taphonomic history; and (3) those inadvertently introduced by the excavators and/or analysts. These biases form a continuum along the life span of an archaeological assemblage, from selection and deposition of food items by the consumers to the recovery of archaeological remains by the modern-day archaeologist. A number of authors have described these processes in great detail (see Hesse and Wapnish 1985; Lyman 1987b, 1994; Reitz and Wing 2008), and therefore they are reviewed briefly here.

2.1.1 Cultural Transformations: Collecting, Processing, and Disposal of Animal Resources

People selected certain animals and plants from the environment to be incorporated into their diet. Their belief systems, including social organization, food preferences, and taboos, would have defined the organisms included in (or excluded from) the diet (Cooke 1992; Gragson 1992). It is recognized that human groups choose to incorporate a relatively small part of the locally available foodstuffs into their diet; these choices may change on a daily, monthly, or annual basis. The mere absence of an animal from an assemblage does not imply avoidance; likewise, presence of an animal does not imply consumption. Interpreting the diet of human groups, using the presence or absence of animals as a criterion, can lead to a number of difficulties.

Specific food processing techniques, such as butchering, marrow extraction, bone grease rendering, roasting, salting and drying, among others, together with waste disposal patterns, determine which foodstuffs actually make it into the archaeological record (Alen and Ervynck 2005; Enloe 1993; Lyman 1994a; Mateos 2005; Noe-Nygaard 1977; Outram 2005; Saint-Germain 2005; Zohar and Cooke 1997). Areas may be specifically designated for disposal (e.g., kitchen middens) (Wandsnider 1997), or food remains may be scattered about a habitation area. If the purpose of one's research is to understand the environment, such socio-cultural beliefs and practices must be taken into account; but the faunal remains deposited at a site are only part of the larger picture. Once disposed of, remains of animals are acted upon by a score of taphonomic processes.

2.1.2 Taphonomic Processes Affecting Zooarchaeological Assemblages

Recovered faunal assemblages do not include all of the materials that were originally deposited. The taphonomic history, the sum of all conditions acting upon the remains of a dead animal, determines the extent of preservation of that animal in the archaeological record. Taphonomy was first defined by Efremov (1940) in relation to paleontological studies; archaeologists have taken this concept and applied it to the study of the archaeological record. At the very least, taphonomic studies and multiple lines of evidence can help us distinguish between deposits that are culturally deposited and those that are naturally accumulated (Nabergall-Luis 1990; Olsen 1989; Peres 1997; Peres and Carter 1999; Peres and Simons 2006). For example, through research of taphonomy, Nabergall-Luis (1990) has shown that many animals recovered from the Windover site, a well-preserved pre-Columbian cemetery in Florida, were part of a natural death assemblage, as were small animal remains analyzed by Peres (1997; Peres and Simons 2006) from the Pleistocene/Holocene transition site of Page-Ladson in the Panhandle of Florida.

Zooarchaeologists look to taphonomic processes to understand what has aided or inhibited a particular assemblage's preservation, and to gain a perception of what may have been lost. Taphonomic processes that can affect faunal assemblages include (but are not limited to): differential preservation, weathering, site inundation, erosion, redeposition, trampling, scavenging, human actions, soil pH, and plant intrusion (Davis 1987; Klein and Cruz-Uribe 1984; Lyman 1994a; Nabergall-Luis 1990; Peres 1997; Reitz and Wing 2008). It is important to understand the factors that affected a faunal assemblage so that we can better interpret the history of the assemblage and how we ended up with any given sample. Indeed, Lyman (1994a:464) notes: "we can say much about *what* happened to an assemblage…and *how* it happened" (emphasis in the original).

Probably the single-most important non-cultural taphonomic process that operates on a faunal assemblage is differential preservation. Faunal remains can be well-preserved, poorly preserved, or only slightly altered depending on the mode of death (Lyman 1994a:115), specific osteological characteristics (Lyman 1994a:234–258), and the conditions of the surrounding environment (Lyman 1994a:138–139, 146, 358–360). Osteological characteristics can include chemical composition (bone vs. shell), relative maturity and size of the individual, diagnostic landmarks, bone density, and friability. Some environmental conditions that affect preservation are soil acidity, climate, geographical location, and the matrix from which the remains were recovered.

The type of deposit and the geographical location of the deposit will determine which taphonomic processes will be most destructive or preservative. In general, taphonomic processes that must be considered include soil pH, erosion, weathering, and disturbance/dispersal by non-human scavengers. When there is very little evidence of destructive taphonomic processes, the sample assemblage will be a close approximation of the deposited assemblage (Klein and Cruz-Uribe 1984; Dixon 2004; Miller et al. 1998). Conversely if a sample assemblage is poorly preserved, has a high degree of non-cultural fragmentation, and has undergone diagenesis the deposited assemblage is less likely to be represented in its entirety (Klein and Cruz-Uribe 1984).

The conditions of the surrounding site matrix are important in understanding the preservational history of animal remains. While Reitz and Wing (2008:141) urge taphonomists to conduct further research into the effects of soil pH on faunal remains, we do have a basic understanding of this taphonomic agent. Bones are best preserved when the soil has a pH of 7.8–7.9 (Reitz and Wing 2008:141). When pH values rise above 8 (alkaline soils), bone mineral dissolves at higher rates (Linse 1992). When soils become acidic (below 7), greater bone destruction takes place for every degree below neutral (Gordon and Buikstra 1981). Even with less than perfect soil conditions, animal remains decompose differentially. Elements that are not as calcified, such as those from subadults, are the least likely to survive, while adult mammal teeth, due to the presence of enamel, are the most likely to survive (Reitz and Wing 2008). The unprecedented preservation of the zooarchaeological and paleoethnobotanical assemblage recovered from the Oakbank Crannog site in Loch Tay, Scotland, is due to the cold loch waters and peat silt of the loch floor. The preserved organic remains, including plants, seeds, nuts, insects, animal bones, and droppings, number in the cubic tons and provide valuable information about past lifeways and the paleoenvironment of Loch Tay (Dixon 2004:130; Miller et al. 1998). The excellent preservation of organic remains has resulted in a catalog of wooden artifacts ranging from house timbers, fruit seeds, bowls and plates to a dish with butter still adhered to the surface, as well as numerous animal remains that indicate the roles of animals in the subsistence economy of this site (Dixon 2004:146–151; Dixon and Peres 2008).

Zooarchaeological samples that are recovered from shell midden or shell mound sites tend to exhibit a high degree of preservation (Linse 1992). Scudder (1996) has shown that the median soil pH value (7.8) in an Archaic shell midden in southwest Florida is favorable to the preservation of vertebrate and invertebrate remains. Mollusk remains recovered from the Estero Island Site in Florida, and currently undergoing identification by Peres, appear to have undergone rapid deposition with little post-depositional disturbance, exposure, or weathering. This is evidenced by the intact exterior and interior colors and bands on many of the gastropods (especially Florida crown conch, *Melongena corona*). Additionally, even the smallest of vertebrate remains (e.g., Osteichthyes) are well-preserved in shell matrix sites, and easily recovered with small mesh sizes (Peres 2001).

The above should not be viewed as inclusive of all of the taphonomic factors that can affect a given assemblage. Most zooarchaeologists do not, and I am not sure that they should, strive to build a complete taphonomic history of every assemblage in their laboratory. Each assemblage should be evaluated taphonomically in light of the research objectives laid out in the research design. The proper curation of zooarchaeological collections allows them to be studied as new research questions and techniques develop.

2.1.3 Biases of Our Own Making

Appropriate measures must be taken by the archaeologist to limit the extent of excavator bias. The principal investigator, if different from the zooarchaeologist, should consult with the analyst when devising and implementing the research design for an excavation. This will ensure that the optimum methods and techniques are used in the recovery of faunal remains. Too often this has not been the case, and the specialist is sent a box of bones and asked to produce a species list, although this is becoming less common. It is imperative for the zooarchaeologist to know the recovery methods; the origin of the sample (i.e., surface collection vs. feature excavation); the field crew's ability to recognize faunal remains during excavation and screening; where the sample was separated (field vs. laboratory); and by whom the sample was separated (i.e., an individual or several people). This information is needed by the analyst to understand possible sources of bias, and to decide which types of information can be provided by the sample. Unfortunately, our ability to answer pertinent research questions is constrained by samples that are often recovered with inadequate strategies and methods. The importance of consultation with a zooarchaeologist during the project planning stages cannot be over-emphasized.

3 Recovery Methods

> Animal remains are often small and fragile and plant remains are even more so, requiring great care in their recovery and subsequent handling…Because archaeological sites are nonrenewable resources, it is our obligation to recover biological and cultural remains as carefully and thoroughly as possible and to preserve them for study. (Lee A. Newsom and Elizabeth S. Wing 2004 *On Land and Sea*, pp. 36 and 42)

If you are reading this chapter or volume, you are likely to be someone who is interested in the study of past environments and subsistence strategies. You may already know from experience that zooarchaeologists are not consulted often enough when it comes to research design and sample recovery strategy. While there is nothing we can do to compensate for first-order changes (those resulting from past decisions that we in the present have no control over), we must be more assertive in voicing our analytical needs when dealing with project directors. As Reitz and Wing (2008:146) emphasize:

> Advice from people trained in the recovery and study of geological and biological remains allows for better understanding of the excavation strategies by the entire archaeological team and permits assistance by the specialists on recovery methods during the field season.

The decisions made by the archaeologist on sampling and recovery procedures directly affect the type, quality, and quantity of samples available to zooarchaeologists. This in turn affects the types of research questions we can and cannot answer with any given sample. As Reitz et al. (2008:10) note: "Our ability to explore significant questions is influenced by the confidence we have that the material was competently recovered and accurately identified."

3.1 Standard Recovery with Mesh Screens

Choice of recovery method is usually based on two principles: (1) the research objective and (2) the sampling strategy. Of course, these are not independent of one another as the research objectives inform the sampling strategy (i.e., test units, column samples, bulk samples, etc.). In the past, and even in the present, we often deal with research plans that are focused on the recovery of artifacts important to the cultural and temporal association of a site. The standard recovery method at most archaeological sites involves dry-screening excavated soils through 1/4 inch (6.35 mm) hardware mesh. This is especially true when samples are recovered during the excavation of test units using arbitrary levels. This strategy has proven sufficient for the recovery of pottery and lithics, the artifact classes that form the basis of site chronologies. This recovery strategy is used in most places where archaeologists trained in the United States have extended their research efforts. Newsom and Wing (2004:42) note that archaeologists working in the West Indies have shifted their research objectives from cultural chronology to environmental manipulation by humans, which has led to a corresponding change in sampling and recovery strategies, particularly a shift towards the use of smaller mesh sizes.

When reconstruction of subsistence strategies and/or paleoenvironments is the main research objective, archaeologists approach features and middens with a slightly modified recovery plan that can include any, or a combination, of the following:

- Excavation of half of a feature that is dry-screened through 1/4 in. mesh
- Excavation of half of a feature that is dry-screened through 1/8 in. mesh
- Water-screening of half or all of the feature through 1/8 in. (3 mm) or 1/16 in. (1.5 mm) mesh
- Excavation of the entire feature and artifacts recovered using a flotation strategy
- Bulk sampling or column sampling, especially within middens
- Resulting samples screened through nested geological sieves

Any and all of these methods can yield adequate sample sizes for the study of paleoeconomies and paleoenvironments, but it is important that the method (or combination of methods) chosen is done so explicitly under the guidance of a trained subsistence specialist, and is carried out systematically.

A number of studies have been carried out to test the efficacy of recovery methods (Clason and Prummel 1977; Cooke and Ranere 1999; Cumbaa 1973; Gordon 1993; Payne 1972; Peres 2001; Shaffer 1992; Shaffer and Sanchez 1994; Wing and Quitmyer 1985). These experiments show that a decrease in the screen-size used for the recovery of faunal remains results in an increase in the quantity of material and variety of taxa recovered. The use of larger mesh sizes (1/2 in. and 1/4 in.) biases the recovered sample towards larger animals (generally mammals), which can result in a skewed picture of the relative abundance and importance of one class of animals compared to another. The use of 1/8 in. and 1/16 in. meshes allows for a more complete recovery of small, delicate animal remains (i.e., small fishes, shrimp mandibles [*Penaeus* sp.]). These small remains can give us information about the environmental setting of the site during and after occupation, subsistence and technology, and site formation processes (Reitz and Wing 2008:148). Additionally, the standardized use of smaller mesh sizes for the collection of animal remains allows environmental archaeologists to more readily integrate their datasets both quantitatively and qualitatively (as can be seen in case studies throughout this volume).

To highlight the importance of smaller screen sizes in the recovery of smaller taxa, Peres (2001) initiated an experiment using the vertebrate faunal remains from a 50 cm-x-50 cm column sample at the Early Ceramic site of Zapotal in Panama. The soil from each level was screened through nested 1/4 in. and 1/8 in. mesh box-screens. The faunal remains from each screen were then sorted into taxonomic classes (e.g., mammals, birds, reptiles), counted, and weighed. In the most dramatic case, a 5309% increase in quantity of faunal remains from one level was noted between 1/4 in. ($n=53$) and 1/8 in. ($n=2{,}814$) meshes (Peres 2001:Table 4.1). The results of this experiment support the argument that the use of finer mesh screens during recovery of faunal remains greatly increases the overall abundance. For some levels, certain taxa would not have been represented at all. For example, the bony fishes would have been underestimated in the number of taxa and overall abundance in the entire assemblage (1/4 in., $n=224$; 1/8 in., $n=12{,}893$). This example shows that using small mesh sizes was an effective recovery strategy for the research questions being asked at Zapotal, and should be considered when devising a recovery strategy during the excavation of all archaeological sites.

3.2 Indirect Evidence of Animal Use in the Archaeological Record

Thus far, I have described techniques for the retrieval of subsistence remains from sediments which are by no means the only source of these artifacts. We can infer past animal use through evidence from extracted collagen and apatite from human bone (Cooke et al. 1996; Norr 1990; Pate 1992; see also Jones and Quinn, this volume), tools related to subsistence activities (i.e., spear points, fish hooks) (e.g., K. Walker 2000), microscopic analysis of residues on ceramic sherds and stone tools (Burgio et al. 1997; Olsson and Isaksson 2008; Smith and Clark 2004); and elemental analysis of sediments (Hjulström and Isaksson 2009). European researchers have shown that the use of Raman microscopy to analyze fragile and perishable ancient materials is ideal because it is reliable, sensitive, and non-destructive in nature (Burgio et al. 1997; Smith and Clark 2004). By taking advantage of the technology available today, archaeologists can look for evidence of past lifeways on a microscopic level, which is extremely important when there is no readily discernible evidence for resource use via traditional artifact classes and analytical methods. For an instructional discussion of different recovery techniques within zooarchaeology, including the positive and negatives of each, the reader is directed to Reitz and Wing (2008:146–150).

4 Specimen Identification and Analytical Methods

A primary objective of any zooarchaeological analysis is to identify as completely as possible all of the represented taxa in a given sample. While care should be taken at all levels of identification, analysis, and interpretation, nowhere is it more important than during the identification stage. O'Connor (2000:39) argues that zooarchaeologists record taxonomic "attributions," meaning "this bone is attributed to white-tailed deer" and not "this bone came from the body of an *Odocoileus virginianus* and cannot be any other animal." Regardless of the terminology used for this stage (i.e., identify vs. attribute), all other units of data are dependent on this first step. The identification of animal remains will only be as good as the skill-level of the analyst and the completeness of the modern comparative osteological collections. Analysts need to secure access to comparative collections and/or collect (and macerate when necessary) modern specimens before they begin their analyses. Several archaeologists have previously distinguished between primary data collection and secondary data derivation (see Clason 1972; Lyman 1994b; Reitz and Wing 2008). These two data categories (primary and secondary) and the types of data recorded in each are discussed in detail below.

4.1 Primary Data Collection

Primary data are the building blocks of all zooarchaeological analyses. The non-quantitative part of primary data includes taxonomic identification; element representation including complete/incomplete portion, anatomical position, etc.; cultural modifications (i.e., cut marks, spiral fractures) and noncultural modifications (i.e., scavenger gnawing); thermal alteration; description of epiphyseal fusion, tooth eruption or wear, and presence of sex indicators (i.e., baculum, medullary bone). Typically, quantitative primary data include specimen counts and weights (see below).

4.1.1 Non-quantitative Primary Data: Identifications of Animal Taxa

Generally, zooarchaeological remains are given to the zooarchaeologist as an assemblage, pre-sorted from the rest of the artifacts. It is important for the analyst to know who did the sorting (and his/her respective skill-level, knowledge, and experience with zooarchaeological materials), where it was performed (field or laboratory), whether the artifacts were washed prior to sorting, and what criteria were used in the sorting (e.g., only elements identifiable by the sorter as animal, etc.). In my experience, the initial sorting of faunal remains into classes often results in the inclusion of a variety of unmodified rocks, lithics, and ceramic artifacts. This always makes me wonder how many and what kinds of faunal remains were left with the other artifact classes (i.e., fish otoliths mixed in with ceramic sherds). Once all of the bags of faunal remains have been sorted, it is good practice to send the nonfaunal artifacts back to the project director and ask for any additional faunal remains to be sent along. Remember, the archaeological assemblage is inherently biased from the start; thus, all attempts must be made to acquire as complete a sample as possible.

The identification and analysis of faunal remains typically follows standard zooarchaeological procedures as set out in Reitz and Wing (2008). Analysis and identification begins with a general rough sort of fauna into classes (Mammalia, Aves, Amphibia, Reptilia, Actinopterygii, Chondrichthyes, Gastropoda, Bivalvia, etc.) within each provenience. Using reference manuals (which should never take the place of a modern osteological comparative collection) and a modern reference collection, remains can then be identified to the lowest taxonomic level (i.e., Family, *Genus, species*). All specimens are identified to *Genus* and *species* when possible, keeping in mind the geographical location of the site so as not to identify a western squirrel in the Eastern woodlands. When this is not practical, the most specific taxonomic classification possible is assigned. In some cases specimens may be identified with "cf." (from the Latin *confere*) before the taxonomic identification (Reitz and Wing 2008:36). In such cases the identification of a specimen is not completely secure, but the specimen compares well with a particular taxon. In addition, it is not always possible to assign a specimen to a species, even if it can be assigned to a genus. In these cases, "sp." is used for species, and "spp." is used if there is more than one species possible (Reitz and Wing 2008:36). In securing identification of taxa, zooarchaeologists should err on the conservative side. Reitz and Wing (2008:164) stress that "specimens should be identified to a particular taxon only if they can be unquestionably assigned to it on the basis of morphological features found through comparison with reference specimens after all other possible attributions are excluded by the same procedure."

In addition to taxonomic identifications, zooarchaeologists also identify skeletal elements/body parts. This involves identifying the specific element (i.e., femur) or element type (i.e., molar) of a given taxon. These are then sided (i.e., left, right) where appropriate. In addition, if the elements are not complete, a description of the portion or fragment is given (i.e., distal humerus, medial scapula). Reitz and Wing (2008:161–164) offer an in-depth discussion of methods for describing specimens in greater detail; for a discussion of cranial fragment categorization, see Hesse and Wapnish (1985:73–74). Data on element representation and fragmentation can lead to interpretations about cultural modifications, taphonomic processes, skeletal part-use, butchery practices, feasting, status, and social structure. Thus, it is important, when time and funding allow, to record as much detail about element representation as possible.

Other types of information that are routinely recorded include evidence of use-wear, thermal alteration, modification, butchering, animal gnawing, and weathering. Whenever possible, age markers of animals should be recorded (i.e., tooth eruption, epiphyseal fusion), and if elements or markers for sex determination are present, these should also be recorded (i.e., a *Canis familiaris* baculum indicates a male dog).

4.2 Quantifying Zooarchaeological Samples

Measuring relative abundance is one of the zooarchaeologist's principle objectives in the collection and quantification of faunal remains. Relative abundance estimates can inform about the importance of particular animals to the diet of a group, change in animal exploitation through time, differences in diet due to status and regional differences (Jackson and Scott 2003; Kirch and O'Day 2003; Klippel 2001; Peres 2001, 2008; VanDerwarker 2006; Walker et al. 2001). Arguments have been made both for and against particular quantification tools, with a common consensus that there is no perfect strategy (Grayson 1984; Jackson 1989; Nichol and Wild 1984; Reitz and Wing 2008). Data should be quantified using tools that will yield the most information from the assemblage. Both primary data (counts and weights) and secondary data (biomass, MNI estimates, and species diversity and equitability) can be used to measure relative abundance in a zooarchaeological sample.

4.2.1 Quantitative Primary Data: Number of Identified Specimens

Quantifying zooarchaeological remains has been, and remains, the keystone upon which all other quantification and statistical analyses of assemblages are based. Taxonomic identifications and specimen counts are the two basic pieces of data that all zooarchaeological analyses should include. The Number of Identified Specimens (NISP), also referred to as count, is the basic quantification unit in zooarchaeological analyses. Each individual bone, tooth, shell, antler, horn, or scale (including complete, partial, and fragmented) is counted as a single unit, regardless of the level of taxonomic identification. Klein and Cruz-Uribe (1984:25) point out two benefits of using NISP: (1) it is calculated during identification, thus it is a basic unit of data and does not need to be further manipulated to have meaning; and (2) "NISP values are additive," meaning the NISP for a given taxon within a given provenience can be readily updated with subsequent excavations or analyses by adding the original number with the new number.

While NISP is the most basic unit of data, it is not without problems. Differential fragmentation is an issue that can result in the overestimation of particular taxa. Some animals have certain skeletal elements that are easily identified more than other animals. For example, pig (*Sus scrofa*) molars are readily identifiable to species even when highly fragmented, allowing for their counts and weights to be recorded as species-specific (Peres 2008). Compare this with the teeth from medium-sized carnivores, which, when fragmented, may only be identified to family or even class. In this instance, pigs would be potentially over-represented when compared to medium-sized carnivores. Additionally, bones of larger animals (typically mammals) are denser, and thus tend to preserve better than the light gracile bones of birds (Lyman 1987b, 1994a; Reitz and Wing 2008).

Reitz and Wing (2008:167–168) provide an indepth discussion on what to count and what not to count, how to deal with crossmends and those specimens that are assigned to more general taxonomic categories (i.e., indeterminate vertebrate). In his synthesizing 1984 work, *Quantitative Zooarchaeology*, Donald Grayson defines the basic means of quantifying faunal samples (NISP) and discusses the extent to which NISP and the more derivative Minimum Number of Individuals (see below) should be used as quantitative measures. Regardless of the method used, Klein and

Cruz-Uribe's warning should be heeded, and count should not be used as the "sole index of species abundance" (Klein and Cruz-Uribe 1984:25).

4.2.2 Quantitative Primary Data: Weights

The recording of the weight (in grams or kilograms) of bone, teeth, antler, otoliths, and shell from archaeological sites is a common practice. This data class is important for several reasons: (1) like NISP, as a basic unit of data it does not need further manipulation to have meaning; (2) it can be used to measure the relative importance of a taxon within an assemblage; and (3) it is the basis for some secondary data measures. There are problems with using sample weights to make substantial interpretations. One of these is the issue of taxa representation and size. Larger animals weigh more than smaller ones; thus if weight is used as a relative measure of abundance, the interpretations will always be biased towards large animals. In addition, this unit of measurement does not compensate for the effects of weathering or thermal alteration on specimen weight. Just as count should not be the "sole index of species abundance" (Klein and Cruz-Uribe1984:25), neither should weight be.

4.2.3 Quantitative Secondary Data: Minimum Number of Individuals

Building on the primary data categories of taxonomic identification, element identification and representation, count, sex, and age, the Minimum Number of Individuals (MNI) can be estimated. MNI is basically the smallest (hence, minimum) quantity of individual animals needed to account for all of the specimens identified to a particular taxon. MNI is widely used by zooarchaeologists and has resulted in the adoption of a variety of techniques (see Reitz and Wing 2008:205–210 for a review of these). I estimate MNI based on the procedure outlined by White (1953) and used by Reitz and Wing (2008). What I consider to be the standard accepted procedure involves using the most abundant diagnostic element of each taxon (Grayson 1984; Reitz and Wing 2008). If this element is paired (left and right), then the higher count of the two is used. Differences in size and degree of epiphyseal fusion are also taken into account when appropriate. Whichever method is chosen, it needs to be explicitly stated in the methods portion of any zooarchaeological report, article, or chapter, and used consistently within an assemblage. As with taxonomic identifications, MNI estimates should be replicable.

4.2.4 Quantitative Secondary Data: Biomass

One area of research in zooarchaeology is the study of the dietary contributions of animals identified in a given faunal assemblage. A number of methods for estimating dietary contributions have been developed, assessed, and modified over the years (e.g., Casteel 1974, 1978; Chaplain 1971; Grayson 1973, 1979; Lyman 1979;

Parmalee 1965; Reitz and Wing 2008; Smith 1975; Stewart and Stahl 1977; White 1953; Wing and Brown 1979). However, the one method that provides information on the quantity of biomass from the materials recovered (sample biomass) is used here. This method is preferred, as it is not based on assumptions of what parts of an animal were considered edible or inedible in the past; rather it is based on a biological relationship that holds true for all organisms over time (Reitz and Wing 2008:239). Thus, all invertebrate and vertebrate specimens identified in an assemblage can be included in dietary contribution estimates.

Sample biomass refers to the estimated total weight represented by the archaeological specimen (Reitz and Wing 2008). Sample biomass estimates are calculated using specimen weights and the regression formula described below. The biomass of an animal is calculated using correlation data between skeletal weight and total body weight (Casteel 1974; Reitz et al. 1987; Reitz and Wing 2008). These data are collected from modern animals for application to biomass estimates. For most faunal assemblages, biomass can be estimated using specimen weight in the following allometric formula (Reitz and Wing 2008:236):

$$Y = aX^b$$

or

$$\log_{10} Y = \log_{10} a + b\ (\log_{10} X)$$

where:

Y = the estimated sample biomass (kg) contributed by the archaeological specimen(s) for a taxon

X = specimen weight of the archaeological specimens for a taxon
a = the Y-intercept of the linear regression line
b = slope of the regression line

To calculate biomass, several values that are class or species dependent are needed. General biomass estimates can be calculated using values from Reitz and Wing (2008:68) and Wing (2001). General class and/or family values should be used in cases where values for specific taxa are not available.

4.2.5 Quantitative Secondary Data: Skeletal Allometry

Allometry is another method to estimate the total body weight of an animal, and is based on the log–log relationship that exists between the dimensions of supportive tissue and total body weight (Anderson et al. 1979; Reitz and Cordier 1983; Reitz et al. 1987; Reitz and Wing 2008). Dimensional allometry is the log–log relationship of the linear dimension of weight-bearing elements and total body weights. Measurements for certain skeletal elements correlate well with body weight and therefore are frequently used. For teleost fishes, the atlas vertebra is a frequently measured element. The atlas vertebra is measured at its widest point, following Reitz and Wing (2008). This measurement can then be used with the biomass formula to calculate the live weights of individual fishes (Y = total weight (gm); X = width of teleost atlas (mm); a = Y-intercept; b = slope).

Allometric data and corresponding weights can be used to infer cohort age or the stage in the life cycle that is represented for an individual taxon. This in turn can inform about the environment that was exploited as well as procurement technologies that were used. The reader is referred to Reitz and Wing (2008:237–242) for an indepth explanation of the various methods used to estimate dietary contributions of animals based on allometry.

4.2.6 Quantitative Secondary Data: Species Diversity for Animals

Ecologists in the second half of the twentieth century have spent much time attempting to explain the multiplicity of Earth's species by comparing the species diversity of different habitats (Colinvaux 1986:650). Colinvaux (1986:650–652) has outlined a number of difficulties or complications in determining species diversity. Objective measures are needed to compare the diversity of different habitats, but these measures have proven difficult to devise, as it is difficult to know which group of species to measure in a sample (e.g., piscivores, pelecypods). This difficulty is compounded in archaeological samples by the fact that, by their very nature, they are not complete representatives of past environments. Another complication with species diversity research is that population sizes vary by location. To overcome the problem of variability, ecologists calculate both *species richness* and *equitability*. Species richness is the actual number of species present in a sample or community. Equitability is the differing relative abundance of each species; a more detailed definition is "the relative evenness of the numerical importance of a species in a sample" (Colinvaux 1986:650). A third difficulty is that no single index measures both richness and equitability. There are several indices that have been used and can be applied to different studies (Colinvaux 1986:651). The best diversity indices are those that express heterogeneity by combining both species richness and equitability (Cole 1994:89).

Zooarchaeologists frequently use the Shannon-Weaver function (sometimes referred to as the Shannon-Weiner function) to address issues of diversity. The formula is:

$$H' = -\Sigma (p_i)\,(\mathrm{Log}_{10}\, p_i)$$

where:

H' = information content of the sample (can be biomass, MNI, etc.)
p_i = the relative abundance of the *i*th taxon within the sample
Log p_i = the logarithm of p_i. This can be to the base 2, e, or 10.

By using the Shannon-Weaver function, assemblages with an even distribution of abundance between taxa have a higher diversity than samples with the same number of taxa, but with less even distribution of these taxa. Samples that have a high number of taxonomic categories and a similar degree of equitability have greater diversity values (Reitz and Wing 2008:110–113; see also VanDerwarker, this volume).

A second approach to sample diversity is one which looks at the number of taxa that are expected for a particular sample size, thus allowing us to control the potential bias of sample size. It is reasonable to assume that larger assemblages (in terms of NISP) tend to contain a richer composition of taxa than smaller assemblages (Baxter 2001; Kintigh 1989; Reitz 1987; Rhode 1988). It should not be assumed that larger assemblages with more taxa are more diverse than smaller assemblages with fewer taxa, as richness and equitability may be functions of sample size. To overcome the possibility that sample size biases interpretations of diversity within faunal assemblages, the statistical program DIVERS can be employed (Kintigh 1984, 1989, 1991). The DIVERS program compares the diversities of different assemblages to themselves, based on the expectations for diversity, given the sample sizes. The assemblages are then compared not to each other, but to the expected diversity for a sample of a given size (Kintigh 1984). This allows researchers to bypass the issue of sample size differences completely. The actual values are then plotted against sample size with a 90% confidence interval that is based on the expected values. Values that plot above the confidence interval are more diverse than expected, while values that plot below the confidence interval are less diverse than expected.

5 Summary and Conclusions

Interpretations of zooarchaeological assemblages demand a consideration of a number of criteria. Analysts must be aware of factors, such as sample bias caused by taphonomic conditions and recovery techniques. Of critical importance to any analysis of faunal remains is a concentrated effort to completely recover materials, to take detailed notes on their context(s), and to understand the nature of their associations. This information assists the zooarchaeologist in interpreting the remains in relation to human subsistence strategies (including diet, requisite technology, procurement, processing, and modification) and achieving an understanding of the past environment. Zooarchaeologists need to be included in the planning stages of all archaeological projects, including academic, research, and salvage. It is important for the zooarchaeologist to know the research objectives, the sampling and recovery methods used, the skill level of the field and laboratory crew, and the cultural contexts of the remains. These data are necessary so that we can determine the possible sources of bias, and structure our analysis and interpretations accordingly.

Acknowledgments The Department of Sociology and Anthropology at Middle Tennessee State University provided support during the research and writing of this chapter. I am grateful to Betsy Reitz, Renee Walker, and Amber VanDerwarker for helpful comments on earlier drafts of this chapter. Any omissions or errors, however, are mine.

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Methodological Issues in Paleoethnobotany: A Consideration of Issues, Methods, and Cases

Patti J. Wright

This chapter summarizes the current perspectives on paleoethnobotany, and the methods and techniques involved in the analysis of archaeological plant remains. The topic is not new, and for nearly three quarters of a century, paleoethnobotanists have not only contributed substantially to a broad range of archaeological questions, but have also compiled detailed guides and summaries of state-of-the-art recovery techniques and laboratory analyses. What is new are the more careful and explicit treatments of the processes that have led to the formation of the paleoethnobotanical record. These processes – or what can be thought of as additional variables – are the subject of field tests and laboratory experiments that have been conducted around the world. Because understanding these processes can contribute to the advancement of paleoethnobotany and are essential to attempts at integrating information derived from plant and animal assemblages, they drive much of the discussions in the pages that come up later (for similar treatment of zooarchaeological remains, see Peres, this volume).

1 Why Study Paleoethnobotany?

The aim of archaeology is to learn about past human behavior through material evidence. The analysis of plant remains from archaeological contexts has facilitated that aim since the days when Kunth (1826) described the botanical traces from ancient Egypt, and Heer (1866, 1865) provided lists of vegetable foods used by the so-called Swiss-Lake Dwellers. These kinds of studies – investigating human–plant interrelationships – became more formalized when, in 1941, Jones published "The Nature and Status of Ethnobotany." The analysis and interpretation of archaeologically derived plant remains, or "paleoethnobotany" as defined by Hastorf and

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_3, © Springer Science+Business Media, LLC 2010

Popper (1988:2), burgeoned in the 1970s as systematic recovery techniques became common. Today, paleoethnobotanists contribute information on diet, origins of agriculture, environmental change, resource availability and use, stone tool and pottery functions, and long-term socioeconomic changes, to name a few. In short, paleoethnobotanical research is increasingly recognized as a valuable tool in unlocking the secrets of past human behaviors and beliefs, and has the potential to add to current discussions of climatic change and sustainability.

1.1 Types of Paleoethnobotanical Evidence

The kinds of plant evidence that may be collected from archaeological sites vary from DNA to pollen to seeds. It is common practice to group the various kinds of remains according to the methods of observation, recovery, and analyses. Macrobotanical remains include complete or fragmented plant parts that are either visible to the naked eye or with a low-power microscope. Microbotanical remains, by contrast, refer to tiny plant parts that are visible only under high-power magnification. Chemical and molecular evidence are residuals that can require very different and complex means of extraction and analyses. While macrobotanical and microbotanical remains and chemical and molecular evidence are treated herein, I often focus discussion on macrobotanical remains, but try to direct the interested reader to more comprehensive coverage of the other categories as well.

1.1.1 Macrobotanical Remains

Macrobotanical remains are perhaps the most commonly studied, and contribute evidence for many archaeological questions. This class of remains consists of plant traces that are large enough to be recognized with the naked eye or low-powered microscope (Ford 1979; Fritz 2005; Pearsall 2000). The different kinds of macrobotanical remains include wood, seeds, fruits, tubers, and nutshell, as well as fibers that have been woven into fabric or stems that have been manufactured into hats, cloaks, baskets, or mats. Their recovery from archaeological contexts may involve hand collecting, screening, or flotation (Fritz 2005; Pearsall 2000).

Wood tends to be the most ubiquitous of the macrobotanical remains. This durable material is making a growing contribution to archaeological reconstructions of natural environments, climate change, human use of timber, and dendrochronological and radiocarbon dating of archaeological sites (e.g., Asouti 2003; Dolby 2008; Figueiral and Mosbrugger 2000; Hastorf et al. 2005; Kreuz 1992; Kuniholm 1990; Kuniholm and Newton 1996; Smart and Hoffman 1988).

Remains of seeds, fruits, nutshell, and tubers are typically used to infer diet and subsistence strategies. These vestiges have been vital to our understanding of biodiversity (e.g., Black 1978), seasonality (e.g., Dark 2004), and the landscape (e.g. Fairbairn 2008). It nearly goes without saying that the analysis of macrobotanical remains has led to the publication of numerous books and articles dedicated to furthering our knowledge of ancient plant domestication and the origins of agriculture (e.g., Bellwood 2005; Smith 2001, 2006). Their interpretations also have implications for discussion about social, political, and economic systems (e.g., Hastorf and Johannessen 1993; Lepofsky and Lyons 2003; Weiss and Kislev 2004).

1.1.2 Microbotanical Remains

Microbotanical remains require a high-power microscope for identification, and have therefore been named so (Ford 1979; Pearsall 2000). Pollen is one of several kinds of very small plant remains that are of interest to the paleoethnobotanist. It forms in an anther or what comprises the male organ of reproduction in seed-bearing plants (Bryant and Holloway 1983; Pearsall 2000). Spores, the asexual reproductive cells of fungi, ferns, and some algae, are traditionally included in pollen analysis or palynology. Recently, palynological studies have expanded to include other botanical entities composed of sporopollenin-like material (see Rowe and Kershaw 2008; van Geel 2001 for additional descriptions). Upon recovery, the shape, size, and surface features of palynomorphs and non-palynomorphs are used to assign a specimen to a particular family, genus, or species.

Sears (1937) was one of the first palynologists to address archaeological issues when he modeled the paleoenvironment of parts of the eastern United States. A few years later, Iversen's (1941) work enabled the identification of the beginning of food production in Denmark. These studies set the stage for more recent palynological projects with an archaeological bent.

Worldwide, palynology is increasingly recognized for enhancing our understanding of past environments and human land-use strategies (e.g., Behre 2007; Birks 2007; Cordova and Lehman 2003; Hunt and Rushworth 2005; Kelso and Good 1995; Kelso et al. 2000; Mercuri 2008). While such studies cannot produce an exact picture of past environments, palynology is matchless in yielding some idea about fluctuations in vegetation that might be associated with climate change and/or human impact (Davis 1994; Faegri et al. 1989). Recent innovations include an automated pollen analysis proposed by France et al. (2000) and Fyfe's (2006) computer-based modeling technique that combines pollen analysis and Geographic Information Systems (GIS) to test landscape hypotheses.

Palynology can contribute other information relevant to people's exploitation of plants (Bryant and Hall 1993; Pearsall 2000). Pollen collected from middens often indicates the types of plants collected and utilized for food or other economic purposes by prehistoric cultures. Fossil pollen found in floor sediments can be used to suggest potential types of room utilization. Scrapings from the inside surfaces of ceramic vessels may include fossil pollen from plants that were stored in or eaten from those vessels. Scrapings from the surfaces of grinding stones may contain the whole or broken fragments of pollen that adhered to the surfaces of seeds that had been ground into flour, and the analyses of sediments attached to the inside surfaces of basketry can sometimes suggest functional uses of those artifacts. The analysis of pollen by Piperno and Pearsall (e.g., 1998) has opened the doors to a new understanding of the origin of agriculture in regions of the world where macrobotanical remains are lacking.

Phytoliths, another type of microbotanical evidence, are produced when certain higher plants absorb silica in a soluble state from ground water, which is then deposited in intracellular and extracellular locations in the epidermal tissues of stems, leaves, and roots (Esau 1965; Pearsall 2000; Piperno 2006; Rovner 1983). There, the silica solidifies as "phytoliths" or discrete, microscopic particles of varying sizes and shapes that are consistent with a family, genus, or species of plant. After the death and decay of the plant, the phytoliths are deposited into soils and sediments.

Phytoliths can be common in hearths and ash layers, but they can also be found inside pottery, plaster, and even on stone tools and animal teeth. Phytoliths are inorganic; thus they survive in a well-preserved state over long periods of time. In fact, Piperno (2006) indicates that they arguably are the most durable terrestrial plant fossil known to science. It is precisely their ability to withstand many of the rigors of nature that affords knowledge about plant use in regions where the recovery of macroremains has been poor. For further understanding, I direct the reader to the work of Piperno and Pearsall (1998) in the lowland Neotropics. In addition, Pearsall (2000:356) indicates that some phytoliths can be dated: those containing carbon can be radiocarbon dated (Mulholland and Prior 1993), and preliminary research utilizing thermoluminescence (Rowlett and Pearsall 1993) has proved encouraging.

Starch grains are another form of microremains that are increasingly acknowledged for their contribution to paleoethnobotanical studies. These granules form within specialized organs called "plastids." There are two kinds of plastids: (1) chloroplasts which occur primarily in leaves and green stems, and (2) amyloplasts which occur within roots, rhizomes, tubers, and seeds (Bailey 1999). The size and shape of starch grains differ by taxa (Coil et al. 2003). Czaja (1978) describes the structure of starch grains in relation to classification of vascular plant families.

Starch granules found on stone tools have received increasing attention from researchers because they can reveal information about human diet and household activities. For example, Piperno and Holst (1998) interpreted starch grains found on prehistoric stone tools as signs of early tuber use and agriculture in Panama; Barton (2007) examined museum artifacts to assess the potential of cooked, starchy foods; and Horrocks et al. (2004) were able to recover starch grains from prehistoric coprolites. Starch grain analysis has proven invaluable, yielding information about roots and tubers, many of which were dietary staples but difficult to document archaeologically (e.g., Chandler-Ezell et al. 2006; Cortella and Pochettino 1994; Dickau et al. 2007; Perry 2002; Ugent et al. 1987; see also Dickau, this volume).

1.1.3 Chemical and Molecular Evidence

Chemical and molecular evidence derive from residual elements found in sediments, ceramic vessels, crevices of stone tools and teeth, human skeletal remains, or in the vestiges of surviving plant tissues (Ford 1979; Pearsall 2000). Most researchers are well aware that $^{13}C/^{12}C$ ratios can be employed to determine the relative importance of maize (*Zea mays*) in past human diets (e.g., Boyd et al. 2008; Vogel and van der Merwe 1977; Wagner 1987). Araus et al. (2003) use carbon isotope discriminations to quantify cereal yields. Dietary contributions of plants can be assessed through ratios of nitrogen isotopes and proportions of strontium and calcium in human bone (Ambrose and DeNiro 1986). Compounds surviving in plant remains, including proteins and lipids, can provide an alternative basis for their identification and offer the prospect of better understanding of human diet, the origins of food production, patterns of trade in plant products, and uses of stone tools and pottery (e.g., Lombard and Wadley 2007; Malainey et al. 1999; Rottlander 1990).

DNA can occur in charred and uncharred plant remains; however, as I learned when working with a plant geneticist at the University of Missouri, Columbia in attempting to extract DNA from ancient *Iva annua* remains, such DNA evidence is often fragmentary and degraded which makes it difficult to amplify (e.g., Wright 1994). More recently, Giles and Brown (2008) report on improved methods for extracting and amplifying DNA. Jones (2002) and Ross-Ibarra et al. (2007) discuss the potential of genetic evidence for understanding plant domestication. Rollo et al. (2002) report on the DNA analysis of the intestinal contents of Otzi, a glacier mummy from the Alps. Equally interesting is Poinar et al.'s (2001) discussion about the dietary diversity of three archaic Native Americans based on molecular analysis.

Other synergies between chemistry and archaeological plant analysis include Lane and colleagues' (Lane et al. 2008) use of stable carbon isotope composition of tropical lake sediments to reconstruct maize cultivation. Braadbaart and I (Braadbaart et al. 2007) have used spectrographic analysis to understand the carbonization of macrobotanical remains. While chemical and molecular investigations open the door to evidence that several decades ago was unimaginable, Leach (1998) and Reber and Evershed (2004) caution against the uncritical use of chemical and molecular data; indeed, inconsistent results were obtained while conducting blind tests with commercial laboratories.

2 Deposition and Preservation of Plant Remains

Understanding how plant remains came to be a part of an archaeological site is essential. For instance, pollen can move through the environment in several ways (Bryant and Hall 1993; Pearsall 2000). Most conifers distribute their pollen by wind; consequently, pollen from a single tree may be transported miles, even hundreds of miles, away from its point of origin. Some crops like almonds (*Prunus dulcis*), apples (*Pyrus malus*), avocados (*Persea americana*), and sunflowers (*Helianthuus annuus*), spread their pollen on the feet and bodies of insects, such as bees. Their pollen distributions tend to be restricted to the range of insects. Still other plants, like peanuts (*Arachis hypogaea*), are self-pollinators, restricting the range even further. Regardless of these natural means of distribution, any of these kinds of pollen may be introduced to an archaeological context by humans. When interpreting pollen, phytolith, or starch grain data, it becomes necessary to consider human and nonhuman activities that might be responsible for their presence. Geib and Smith (2008) designed hands-on experiments to test the relationship between processing seeds and pollen deposition. They found, contrary to traditional practices of interpreting archaeological pollen washes according to how pollen is transported and deposited in natural settings, there exists a dynamic association of pollen ecology, seed architecture, and human behavior that not only warrants additional investigation but also can be expanded to include other classes of microremains. Pearsall (2000:349) and others (e.g., Davis 1994; Faegri et al. 1989) also recognize that working with pollen, phytoliths, and starch grains is complex, and they echo Geib and Smith's (2008:2100) call to unravel "the complexities of how human behavior creates pollen assemblages and how natural pollen rain and post-depositional processes distort and transform the pollen record."

2.1 Potential Sources of Biases in the Paleoethnobotanical Record

Plant use, discard patterns, pedoturbation, recovery techniques, and a host of other processes have distorting effects on the paleoethnobotanical record. These processes may mask or exaggerate the patterns in plant resource exploitation or even suggest change where none occurred. Over the past decade, I have examined a host of biases, including the carbonization process, measuring of samples, and differential recovery associated with the flotation process, and have argued that to understand the human behaviors associated with any particular assemblage (Wright 1998, 2003, 2005, 2008), we must first understand the taphonomic history of the surviving remains.

In the following pages, I review my work and that of others who have attempted to test our assumptions and to contribute to the growing body of data involving the formation of the paleoethnobotanical record. This information is broken into subsections, according to the stage in which the transformation occurs. This scheme is roughly based on the work of Schiffer (1987). Initially, a plant resource is chosen for exploitation, acquired, possibly processed, then used, consumed, or discarded. These kinds of decisions and activities occur within the cultural realm of the people using the plant and are herein referred to as "cultural transformations." It should be acknowledged that the where, when, and how a plant resource enters the record is dependent on the specifics of each succeeding decision. If the plant resource (e.g., nutmeat) or its byproduct (e.g., nutshell) survives to be discarded, abandoned or lost and ultimately becomes part of an archaeological deposit, then a host of natural taphonomic factors determine whether the plant specimen will survive and, if it does, in what condition (e.g., eroded beyond recognition, fragmented, or perfectly intact). Analytical processes (or our decisions about how to sample a site, process the samples, quantify the remains, etc.) are the final determinants of how a plant specimen is included in the record, and, ultimately, how it is interpreted.

2.1.1 Cultural Transformations: Collecting, Processing, and Disposal of Plant Remains

Researchers have designed and implemented experiments to evaluate potential sources of cultural biases, such as harvesting techniques, processing, use, and disposal practices. For example, Munson (1984) edited a volume of papers devoted to the experiments on acquiring and processing plants associated with archaeologically known cultures of the Eastern Woodlands of the United States. Some of the researchers took to the field with sickles or simply bare-handed. Their experiments show that the techniques used to collect plants can be quite diverse and, at the very least, are dependent upon the kind of resource being exploited and the level of available technology. On the other side of the world, Abbo et al. (2008) experimentally harvested several species of wild peas (*Psium* spp.) in Israel. Interestingly, they conclude that the "potential productivity of wild peas was not the only or even the major consideration for its domestication" (Abbo et al. 2008:922).

In a farming economy, plant foods may be processed for consumption and storage. Processing may involve several stages; for instance, cereals have to be threshed, winnowed, and cleaned to separate the grain from the chaff, straw, and weeds. From ethnoarchaeological and experimental observations, it is known that some of these activities leave characteristic residues. Hillman (1973, 1981, 1984), Jones (1984), Goette et al. (1990) and de Vartavan (1990) have examined how crop husbandry, harvesting, preparation, and/or storage influence the kinds of products or byproducts that may be found in the archaeological record. Hillman (1973:241) asks what "a particular set of plant remains represents in terms of human activities." He goes on to establish sets of associations, including correlations between (1) the composition of an assemblage and a particular processing technique and (2) a specific context and a processing strategy. Jones (1984), on the other hand, borrows from Hillman and proposes a statistical means for discriminating amongst crop products and byproducts. These kinds of studies illustrate the value in assessing plant samples within the context of likely harvesting and processing strategies because differences in assemblage composition may represent the same crop at various stages of processing or modifications in the subsistence economy. Furthermore, Lopinot (1984:192) cautions that, if preservation of seeds (or other remains) depends on cooking accidents, changes in the preparation of seeds prior to consumption may affect seed preservation.

It is logical that microbotanical remains, such as pollen, can also be biased by human activity. Apparently, few, if any, experiments designed to test the interrelationships of cultural processes and assemblages of microbotanical remains have been conducted. In the early development of paleoethnobotany, researchers like Bohrer (1968) and Schoenwetter (1962) recognized that it is inappropriate to infer paleoenvironmental conditions based entirely on plant samples collected from levels within archaeological sites because of distortions resulting from human activities. Rather, they recommended interpretations on the analysis of pollen and macrobotanical remains from nearby dated sections of relatively undisturbed sediments in addition to sediments from archaeological sites. These kinds of ecological studies can be used to identify anthropogenic influences on vegetation (Pearsall 2000). However, associations between pollen (and phytolith and starch grains, for that matter) and other kinds of human activities (e.g., collecting, processing, storage, consumption, and disposal of plants) tend to be implicitly rather than explicitly stated and certainly could benefit from experimental testing.

2.1.2 Crossing the Threshold: The Archaeological Context

Plant remains shift from what Schiffer (1987:47) has termed the "systemic context" to the "archaeological context" as a result of discard, abandonment, or loss. The former implies items that have been discarded because they were deemed useless or unpleasant. The charred cleanings and ash of a hearth dumped into a trash pit is but one example. Abandonment, like discard, is a deliberate action. It implies giving up something out of disinterest. A scorched tuber may be abandoned in a cooking fire because it is considered unpalatable. Loss, such as a few tiny grains spilled during transport, is an unforeseen outcome of human behavior. Macrobotanical remains may also become incorporated in the archaeological context by nonhuman activities or byproducts of activities; for instance, Miller and Smart (1984) discuss the burning of dung as a mechanism for introducing charred seeds.

Van der Veen (2007) compares formation processes associated with desiccated and carbonized plant remains from Europe and North Africa, and adds information about water-logged assemblages. Interestingly, she points out that most desiccated plant assemblages are made of secondary refuse and discusses their incorporation into mixed deposits. Entry for carbonized assemblages is also discussed. In the need to compare "like with like," van der Veen (2007:988) emphasizes the need to understand formation processes:

> routine practices are ordered by socially perceived norms and the discard of waste from such activities is thus socially and culturally structured. This means that the analysis and understanding of formation processes can bring to light changes in such routine practices and consequently changes in the way that social relationships were negotiated and reproduced.

Pollen may enter the archaeological record either as a result of human activity or incidentally as a result of so-called pollen rain. The other kinds of microbotanical remains – phytoliths and starch grains – derive largely from on-site plant discard as a result of human activity (Piperno 2006).

2.1.3 Taphonomic Processes Affecting Paleoethnobotanical Assemblages

Once macrobotanical remains are deposited in archaeological contexts, there are several ways that they may survive physical and chemical decomposition: carbonization, desiccation, quick-freezing, mineralization, water-logging, and preservation in coprolites (Minnis 1989). These processes inhibit the growth of decomposers like bacteria or saprophytic fungi, slow the rate of enzyme action, and/or lower the speed at which chemical reactions occur (Bryant 1989). Desiccation, quick-freezing, and water-logging, in particular, are remarkable for the preserved tissue types, if not for the sheer abundance of the material. Carter (1972) found the tomb of Tutankhamen filled with desiccated food, linen clothing, and wooden objects; whereas the water-logged deposits of the Swiss-Lake dwellers have yielded cultivated grains, fleshy fruits, legumes, nuts, fiber, and timbers that afforded a breakthrough in establishing a tree-ring chronology for parts of northern Europe (Eckstein 1984). Unfortunately, such instances of preservation are rare. Rather, most plant resources are used in temperate and tropical environments where their products or byproducts will not survive natural processes unless they have undergone the physical and chemical changes associated with carbonization (Bryant 1989). However, some kinds of remains, like starch grains, rarely survive charring (Fritz 2005:808). Perhaps Wilson (1984:14) put it best when he stated that "carbonization is generally thought of as a means by which plant remains are preserved. It is more accurate and less misleading to consider it a process of partial destruction."

For many years, it was assumed that the conversion to charred remains was a straight-forward process. However, as taphonomic and site formation studies grew in popularity, researchers (e.g., Braadbaart et al. 2007; Boardman and Jones 1990; King 1987; Lopinot 1984; Prior and Alvin 1983; Rossen and Olson 1985; Smith and Jones 1990; Wilson 1984), including myself (e.g., Wright 1998, 2003), began experimenting with the carbonization of macrobotanical remains. These studies show that carbonization is the conversion of organic substances into carbon or other kinds of residues. For example, Braadbaart and I (Braadbaart et al. 2007) used a mass spectrometer to record the chemical changes and a scanning electron microscope and dissecting microscope to record the morphological changes in sunflower (*Helianthuus annuus*) achenes as they are exposed to different temperatures. Moreover, the above investigations document differences in the circumstances surrounding thermal exposure that may influence the final product. Rarity or absence of a species and/or element may reflect its sensitivity to thermal exposure rather than a lack of use. A particular element accidentally subjected to a high temperature for a very short time may differ in distortion or degree of degradation than one exposed to a lower temperature for a longer time. Moisture and chemical content, as well as the microenvironment at the time of exposure, may also affect the outcome. Given that our interpretive abilities are often contingent upon charred macrobotanical remains, knowledge of such variables becomes paramount.

I conducted a small experiment to test the influence that fluctuations in moisture, temperature, and pH might have on the preservation of carbonized macrobotanical remains (Wright 1998). It is no surprise that fluctuations in moisture were the most detrimental. However, I was amazed to observe that pH appeared to have little effect. It could be that the year of exposure that I chose as an interval was too short. However, in casual conversations with biologists and chemists, I learned that the critical element is more likely the presence or absence of bacteria that feed on the macrobotanical remains, and that these bacteria vary dramatically depending on the chemical and physical characteristics of the archaeological matrix. Additional research is needed to test assumptions on macrobotanical remains (as well as microbotanical remains and chemical and molecular remains) and soil pH. This line of research would be especially useful to understand the different preservation trajectories of plant and animal remains and any future hopes of integrating those kinds of databases into more precise discussions of past subsistence behaviors.

Like macrobotanical remains, microbotanical remains are organic and can fall prey to chemical erosion, physical erosion, and destruction by a host of biological organisms (Bryant 1989; Pearsall 2000; Piperno 2006). At some point in our careers, we have heard that the outer walls of pollen, spores, and non-pollen palynomorphs tend to be highly resistant to deterioration. Yet a cautionary note is in order; these entities do not always preserve equally well in all types of archaeological deposits. Rowe and Kershaw (2008: Table 42.1) prepared a valuable table that summarizes not only the preservation characteristics of pollen and spores, cellular tissues, starch, phytoliths, diatoms, and chrysophytes, but also information about their deposition, applications, advantages and limitations. The authors point out that pollen and spores fare better in acidic and/or anaerobic environments like peat bogs and lake beds. Cave sediments are also suitable because of their humidity and constant temperatures. In contrast, sandy sediments or open sites that are exposed to weathering generally result in poor preservation. Pollen can also be found in mud bricks, vessels, tombs, mummy wrappings, the guts of preserved bodies, fossil feces, and many other contexts. For those interested in differential pollen preservation, studies by Sangster and Dale (1961, 1964) show that not only is the depositional environment critical to pollen preservation but that the pollen of some species is more durable than others. In the early 1990s, additional studies were conducted and published by the Campbells; Ian Campbell (1990) reports on experiments designed to test mechanical destruction of pollen grains, and Campbell and Campbell (1993) discuss pollen preservation in saline and desert sediments. King et al. (1975) discuss the preservation of pollen associated with copper artifacts, while Kelso et al. (2000) indicate that shells preserve prehistoric pollen from percolating rainwater, free oxygen, and aerobic fungi.

Starch grains may be the most vulnerable of the microbotanical remains. According to Rowe and Kershaw (2008), starch grains are reduced when left in open conditions but can be found in geological, archaeological, and museum contexts. Based on laboratory experiments, Korsanje (2003) provides more precise information about the preservation of starch grains. Specifically, she claims that they preserve best in semi-arid environments with sandy soils and a pH of 7. Haslam (2004) also reports on the differential decomposition of starch grains and its implications for analysis.

Phytoliths are considered the most durable of all plant remains (Rowe and Kershaw 2008). The name comes from the Greek words for “plant” and “stone,” which is literally what they are: microscopic silica bodies formed in living plants. These tiny remains can be found where other micro- or macrobotanical remains are commonly absent, including dry, alkaline, and anaerobic conditions.

Movement as a result of natural processes is also a concern. Sediments are dynamic layers; they can expand, contract, aggregate, and conflate. For instance, Edwards (1979) observed that a 1-cm thick pollen sample may represent as much as 25–30 years of deposition – more than enough time for forest clearance, agriculture, and regeneration to have occurred. Conflation can be a problem for the analysis of macrobotanical remains as well. In fact, paleoethnobotanical remains may move from their initial location of deposition dependent on a variety of "turbations," including faunalturbation, floralturbation, cryoturbation, graviturbation, aquaturbation, and aeroturbation. These soil mixing phenomena can be peculiar to very limited environmental contexts and are poorly understood with respect to their archaeological implications. While they are often thought of as agents of transport that disrupt the spatial integrity of the remains, we must bear in mind that many of these processes also possess the ability to accelerate the attrition of plant remains both directly and indirectly. Yet we know little of their degenerative impact; such an understanding is dependent on future experiments and observations.

2.1.4 Biases of Our Own Making

The plant evidence that survives the ravages of natural processes is then subjected to biases of our own making. Our choices of sampling or recovery strategies or how we choose to quantify remains further filters the record and, ultimately, challenge our interpretations. In the following discussions on collecting, extracting, processing, identifying, and quantifying plant remains, I include information about the various analytical processes associated with each.

3 Recovery Methods

The divisions of macrobotanical remains, microbotanical remains, and chemical and molecular evidence are based, in part, on methodological differences in recovery, processing, and identification. Consider the recovery of pollen from a metate found in a structure as compared to the technique used to retrieve carbonized plant tissues embedded in the floor of that structure. The former calls for a pollen wash to remove the grains from the metate surface (Bryant and Morris 1986; Pearsall 2000), while the recovery of the carbonized fragments may involve the flotation of the house fill (Pearsall 2000). Furthermore, portions of the floor may not yield botanical remains but may contain chemical residuum that can be indicated by pH or trace element assays (Bryant 1989). Books, such as Pearsall's (2000) *Paleoethnobotany* or Piperno's (2006) *Phytoliths* have become important texts for methodology. They provide information on various collection, processing, and analytical techniques.

We all realize that it is impractical to collect and analyze every cubic centimeter of an archaeological site. Sampling in the field and in the laboratory can keep processing and analysis from reaching unmanageable proportions and still yield an assemblage that is representative of the total population of the remains at a site.

However, decisions have to be made on how much and from what context(s) sediments will be collected. Is a pinch or column strategy more appropriate? What size of sample is appropriate? Should the sample size be standardized across the site? Too small a sample and rare plants may be missed; investigating obviously rich loci at the expense of areas that seem devoid of remains can negatively impact interpretations about subsistence strategies and site use. Of all the potential biases, sampling seems to be the most discussed (e.g., Brady 1989; Jones 1991a, b; King 1987; Lennstrom and Hastorf 1995; Lepofsky and Lertzman 2005; Pearsall 2000; Riley 2008; van der Veen 1984; Wright 1998). Jones (1991a, b) examines sampling strategies at intrasite, site, and regional levels. Authors such as Lennstrom and Hastorf (1995) and Pearsall (2000) discuss three kinds of sampling techniques typically employed for taking macrobotanical or flotation samples – composite/scatter, column, and point samples – and the impact of each on densities and assemblage composition. King (1987) writes about sample size and its influence on the diversity of assemblages and the probability of collecting rare or unusual plant remains. Riley (2008) discusses how the individual nature of coprolites can skew dietary data; by using cluster analysis to examine a large collection, Riley is able to answer questions related to seasonality, mobility, and resource acquisition. My own research presents information on biases associated with different techniques used to calculate sample size (e.g., bucket and *in situ* measurements) and the relevance of soil type (Wright 2003).

For pollen, samples may be extracted in long cores at wet sites or in lake beds, or as a series of separate samples from dry sites or structural remains. Pollen can also be collected from adobe bricks, vessels, mummy wrappings, the guts of preserved bodies, and paleofecal materials. Whatever the provenience, great care must be taken to avoid contamination. Pearsall (2000:270–280) provides a thorough discussion of how research questions should guide both the planning of a sampling strategy and the choice of techniques for taking the samples. She cites the work of Bohrer and Adams (1977) at Salmon Ruin as a guide to select samples for a large body of systematically collected samples; Fish et al. (1982) to illustrate a sampling strategy designed to recover information about subsistence and environmental changes; and Kelso and Good (1995) for a strategy that lends itself to questions about land use, human and domesticated animal diet, room and artifact function, and construction sequences.

Because phytolith analysts have borrowed sampling strategies and collection techniques from palynologists, there are a number of parallels in both approaches. Both Pearsall (2000) and Piperno (2006) discuss collection and sampling strategies for phytoliths. Piperno (2006:81–86) categorizes the strategies into two basic groups: sediment column sampling and horizontal sampling of sediments and artifacts. As with pollen samples, the former is used to establish broad trends across time, whereas the latter can be used to answer questions about the organization of space and social relations as well as site and artifact functions, subsistence practices, and technology. While Lennstrom and Hastorf's (1995) and Pearsall's (2000) discussions of composite/scatter, column, and point samples that I cited above are focused on macrobotanical remains, the information can also be applied to microbotanical remains like pollen, phytoliths, and starch grains. In addition to samples collected from archaeological contexts, both kinds of microbotanical remains require that offsite control samples be taken to better understand the deposits, to identify any mixing of sediments that may skew interpretations of the samples from archaeological contexts, and to understand pollen rain.

For macrobotanical remains, modern recovery techniques include hand collection, screening, and flotation. At the very least, all three techniques introduce a size bias that can create analytical and interpretive problems (Wright 1998). The majority of macrobotanical remains are recovered through the flotation of archaeological deposits. This specialized technique uses water or chemicals to free seeds and charcoal flecks along with other remains from their geological matrix. Several researchers (Hunter and Gassner 1998; Pearsall 2000; Wagner 1988) systematically tested the recovery rates of various flotation machines, and I (Wright 2003) looked at differential loss and recovery of carbonized macrobotanical remains. On the basis of their systematic study, Hunter and Gassner (1998) suggest that the Flote-Tech machine is a reliable mechanism for the processing of flotation samples, whereas Rossen (1999) suggests that the machine is expensive and over-rated, citing the potential of small remains collecting in the corners of the machine as a potential source of contamination. Wagner's (1988) seminal study demonstrates the variation in recovery based on the kind of technique or machine used, with differences in the mesh sizes of the catch screens being among the main contingencies impacting recovery. Keeping the system a constant, I found that different kinds of plant remains (e.g., a chenopod [*Chenopodium* spp.] seed versus a maize kernel) will vary in their rates of recovery; some of the differences can be attributed to size while others are a function of the fragility of the specimen.

A number of techniques for extracting phytoliths can be found in the literature (e.g., Lentifer and Boyd 1998, 2000; Pearsall 2000; Piperno 1985; Powers and Gilbertson 1987; Zhao and Pearsall 1998). Significant works addressing the recovery of pollen include Davis (1994), Faegri et al. (1989), Gorham and Bryant (2001), and Lentifer and Boyd (2000). Korsanje (2003) and Pearsall (2000) provide information on the retrieval and preparation of starch samples while Loy (1994) discusses the removal of starch residues adhering to stone artifacts. Both Pearsall (2000) and Piperno (2006) detail techniques for extracting these microbotanical remains from soils, paleofeces, dental remains, and artifacts, and Coil et al. (2003) offer a means for extracting multiple kinds of microbotanical remains from a single sample.

The previously cited literature is focused on methods for the recovery and analysis of microbotanical remains from terrestrial settings or artifacts. Gorham and Bryant (2001) explore the formation of underwater sites and their potential to yield microscopic remains, and in turn recover information on cargoes; a ship's food supply; plants used to make rope, baskets, and the like; and port locations. In addition, they provide information on how and where to sample, and the conservation of samples.

Unfortunately, systematic investigations on recovery biases for microbotanical remains are lacking or at least difficult to locate in the literature. A recent chapter by Perry (2007) does provide an interesting discussion of differential recovery of starch types from lithic and sediment samples.

4 Specimen Identification and Analytical Methods

Processing of samples is followed by the challenge of identifying and analyzing the remains. Overviews by Pearsall (2000), Piperno (2006), and Fritz (2005) provide information on the basics of laboratory analyses for macrobotanical and microbotanical remains, how to set up laboratories, the kinds of equipment that are needed, and how to prepare reference collections.

4.1 Identification of Paleoethnobotanical Remains

Identification of macrobotanical and microbotanical remains is accomplished by visually comparing archaeological specimens to known specimens. Access to comparative material is essential. Even with the best reference collection, identification depends on the type and quality of traces (e.g., how eroded or fragmented they may be) and on the abilities of the researcher to discern attributes that are diagnostic of particular families, genera, or species of plants. While ancient seeds and fruits can usually be identified to species despite changes in their shape caused by charring, water-logging, and the like, systematic experiments to understand errors associated with the identification of macro- and microbotanical remains are scarce. Leach (1998) and Lombard and Wadley (2007) have experimented with blind tests to highlight the difficulties of distinguishing between plant and animal residues on tools. While guides and comparative collections are helpful, personal experiences associated with processes like collecting, processing, and carbonization (e.g., Hillman 1984; Wright 2008) can enhance identification and interpretation.

4.2 Quantifying Paleoethnobotanical Samples

Excellent discussions concerning quantitative analysis of macrobotanical and microbotanical remains are presented by Fritz (2005), Hastorf (1999), Jones (1991a, b), Kadane (1998), Miller (1988), Pearsall (2000), and Popper (1988). Counts and/or weights are often used, but as Popper (1988) points out absolute counts and weights assume that those measures accurately reflect human–plant interrelationships. Rather, absolute measures are heavily influenced by factors such as preservation and sampling. Various manipulations of counts and weights (e.g., conversion factors, diversity indices, rankings, ratios, and ubiquity measures) help to standardize the remains but do not necessarily alleviate all the biases. Even the use of more sophisticated methods like multivariate statistical analyses does not preclude the conditioning of the assemblage by cultural, natural, or analytical processes that may ultimately influence interpretations. Some researchers, such as Jones (1987), have turned to statistics to identify the effects of these transforming processes.

4.2.1 Absolute Counts and Weights

One means to document plant remains is merely to cite their occurrences. While simplistic in approach, even a laundry list of species present can provide qualitative information about subsistence, domestication, trade, and seasonality of occupation. Frankly, there are those researchers (e.g., Dunnell 1980) who question the validity of reporting anything more than the presence of taxa. It has been suggested that if preservation of carbonized macrobotanical remains is primarily the result of accidental inclusion in a fire, quantification is useless. Yarnell (1982:3–4) has responded to the critics by stating that "the usefulness of quantification is not a function of how materials happen to be preserved, but rather it is a function of regularity of preservation…[t]he problems of interpreting plant food remains do not differ greatly in kind from problems of interpreting many other categories of archaeological remains." It becomes necessary to consider which items to count. Does one count all maize embryos and kernels and include them in a calculation of percentages? What about fragments? Quantifying fragments is an issue that has confronted zooarchaeologists, and, in following their lead, Watson (1979) and Jones (1990) attempted to standardize the counts of charred cereal grains for comparing stages of processing by quantifying diagnostic attributes like glume bases or tops of rachis internodes. While he asserts that his calculations can provide some guide to understanding the effects of cereal processing, Jones (1990:93) acknowledges that some components are more likely to be preserved by charring than others. Once again, we return to the need for understanding the histories and characteristics of the remains that we study.

Generating interpretations based on absolute counts and weights assumes that those measures accurately reflect human–plant interrelationships (Popper 1988). Absolute measures are too heavily influenced by factors, such as preservation and sampling, to serve on their own as meaningful foundations for interpretations. Instead, various manipulations of counts and weights help to standardize the remains, but they do not alleviate all the biases.

4.2.2 Presence/Absence and Ubiquity Indices

Ubiquity or presence analysis describes the number of proveniences in which a plant resource is recovered (Popper 1988). In other words, if maize kernels were identified in 10 of 80 proveniences, they would be given a score of 12.5%; if additional kernels dating later in time were identified in 65 of 70 proveniences, they would be given a score of 92.9%. The larger index is interpreted as a sign of greater use of maize with time. This application of ubiquity assumes that, if a plant resource is used often, its chances of occurring in more and varied contexts are enhanced. Minnis

(1985:104), among other researchers, prefers ubiquity to absolute counts and weights, because it is potentially "more closely related to the degree of utilization." He explains that "a change in the number of samples in which a taxon is present is an imprecise but useful measure of the relative change in the use of that resource" (Minnis 1985:106). Critical to the assumption is how a plant resource is used and whether increases or decreases are actually a function of the frequency of use or merely reflect a change in the way that resource was used.

While Popper (1988) employs Hubbard's (1980) research at Çayönü to exemplify an error in analytical judgment (an inadequate sample for answering his question and assuming that each grouping represented the full range of plant use at Çayönü), I borrow the study to emphasize how transformation processes come into play. Hubbard (1980) initially grouped his samples chronologically. This arrangement depicted a shift in high scores from cereals to pulses. He then reanalyzed the data according to location. Another pattern emerged which suggested that the variations in scores more accurately reflected differences in the logistics of plant processing activities. These perceived differences could be a result of use or logistics, but could also be a result of changes in processing or disposal of the cereals and pulses through time or across space. Also differences in microenvironments might be at play. Hubbard's (1980) arguments would have been strengthened if he had discussed other issues, such as differences in use, logistics, microenvironments, etc.

As with absolute counts and weights, the possibility of differential cultural, natural, and analytical transformation processes limit the usefulness of ubiquity. When comparing different plant resources, such biases quickly come to mind, but many of these same biases may be overlooked when comparisons of the same resource are used. Rather it is assumed that a resource will act and be treated the same across space and through time. Yet, changes in processing, use, disposal, and microenvironments may affect the reliability of the comparison for even a single resource type. This places the comparisons of the same resource on similar ground as comparisons among different resources with respect to error as a result of divergence in transformation processes.

Another potential source of error can result from scoring samples as independent. Popper explains (1988:61):

> it may be difficult to fulfill the assumptions of independent samples and to insure that the data are appropriate for answering the research question. ... Because the presence of a taxon in each analytical unit receives equal weight, mistakenly splitting one sample into two analytical units inflates the frequency scores of the taxa in those analytical units. This could happen if one inadvertently takes two samples from one archaeological deposit and treats them as independent analytical units; or one might intentionally take two samples but then inadvertently score them as independent samples instead of averaging or combining them in an appropriate fashion. Clearly, mistakes alter the frequency scores less significantly when a group contains many samples.

4.2.3 Ranking

Popper (1988:64) suggests ranking as a more precise means for measuring plant frequencies than ubiquity. With ranking, absolute counts are translated into an ordinal scale. For each taxon, a “scale of abundance” is created. This is accomplished by selecting important post-depositional transformations and weighting the taxon according to the presumed influences. The subsequent rankings are perceived to have neutralized the biases, thereby providing a more accurate means of comparison.

Popper (1988:165) notes some of the flaws and benefits of such a process. She praises ranking because it allows for independent evaluations of taxa. Disadvantages include a need for good preservation and high counts of taxa per sample. Because post-depositional transformational processes associated with a pit feature may differ in degree and kind from those associated with a structure, ranking may be limited among those samples collected from similar contexts. Most importantly, “the *subjective* weighting of taxa frequencies to determine their scales of abundance increases the potential for introducing errors into the results” (Popper 1988:66; emphasis mine). Weighting is more likely to be based on assumptions than on systematically collected data regarding post-depositional transformation processes.

4.2.4 Ratios

Ratios are frequently used as a basis for paleoethnobotanical interpretations. In the literature, one encounters such measures as charcoal volume of sediment, nut:wood, seed:charcoal, or maize kernels:cob fragments. These ratios are proposed as a means to standardize the data and enable the paleoethnobotanist “to compare (1) samples of unequal size, (2) samples differing in circumstances of deposition or preservation, and (3) quantities of different categories of material that are equivalent in some respect” (Miller 1988:72).

Miller (1988) defines and critiques several basic types of ratios. These include densities, percentages, and comparisons. While the latter allows for the comparison of relative amounts of mutually exclusive items, densities and percentages are measures whereby the denominator is inclusive of the numerator. The count of a particular species of seed relative to the count of the identified seed assemblage, or the weight of a particular species of wood relative to the weight of the identified wood assemblage, falls under the rubrics of percentages. When calculating percentages, units of measures must be the same for the dominator as the numerator. Densities are typically expressed as the amount of charred material relative to the amount of sediment. For example, grams of ≥2.0 mm charred materials:liters of sediment, or seed counts:liters of sediment may be documented. Here, the units of measure chosen for the denominator and the numerator may vary.

The amount of nutshell:wood or seeds:wood exemplify frequently used comparisons. The units of measure are up to the discretion of the researcher and may include count, weight, volume, or some combination thereof. Wood charcoal is often used in constructing comparison ratios. We frequently assume that wood charcoal represents ordinary, domestic fuel use (Miller 1988). We then put charcoal in the denominator to control the likelihood of preservation. However, shifts in wood species employed for fuel may affect the outcome, because different taxa are subject to different preservation trajectories (e.g., Lopinot 1984; Rossen and Olson 1985; Smart and Hoffman 1988).

Another source of error is context. In eastern North America, nutshell:wood ratios are used to gauge variability in nut use through time or across a geographical cline. To make a point, I analyzed some samples from Simpson Quarry and calculated one nut:wood ratio based on all the samples and then calculated a second nut:wood ratio based on the context of the samples (Wright 1998). The former produced a nutshell:wood ratio of 0.47:1 and the latter yielded a ratio of 0.32:1. Although the latter could be interpreted as indicating relatively less dependence on nuts when compared to coeval assemblages in the region, it actually reflects the abundance of carbonized wood from burned posts. Hence, sample context may have a significant bearing on the interpretation of nut:wood ratios or any other type of ratios for that matter.

When constructing ratios, we must critically assess our variables. The foregoing examples show how differential use and deposition may affect subsequent interpretations, and such factors should be given adequate consideration. For every instance of ratio use, Miller (1988:83) poses the following questions:

1. What will a particular density, proportion, or comparison measure in a given assemblage?
2. Are the variables chosen relevant to the question asked?
3. Are assumptions of the equivalence of use and preservability among taxa and deposits warranted?

Furthermore, assumptions, whether they are based on ecological, functional, or preservational grounds that are associated with the ratio, should be discussed. Such discussions better enable the reader to evaluate any interpretation based on the ratios.

Regardless of the quantification technique used, the context of the samples and any associated cultural, natural, and/or analytical biases should be assessed (Hubbard and Clapham 1992; Wright 1998). Hubbard and Clapham (1992) provide a three-class scheme for evaluating what they refer to as “archaeological integrity.” These classes range from “A” which consist of “[s]amples whose origins are quite unambiguous and capable of rigid definition” (Hubbard and Clapham 1992:118) to “C” which consists of “[s]amples whose archaeological context is not clearly understood” (1992:119). The authors provide examples and reflect upon various kinds of quantification techniques in their efforts to elucidate which practices are of interpretive value and which are wasted efforts.

5 Summary and Conclusions

Problem orientation and subsequent interpretations are project-specific. The interests of the paleoethnobotanist, the overall research goals, and theoretical perspectives structure how paleoethnobotanical remains will be collected, analyzed, and ultimately interpreted. It is widely recognized that plants serve dietary, medicinal, ritual, and technological functions.

The origins of agriculture has been a topic of interest to the archaeologist since the discovery of the first archaeological plants. Issues, such as motivation, the effect on health, and how this shift is interrelated to other aspects of culture are continually raised. Ultimately, our interpretations are dependent upon assigning the archaeological material with certainty to a particular species or variety. This task is especially challenging when dealing with carbonized macrobotanical assemblages where morphological markers and measurements are commonly used in classifying the remains, i.e., designating a specimen as domesticated versus wild. Morphological markers and measurements are both subject to transformative processes. The reliability of measurements has been the subject of debate. Researchers, like King (1987), working with maize and me working with sunflowers (Braadbaart and Wright 2007; Wright 2003, 2008) caution about the reliance on measurements involving small samples without considering the contexts of the remains. For example, seeds from trash heaps may reflect *small* throw-aways, while seeds from storage contexts might represent the *larger*, more desirable specimens that were stored for food or for next year's planting.

Early research in paleoethnobotany tended to emphasize the analysis of macrobotanical remains of cultivated plants in arid and temperate zones, and thus provided evidence for the domestication and spread of farming communities in those regions. The extension of research into tropical areas dominated by tubers, root crops, or tree crops, encouraged the development of methods employing microbotanical remains like pollen, phytoliths, and starch grains. Pearsall (2007) clarifies some of the methodological challenges of trying to identify ancient agricultural practices based on the analysis of ancient plant remains and highlights the usefulness of the analysis of sediment cores for understanding people–plant relationships in the neotropics.

Weiss et al. (2008) employ intrasite spatial patterns of macro- and microbotanical remains to delineate activity areas on a brush hut floor at an Upper Paleolithic site in Israel. While they assume that "different taxa have roughly equal preservation rates," which is questionable unless tested, they do consider numerous post-depositional processes that might result in the displacement of the remains (Weiss et al. 2008:2401). To take their interpretations a step further, they integrate data about the distribution of plant remains and lithic remains to discuss the gender-related use of space. In an earlier article, Weiss combines efforts with Kislev (Weiss and Kislev 2004) to gain insights into Iron Age economic activities by using weedy species as markers for locating wheat fields. Hu et al. (2007) analyzed pollen and found that the famous terracotta warriors and horses found in the Qin Shihuang Mausoleum were produced at different locations. We have moved beyond mere assessments of the economic significance of plants (Fritz 2005), but many questions remain unanswered, including those associated with the formation of the paleoethnobotanical record.

Certainly, combining different kinds of analyses can provide corroborative evidence. The chapters in this volume illustrate numerous instances where macro- and microbotanical remains and/or zooarchaeological remains have been combined to elucidate exciting interpretations about past human behaviors. Biological, paleoethnobotanical, and zooarchaeological approaches converge to document domestication and address basic questions about when, where, and from which progenitor population(s) a domesticate is derived. Smith (2001), for example, discusses how biologists have focused on genetic profile comparisons, paleoethnobotanists on morphological markers to distinguish between wild and domesticated forms of plants, and zooarchaeologists on changes in age and sex profiles that are interpreted to reflect human management of herd animals; together these approaches have yielded remarkable results, and future "regional scale and species-specific research should provide richly diverse and productive avenues of inquiry for biologists and archaeologists alike for decades to come" (Smith 2001:1324, 1326). Iriarte (2007) acknowledges recent advances in the study of early domestication and crop dispersal while illustrating the potential of integrating soil analysis to revitalize studies on later agricultural landscapes. It is not uncommon to rely on the analyses of one of more classes of microbotanical remains in regions of the world where macrobotanical preservation is poor (e.g., Chandler-Ezell et al. 2006; Dickau et al. 2007; Horrocks et al. 2004; Perry 2002; Piperno and Pearsall 1998; see also Dickau, this volume).

Our interpretations, whether based on one class of archaeological remains or a combination thereof, are only as strong or weak as our understandings of the formation of the record(s) that we interpret. Collins (1975) presents an explicit statement regarding the formation processes that were predicated upon the idea of statistical samples. Below I have modified his scheme to apply to paleoethnobotanical remains:

1. Not all human behaviors and values result in patterned plant remains;
2. Of those which do, not all will occur where there is an opportunity for inclusion in archaeological contexts;
3. Of those which are included, not all will be preserved;
4. Of those which are preserved, not all will be exposed to, or by, the archaeologist; and
5. Among the plant remains exposed to the archaeologist, not all will be perceived or properly identified.

These processes are analogous to a series of filters, continuously acting to change the context and to reduce the quantity of observed plant remains. The scheme is not limited to the analysis of archaeologically derived plant debris but is applicable to any class of archaeological artifacts and features.

Without doubt these processes are complicated because methods, techniques, and experiments that might work well for paleoethnobotany in one region often do not for another. Any endeavors to offer worldwide coverage necessarily results in a less than sharply focused critique as seen here. Consequently, I have tried to offer a broad range of examples based on regional investigations. As seen in these examples, understanding these transforming processes can bring changes in routine practices and contribute to the social, economic, and political archaeologies of regions and periods from which the remains are derived. In essence, whether looking at paleoethnobotanical evidence in isolation or attempting to integrate it with zooarchaeological or other kinds of archaeological remains, we cannot be certain about our interpretations but rather aim for the best approximations available.

Moreover, researchers (e.g., Hayashida 2005; Peacock and Schauwecker 2003; van der Leeuw and Redman 2002) suggest that in today's changing patterns of university and government research, we need to reevaluate the methods and goals of archaeology to bring long-term perspectives to bear on contemporary issues. As paleoethnobotanists, we have accumulated a large body of empirical evidence documenting such changes as deforestation, spread of savannahs, increased rates of erosion, rearrangement of landscapes for agriculture, and resource depression and depletion. These avenues of investigation illuminate past human actions and their environmental consequences, and ultimately can contribute to today's conservation and restoration efforts (Pearsall 2007). Accordingly, it becomes increasingly important to understand not only how historical processes have shaped the modern landscape but also how they have shaped the archaeological vestiges of past humans actions and values.

Acknowledgments Many thanks to Tanya Peres and Amber VanDerwarker for their invitation to participate in this volume and for their advice, enthusiastic support, and patient editing. Also, I would like to recognize the hard work and endless efforts of all of those individuals whose works I have cited in this chapter and the others who I missed because of lack of time and space. I am extremely thankful to many family members, friends, and colleagues who have motivated, inspired, and encouraged me.

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Simple Measures for Integrating Plant and Animal Remains

Amber M. VanDerwarker

Numerous simple measures are available for integrating both archaeological plant and animal data. It is difficult to provide a complete coverage of all these measures in this chapter for lack of space (for further reading see Grayson 1984; Hastorf and Popper 1988; Reitz and Wing 2008). Hence, the focus is on simple yet common measures that can be used to characterize both types of data, producing results that can be compared to achieve a broader understanding of ancient subsistence: ubiquity, diversity, ratios, correlation, and spatial analysis. For each measure, basic information is provided on the method of calculation and the method of integration of plant and animal data.

Published cases that have attempted to integrate plant and animal data using these measures are also discussed. The introductory chapter to this volume briefly discussed publications that incorporate both archaeological plant and animal data. Most of the works cited treat plant and animal data separately in terms of analysis and quantification, followed by an interpretive discussion that integrates independent patterns in a qualitative and complementary fashion. Very few authors have actually attempted to quantitatively integrate plant and animal datasets; these are the cases that have particular relevance to this chapter. I begin with a review of simple comparative measures and discuss the best way to arrive at appropriate comparative results. Most of the more integrative measures (also discussed below) can build on these simple measures.

1 Ubiquity

While ubiquity analysis is typically used to characterize paleoethnobotanical data, this technique is occasionally applied to zooarchaeological data, and when applied similarly to both datasets has the potential to allow a broader look at subsistence

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_4, © Springer Science+Business Media, LLC 2010

(see Crane and Carr 1994; see also Spielmann and Angstadt-Leto 1996). Ubiquity measures are useful for determining which types of taxa routinely find their way into specific depositional contexts. This type of analysis is essentially a presence/absence analysis that measures the frequency of occurrence (as opposed to abundance), through measuring the number of samples in which a taxon was identified. The researcher first records the presence of a specific taxon in each sample, and then computes the percentage of all samples in which the taxon is present (Popper 1988). For example, if acorn (*Quercus* sp.) nutshell is present in four of the ten samples, then its ubiquity value is 40%. While this type of measure is normally used for calculating the presence/absence of plant remains in the number of flotation samples, the flotation sample does not have to be used as the unit of aggregation. By assigning a different unit of aggregation, such as feature or unit, or levels within units, ubiquity can be measured for both archaeological plant and animal taxa. Thus, if we are interested in comparing ubiquity measures for plants and animals at a particular site, we could consider the presence of different taxa in the features in which they are present, calculated as a percentage of total features at the site.

There are, however, a couple of constraints on the use of ubiquity measures, true for plants, and thus also true for making comparisons between plants and animals. Because different types of plants are disposed of differently, direct comparisons of ubiquity values between taxa can be challenging (Hubbard 1980:53). For example, a 70% ubiquity value for hickory (*Carya* sp.) nutshell would not be equivalent to a 70% ubiquity value for beans (*Phaseolus* sp.) as these categories have different preservation opportunities – hickory nutshell represents a processing byproduct often used as fuel, while beans represent edible portions. Of course, all animal bones represent byproducts of processing edible food (meat, organs, etc.). Thus, the meaning of the term “discard” may vary depending on the particular plant or animal represented. While this fact necessitates a certain level of caution when comparing ubiquity values of different taxa, this does not mean that ubiquity values cannot be compared at all.

The second potential constraint on the use of ubiquity measures is sample size. A minimum amount of samples (or contexts) is required for calculating ubiquity percentages for plant or animal assemblages. Hubbard (1976:60) suggests a minimum of 10 samples as a means to reduce the probability of sampling error. The greater the number of samples/contexts used, the more reliable the results. If we were calculating ubiquity values for plant and animal assemblages as a percentage of features in which different taxa appear, then we would need a minimum number of 10 features represented at the site. Finally, ubiquity measures can be converted to ordinal data through the ranking of resources; these rankings can then be used to perform simple correlations between plant and animal data, effectively *integrating* comparative measures (see below; see also Spielmann and Angstadt-Leto 1996).

Crane and Carr (1994) present an integrative case study using ubiquity in their article: “The Integration and Quantification of Economic Data from a Late Preclassic Maya Community in Belize.” This case is specifically focused around integrating paleoethnobotanical and zooarchaeological data to provide a more holistic determination of diet at the site of Cerros, Belize. Indeed, Crane and Carr

(1994:67) argue that "a true understanding of subsistence requires examining the role of all resources, especially since plants and animals, including humans, form interrelated parts of an ecological system." Thus, their case study provides a means for embarking on a new methodological endeavor.

Crane and Carr are concerned with temporal change in diet at the Mayan site of Cerros (275-50 BC), during a period when the community witnessed the emergence of social inequality in the form of a rising elite class (Crane and Carr 1994:68–70). Crane and Carr (1994) are thus interested in how changes in societal structure are reflected in the diet of the site's inhabitants. In order to assess plant and animal subsistence during this period, the authors transform their zooarchaeological and paleoethnobotanical data into ubiquity values and present these values in a series of bar graphs (Crane and Carr 1994: Figures 2–5). Based on these bar graphs, the authors conclude that the consumption of tree fruits [nance (*Byrsonima crassifolia*) and coyol (*Acrocomia mexicana*)], dogs (*Canis familiaris*), white-tailed deer (*Odocoileus virginianus*), collared peccary (*Tayassu tajacu*), and turtles (Testudines) increased through time (Crane and Carr 1994:70); and they argue these changes in subsistence to be the result of "elite dietary preferences" (Crane and Carr 1994:75).

In order to deal with the inherent differences between paleoethnobotanical and zooarchaeological data, Crane and Carr render both datasets for comparative purposes by using ubiquity analysis. Ubiquity analysis is a presence/absence measure, thus its use is equally valid for both types of data. However, as mentioned above, the use of ubiquity as a means to compare different taxa may be problematic. If it is problematic to directly compare ubiquity values of different *plant* taxa, then it may also be problematic to compare ubiquity values of plant *and* animal taxa, given their vastly different discard/preservation histories. It is important to note, however, that Crane and Carr do not directly compare ubiquity values between plant and animal taxa, thus side-stepping this potential problem. Thus, their analysis can be considered a qualitative integration as they consider plant and animal ubiquity values as being separate and complementary.

2 Diversity

Measures of diversity and equitability share a long-standing use among paleoethnobotanists and zooarchaeologists (see also Peres, this volume for formulae and instructions on calculating diversity and equitability), but rarely are these measures calculated and compared for plant and animal datasets from the same contexts. Comparison of species diversity among contexts or through time is particularly useful in identifying differences in plant and/or animal exploitation – whether people are adding/subtracting types of foods from their diet(s), or if people are focusing their efforts on specific resources. Species diversity can be best understood as composed of two concepts – richness and evenness (or equitability). Richness refers to the number of taxa in a given assemblage; the more taxa present, the richer the assemblage (Kintigh 1984, 1989; Reitz and Wing 2008). Evenness, or equitability, refers to the uniformity of the distribution of taxa in the assemblage; if each taxon is represented by the same number of specimens or individuals, then they are distributed more evenly than an assemblage dominated by a specific taxon (Kintigh 1984, 1989; Reitz and Wing 2008). The most commonly used method among subsistence specialists is the Shannon–Weaver (or Shannon–Weiner) index, but Kintigh's DIVERS method is becoming more prevalent in the subsistence-based literature.[1]

A detailed explanation of the different methods for calculating species diversity is beyond the scope of this chapter [see Kintigh (1984, 1989) and Reitz and Wing (2008) for details]. Rather, the focus here is on using the calculated diversity values for comparing plant and animal assemblages. The Shannon–Weaver index calculates richness as an overall diversity index (H') and equitability (V'). Higher numeric values for H' indicate higher species diversity (richness). Equitability values (V') range from 0 to 1, with a value of 1 indicating an even distribution of taxa, and lower values representing less even (more skewed) distributions. A comparison of H' and V' values from both plant and animal assemblages from different contexts and/or time periods allows us to examine how different food exploitation activities vary with respect to each other. For example, a comparison of diversity values for plants and animals from the same contexts can be achieved qualitatively in the form of a simple bar graph.

A comparison using data from Bezuapan, a Late/Terminal Formative (400 BC–AD 300) farmstead from southern Veracruz, Mexico is illustrated (see Fig. 1 in "Correspondence Analysis and Principal Components Analysis as Methods for Integrating Archaeological Plant and Animal Remains" for regional map with site location; see also VanDerwarker 2006). This type of visual display highlights the relative similarity between Shannon–Weaver diversity values (H') for both plants and animals from consecutive temporal periods (Fig. 1). Diversity values for the plant assemblage increase from the Late Formative period to the first Terminal Formative occupation, and decrease again during the second Terminal Formative occupation; diversity values for the animal assemblage show a parallel pattern. The fact that these patterns in the plant and animal assemblages show a positive relationship (as opposed to an inverse one) indicates that peoples' selection of plant and animal species at Bezuapan are probably linked in some way (as opposed to being completely independent food selections). Perhaps people were exploiting plant and animal species from the same ecological zones; for example, if one or more of these ecological zones were impacted negatively (e.g., through flooding, drought, or in the case of Bezuapan, volcanic eruption and ash fall), then we can expect ramifications for both plant and animal populations native to those zones. Thus, one possible hypothesis for the linkage between plant and animal diversity values may be that humans exploited plant and animal resources from the same environmental zones. This possibility could have implications for modeling hunting/collecting strategies based on age, gender, and group size. Such a hypothesis could then be tested by looking more closely at the ecological requirements and modern biogeographical distributions of plant and animal species to determine a correspondence. Moreover, simple correlation analysis between the resulting plant and animal diversity/equitability values can take the diversity analysis to the next

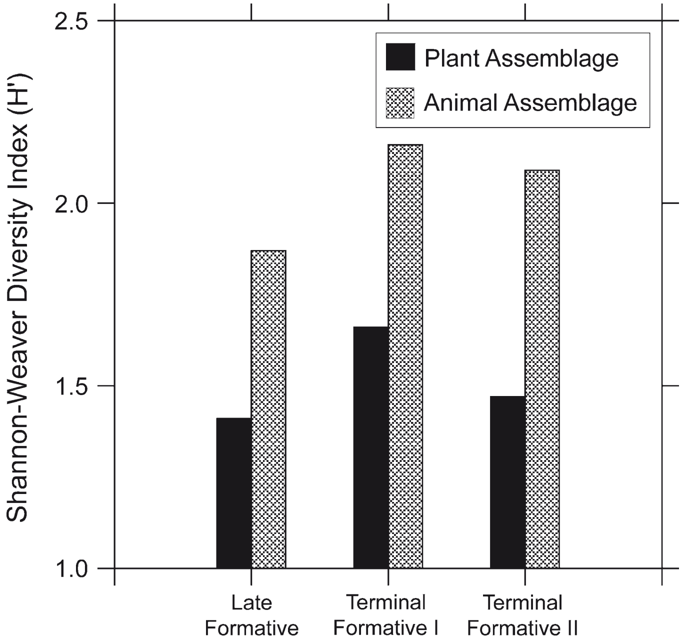

Fig. 1 Bar chart of Shannon–Weaver diversity values for Bezuapan plant and animal assemblages for Late and Terminal Formative occupations

level, from a *comparative* analysis to an *integrative* analysis (see section below on correlation).

With respect to the Bezuapan example, there are several alternative hypotheses that could be put forward to explain the parallel diversity pattern shown in Fig. 1. Exploring all of these possibilities, while beyond the scope of this chapter, would be a necessary next step in carrying forward the analysis. The bar graph itself represents a simple exercise in exploratory data analysis that allowed the identification of a pattern. It is then up to us to determine possible explanations for that pattern and to filter through the archaeological expectations for the types of evidence associated with each potential explanation.

3 Ratios

Attempting to combine plant and animal data in a strictly quantitative fashion requires caution. Preservational and taphonomic biases, sampling strategies, and a myriad of other issues affect plant and animal assemblages differently (Peres, this volume; Wright, this volume), and we must be wary of the techniques we use to attempt data integration. The simplest method for directly integrating archaeological plant and animal data is through the use of independent ratios. Common independent ratios employed by paleoethnobotanists and zooarchaeologists are the nutshell/wood ratio the maize (*Zea mays*) kernel/cupule index, and the artiodactyl index, among others. Independent (or comparative) ratios involve two mutually exclusive variables, and thus compare the relative amounts of two different items, the measures of which are categorically independent (see Miller 1988). Because both the variables are independent of each other, the numerator and denominator do not need to be expressed as the same unit of measurement (see also Wright, this volume). For example, the nutshell/wood ratio in paleoethnobotany calculates the count of weight of nutshell divided by wood weight (per sample or context); this is an one way to standardize plant data in order to make them comparable. Like the nutshell/wood ratio, the artiodactyl (deer) index uses two different groups of taxa as the respective numerator and denominator for calculating ratios (e.g., artiodactyl NISP/lagomorph NISP and other variations). The maize kernel/cupule index uses two different portions of the same taxon to arrive at a value. Moreover, the values used in the numerators and denominators are raw, unstandardized data – basic counts or weights. The ratio itself is the means of standardization, thus allowing for valid comparisons (but see Miller 1988; Wright, this volume for statements of interpretative caution).

Given the use of different taxa (or portions of taxa) and raw counts/weights in calculating independent ratios, it seems reasonable to suggest that independent ratios would be a valid tool for simple data integration of archaeological plant and animal remains. For example, one might be interested in comparing relative values of the highest ranked plant and animal foods through time or across space. Independent analyses of plant and animal data might reveal maize to be the most important plant food and white-tailed deer to be the most important animal resource at a site through time; but how might these two important resources vary with respect to one another? Constructing a maize/deer ratio (or deer/maize ratio) would allow us to investigate a more direct relationship between these two resources. Independent ratios, such as a maize/deer ratio, however, cannot be used uncritically. First, patterns in the maize and deer data have to be assessed independently in order to interpret the resulting ratio. I have fiddled around with these types of ratios in past analyses; sometimes the resulting values make sense and sometimes they are baffling. As with any type of analysis, we must always ask ourselves whether our results are meaningful and whether the index we have chosen is the most appropriate one for the questions we ask.

4 Correlation

A slightly more sophisticated way of determining how different plant and animal taxa vary with respect to each other is the use of correlation coefficients [see Shennan (1997) for a more involved discussion on correlation techniques]. It is not my intention to review all the correlation techniques, nor to give instruction on how to calculate them. Rather, the purpose is to discuss some common techniques and appropriate ways to use them with respect to plant and animal data.

A great example of integrating plant and animal data using a correlation technique can be found in Spielmann and Angstadt-Leto (1996), "Hunting, Gathering, and Health in the Prehistoric Southwest." This article deals with the connection between nutrition and agriculture at several sites throughout the southwestern United States. The authors are specifically interested in how prehistoric agriculturalists dealt with shortfalls in meat resources. Spielmann and Angstadt-Leto (1996) suggest that people might have made up for deficiencies in Vitamin C and Iron (available in animal meat) through targeting certain plant foods. They test this possibility by correlating artiodactyl consumption with consumption of plants from the following genera, all of which are high in Iron and Vitamin C: *Amaranthus*, *Chenopodium*, *Artemesia*, *Portulaca*, *Solanum*, *Sphaeralcea*, and *Lepidium* (Spielmann and Angstadt-Leto 1996:96).

The variable used for estimating artiodactyl consumption is the artiodactyl index, calculated as the ratio of artiodactyl NISP (Number of Identified Specimens) and lagomorph (jackrabbit/cottontail) NISP (Spielmann and Angstadt-Leto 1996:84; see also Bayham 1982). Ubiquity is used as a measure for estimating the consumption of plants high in Iron and Vitamin C. Spielmann and Angstadt-Leto calculated the average and sum of ubiquity values for this category of plants as a whole. First, they calculated the ubiquity value for each plant in the plant category (for each site under consideration); these values were then summed for each site (representing the sum of ubiquity values). To calculate the average ubiquity value, the sum value was divided by the number of plants in the plant category for that particular site (see Spielmann and Angstadt-Leto 1996:Table 9). To assess the relationship between artiodactyl consumption and the consumption of plants high in Iron and Vitamin C, Spielmann and Angstadt-Leto calculated Spearman's rho using (1) the artiodactyl index and average ubiquity values and (2) the artiodactyl index and sum of ubiquity values.

Spearman's rho is a coefficient of rank correlation (see Shennan 1997); it is appropriate in this example because ubiquity values were converted to rank (ordinal) data. Spielmann and Angstadt-Leto calculated the artiodactyl index as artiodactyl NISP/lagomorph NISP. The calculation effectively takes the nominal-level (abundance) data and transforms it into interval/ratio-level data. If the second variable (the artiodactyl index being the first) was also an interval/ratio-level measure, as opposed to an ordinal measure like the converted ubiquity values, then a different measure of correlation would be needed – Pearson's r, for example. It is important to choose a technique that is appropriate to the type of data being used (e.g., nominal, ordinal, interval/ratio); most introductory statistics texts and "help" functions in statistical computer programs will provide this information.

The resulting values from Spielmann and Angstadt-Leto's correlation analysis were both strongly negative (−0.915 for artiodactyl index and average ubiquity, −0.806 for artiodactyl index and sum of ubiquities), indicating an inverse relationship between meat consumption and the consumption of key plant resources (Spielmann and Angstadt-Leto 1996:97). Spielmann and Angstadt-Leto were able to quantitatively demonstrate that prehistoric southwestern agriculturalists made up for nutritional deficiencies resulting from meat shortages (loss of Iron and

Vitamin C) through collecting and consuming key plant resources. Such an inference was only possible through the quantitative integration of plant and animal data. The most encouraging aspect of this study is the way in which Spielmann and Angstadt-Leto were able to sidestep problems of data comparison by using measures appropriate to both datasets (artiodactyl index and ubiquity values). Ultimately, a simple measure of correlation was all that was necessary in order to test how plant and animal resources varied with respect to each other.

5 Spatial Analysis

There are a variety of ways to conduct a spatial analysis and a variety of statistical techniques to assist in this type of analysis. In its simplest form, a spatial analysis that plots the distribution of plant and animal taxa across contexts at a site can have powerful interpretative value. Smith and Egan (1990) present this type of spatial analysis in their article "Middle and Late Archaic Animal and Plant Exploitation at the Weber I Site (20SA581), Michigan." In terms of research questions, the authors are broadly concerned with reconstructing "subsistence practices, seasonality, and palaeoenvironment" (Smith and Egan 1990:39). Like the Crane and Carr example discussed above, Smith and Egan's analysis is focused on a single archaeological site, although Smith and Egan consider both temporal and spatial patterns in the subsistence remains.

It is the spatial analysis that is of interest here, as this is the means by which data integration occurs. Smith and Egan (1990) plot the spatial distribution of plant and animal remains for both the Middle Archaic (ca. 4,000–2,500 BC) and Late Archaic (ca. 1,900–1,000 BC) occupations of the Weber I site. Plant remains[2] are plotted by counts only (≥5 ct.) while animal remains are plotted by counts (≥50 ct.) and weights (≥20.0 g).[3]

The results of the spatial analysis indicate that plants and animals were, respectively, processed and discarded in separate locations of the site during both Middle and Late Archaic occupations. While the authors do not explicitly discuss the implications of separate processing areas for plants and animals, this type of information could allow for the consideration of differences in the spatial dynamics of labor allocation. Indeed, this spatial pattern suggests that these separate food processing areas could reflect a gendered division of labor in which women gathered and processed plant foods and men hunted and butchered game animals. It is interesting that such a spatial division in food processing areas remains consistent throughout both occupations of the site. Ultimately, the analysis presented by Smith and Egan successfully attempts an integration of paleoethnobotanical and zooarchaeological data that leads to interpretive results that would not otherwise be possible. Moreover, their spatial integration allows for the consideration of broader economic issues that would not be possible had they restricted their analysis to temporal trends in the data.

6 Conclusion

This chapter represents a starting point for the consideration of simple quantitative methods for integrating paleoethnobotanical and zooarchaeological data. Methods were presented alongside relevant cases from the archaeological literature where possible. The different methods used in the sample cases represent several potential ways to integrate plant and animal data. The following chapter focuses on more complex statistical procedures for directly integrating plant and animal data, namely multivariate techniques. The case studies in this volume consider some of these methods and some present new methods for integrating data. The choice of any particular method depends on a number of factors, including comparability of plant and animal datasets in terms of preservation, taphonomy, and recovery; sample sizes of respective datasets; and research questions being addressed. The following chapters consider these factors in depth and provide a template against which to determine the suitability of particular datasets for different qualitative and quantitative methods of integration. Finally, the suitability of any method for data integration must be determined on a case-by-case basis.

7 Notes

1. For information on the use and purchase of Kintigh's *Tools for Quantitative Archaeology* (TFQA), visit http://tfqa.com/index.html.
2. Plant remains plotted as part of the spatial distribution were restricted to food remains (e.g., nuts and seeds).
3. Plant remains were only plotted as counts because weights are often negligible; it is possible to identify several seeds in a sample that collectively weigh <0.01 g.

Acknowledgments The National Science Foundation deserves recognition for funding the analysis of plant and animal data from the site of Bezuapan as part of a doctoral dissertation grant (#9912271). I also thank Katherine Spielmann and several anonymous reviewers for comments on earlier versions of this text. Conversations with C. Margaret Scarry over the past several years have greatly shaped how I conceptualize methods for data integration. Finally, I acknowledge the research of Katherine Spielmann, Eric Angstadt-Leto, Beverley Smith, Kathy Egan-Bruhy, Cathy Crane, and H. Sorayya Carr for leading the way with cutting edge integration of plant and animal remains.

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Correspondence Analysis and Principal Components Analysis as Methods for Integrating Archaeological Plant and Animal Remains

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Multivariate analyses, such as correspondence analysis (CA) and principal components analysis (PCA), have gained prominence in archaeology over the past several decades, with applications to a variety of archaeological datasets, including subsistence data (Hollenbach 2005; VanDerwarker et al. 2007; Whitridge 2001, 2002; see also Hollenbach and Walker, this volume, and Peres et al., this volume). These analytical techniques are especially useful in that they allow for the consideration of multiple cases (e.g., contexts, sites, periods) along with multiple variables, producing solutions that can "map" associations between the two. The implication of these techniques for integrating archaeological plant and animal datasets is the ability to consider how different plant and animal resources cluster together in relation to different contexts or time periods. Thus, we can imagine a single solution that differentiates between the diets of different periods (see below) or diets related to different social or spatial contexts (see Peres et al., this volume), just to name a few possibilities.

This chapter offers a method for the direct quantitative integration of zooarchaeological and paleoethnobotanical remains. I demonstrate the utility of correspondence analysis and principal components analysis for different types of datasets (e.g., CA for nominal data, PCA for ratio/interval data). Using the site of La Joya as a case study from Formative Gulf Coastal Mexico, I argue that multivariate statistics are well-suited for exploring the covariance of large zooarchaeological and paleoethnobotanical datasets. Indeed, these techniques have the potential to crosscut subsistence specialties by enabling a broader consideration of foodways at different levels of analysis; we can examine the degree of correlation between different categories of plant and animal remains that originate from multiple sites, multiple features at a single site, or multiple temporal periods. Thus, in situations in which we are interested in exploring multiple contexts alongside multiple food taxa, multivariate analysis is an ideal method for integrating zooarchaeological and paleoethnobotanical data.

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_5,

1 Using Complex Statistics at La Joya

Correspondence analysis and principal components analysis are similar techniques, but CA is appropriate for nominal data and PCA for interval/ratio data (Shennan 1997). Thus, if we are interested in raw abundance data, then each plant/animal fragment constitutes a datum that is present; correspondence analysis takes these nominal-level data and calculates the chi-squared distances between observed and expected values for both cases and variables. If we choose not to use raw abundance data (for example, acknowledging that plant and animal datasets are sampled and collected differently, and thus require different treatment), and thus we standardize our datasets in some way, then we would use PCA. For example, we might choose to standardize the plant data by soil volume or total plant weight, and perhaps standardize the animal data according to %NISP or bone weight (see Peres et al., this volume). In this case, PCA would take these data and calculate the Pearson's r correlation coefficients to measure the associations between the plant and animal variables.

The case presented in this chapter focuses on the use of correspondence analysis. Principal components analysis is discussed further in Peres et al. (this volume). The method of CA is discussed in greater detail within the context of the case study below. I begin by setting the stage for the case study by summarizing the background on the site of La Joya and the broader southern Gulf Coast of Mexico during the Formative period. This is followed by a discussion of recovery and analytical methods for both the plant and animal datasets. After summarizing the interpretations of the plant and animal datasets based on the independent analyses of the datasets, I turn to a discussion of correspondence analysis in the context of the La Joya subsistence data. The purpose of presenting the independent interpretations prior to the presentation of the CA results is to demonstrate the replicability of results, thereby scientifically validating the use of CA for quantitatively integrating archaeological plant and animal data. Ultimately, correspondence analysis (and PCA, for that matter) represents an efficient approach that can produce results above and beyond independent analyses of the data. I purposely chose a case study with few cases as a means to demonstrate the correspondence between the integrative results and the independent results. In reality, multivariate statistics should be chosen when the number of cases and variables exceeds our ability to produce independent results – for example, we can imagine trying to explore the correlation between plant and animal remains in contexts/cases numbering in double or triple digits (e.g., multiple features and multiple sites).

1.1 La Joya in Local and Regional Context

Located in the Sierra de los Tuxtlas in southern Veracruz, Mexico, the site of La Joya provides an excellent case for exploring methods of integrating paleoethnobotanical and zooarchaeological data (Fig. 1). The site was excavated by Philip J. Arnold

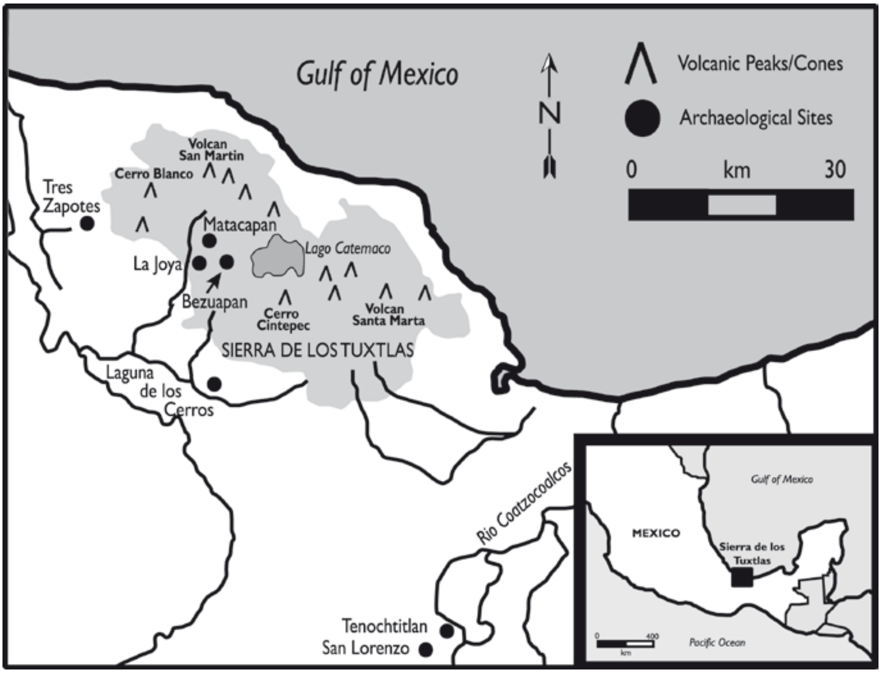

Fig. 1 Map of the Sierra de los Tuxtlas highlighting archaeological sites

III in 1995 and 1996, and has since been the subject of numerous articles (Arnold 1999; 2000; 2002; 2003; VanDerwarker 2005; VanDerwarker and Jaime-Riveron 2008) and two dissertations (McCormack 2002; VanDerwarker 2003). My recent book (VanDerwarker 2006) examines the connection between the subsistence economy and the emergence of social inequality at the site through the identification and examination of both plant and animal datasets. I did not attempt to quantitatively integrate these data in the book, but considered them independently. The independent analyses, thus, represent a template against which the results of the correspondence analysis can be assessed.

Before I discuss the correspondence analysis, it is important to first provide some background and interpretation of the site in a regional context. This is followed by a discussion of sampling and recovery procedures for both floral and faunal remains, as well as potential taphonomic bias in the faunal assemblage; because my analysis considers temporal patterns in the data, it is important to determine whether samples deriving from different temporal contexts are comparable. I then present my interpretive model of subsistence practices at the site with reference to my independent analyses of the data, in addition to relevant information on settlement history and other artifactual materials. The specifics of the independent analyses have been presented elsewhere (VanDerwarker 2003, 2005, 2006); readers can refer to these for a detailed discussion of data analysis and quantitative techniques used in the independent assessment of both plant and animal datasets. After presenting my model, I discuss the method of correspondence analysis and use it to quantitatively integrate the paleoethnobotanical and zooarchaeological data from La Joya.

The Sierra de los Tuxtlas is an ecologically diverse region, replete with an abundance of faunal and floral resources (Andrle 1964; Gomez-Pampa 1973; West 1965). The combination of regional climatic variables, such as high temperatures, frequent rainfall, and year-round frost-free conditions, coupled with its rich volcanically-derived soils makes the Tuxtlas an excellent place for agriculture (Andrle 1965; Gomez-Pampa 1973; West 1965). Palynological (Byrne and Horne 1989; Goman 1992; Goman and Byrne 1998) and macrobotanical data (VanDerwarker 2003, 2005, 2006) indicate that people were cultivating maize (*Zea mays*) in the region by the Early Formative period (1,400–1,000 BC). Nevertheless, Tuxtla residents do not appear to have been fully sedentary until the close of the Early Formative period (Arnold 2000:128; McCormack 2002:133, 185). During the Middle Formative period (1,000–400 BC), ceramic assemblages became more diverse, indicating the development of a wider range of cooking and serving practices (McCormack 2002:184). The manufacture and use of ground stone tools also became more specialized at this time, suggesting an increased focus on maize grinding, and by extension, maize production and consumption (Arnold 2000:126; McCormack 2002:169, 181). The Late Formative period (400 BC–AD 100) heralded the emergence of a regional hierarchical settlement system in the Tuxtlas, with the establishment of the first political center at the site of Chuniapan de Abajo (Santley et al. 1997; see Fig. 1).

A volcanic eruption at the close of the Late Formative period (ca. 150 BC) blanketed the region with ash, and by the Terminal Formative period (AD 100–300), population levels declined dramatically. Nevertheless, some people remained in the Tuxtlas and continued to farm in the altered landscape (Santley et al. 1997; VanDerwarker 2003, 2005, 2006). In the long-term, volcanic ash would have increased the soil fertility, enabling sustainable agriculture. But in the short-term, deep ash deposits would have crippled the local subsistence economy. In addition to negative health consequences and the collapse of house structures, volcanic ash would have destroyed the existing crops and limited the potential for planting new ones (Chase 1981:63–65; Warrick 1975:11–12). While larger trees might survive and continue to bear fruit, most plant life would have required time to regenerate, and local game would have died or fled the region as natural forage died (Eggler 1948; see also Chase 1981:64). Those families that stayed in the Tuxtlas following the eruption would have had to alter their subsistence practices accordingly.

La Joya covers approximately 25 ha and is located on the alluvial flatlands along the Catemaco River in the southern portion of the Tuxtlas (see Fig. 1). Excavations at La Joya uncovered substantial domestic occupations, including house structures, hearths, and storage pits. Radiocarbon dating of charcoal from feature contexts at La Joya reveals that the site was occupied throughout the Formative period, although occupation during the Middle Formative period was rather sparse (see Arnold 2002; 2003). Indirect evidence of subsistence suggests an increasing reliance on maize throughout La Joya's occupation. An increase in the presence and size of subsurface pits from the Early to Late Formative periods indicates that La Joya residents may have been producing, accumulating, and storing more maize through time (Arnold 2000). Moreover, the remains of ridged agricultural fields were identified in several excavations units – these fields were overlaid with a layer of volcanic ash from the Terminal Formative eruption (Arnold 2000). Constructing and maintaining ridged fields constitutes an intensive strategy in that it involves a considerable addition of time and labor (Matheny and Gurr 1983:88). Thus, by the end of the Terminal Formative period, residents of La Joya were farming more intensively.

1.2 Field and Laboratory Procedures

All units excavated at La Joya were dug in 10-cm levels within natural stratigraphy. All soil (except for soil samples taken for flotation) was dry screened through ¼-in. (6.35 mm) mesh. A total of 4,585 specimens weighing 2,920 g were recovered through screening. More than 600 soil samples were taken for flotation from contexts that appeared to have cultural integrity, including pit features and activity surfaces; of these, a total of 318 flotation samples (deriving from all feature contexts and well-defined activity areas) were selected for analysis. Soil was floated using a modified SMAP flotation machine (Watson 1976); the volume of soil sampled was not standardized, but it was systematically recorded, with most samples measuring 3–8 L.

Both the light and heavy fractions of the flotation samples were analyzed. Although the materials from the light and heavy fractions were processed and sorted separately, data from the two fractions were combined for analysis. According to standard practice, the light fractions were weighed and then sifted through 2.0-mm, 1.4-mm, and 0.7-mm standard geological sieves. Carbonized plant remains were sorted in entirety down to the 0.7-mm sieve size with the aid of a stereoscopic microscope (10–40×). While most paleoethnobotanical analyses do not usually identify plant taxa beyond the 2.0-mm or 1.4-mm sieve sizes, most of the maize kernel and cupule fragments identified in the La Joya samples were smaller than 1.4 mm. Thus, I chose to sort all the carbonized plant remains from La Joya down to the 0.7-mm sieve size. Residue less than 0.7 mm in size was scanned for seeds, which were then removed and counted.

My identification of screened faunal materials included recording of the provenience, animal class, genus and species, element, percentage and portion of the element represented, number of specimens, side of element (when applicable), observations regarding the age of the animal, bone modification (whether natural or cultural), and weight (grams). Each specimen was first assigned to the appropriate animal class whenever possible (e.g., mammal, bird, etc.). The anatomical element was recorded when identified. When the element could not be identified, it was placed in an unidentified category. Data collected regarding age included information on cranial fusion, long bone fusion, and tooth eruption, in addition to qualitative observations regarding bone porosity. Observations made with respect to bone modification included the presence or absence of burning and calcination, tool modification, discoloration not associated with burning, and cut marks.

1.3 Taphonomic Analysis

All mammal specimens assigned to a medium or large size class were also observed for carnivore gnawing, rodent gnawing, root etching, and evidence of weathering. Observations of gnawing and root etching were recorded as presence/absence data (Table 1). I ran a Kolmogorov–Smirnov one sample test using a chi-square distribution for all time periods and nominal taphonomic variables. The results reveal no significant differences between different temporal occupations with respect to carnivore gnawing ($\chi^2=0.748$, df=3, $\alpha=0.05$), rodent gnawing ($\chi^2=0.388$, df=3, $\alpha=0.05$), or root etching ($\chi^2=0.747$, df=3, $\alpha=0.05$).

Observations of weathering were recorded as ordinal data based on Behrensmeyer's (1978) descriptions of weathering stages (see also Lyman 1994). Although Behrensmeyer's categories were designed for large mammals, I applied them to medium sized mammals as well, specifically to all mammals equal in size to or larger than the dog specimens identified in the assemblage. I present these data as box plots (Fig. 2; see also Cleveland 1994; McGill et al. 1978; Scarry and Steponaitis 1997; Wilkinson et al. 1992). Box plots summarize actual distributions of data using several key features. The median of the distribution is marked by the an area of maximum constriction at the center of the box. The edges of the box, or hinges, represent the 25th and 75th percentiles of the distribution – the approximate middle 50% of the data fall between the hinges (Cleveland 1994:139). Vertical lines, or whiskers, extend outward from the box and represent the tails of the distribution. Box plots also designate outliers – these are unusually large or small data values that "portray behavior in the extreme tails of the distribution" (Cleveland 1994:140). Outliers are depicted as asterisks and far outliers as open circles.

Table 1 NISP of medium-large mammal bones observed for taphonomic indicators

	Total specimens observed	Carnivore gnawing[a]	Rodent gnawing[b]	Root etching[c]
Terminal formative	417	32	12	14
Late formative	146	4	6	4
Middle formative	86	15	1	20
Early formative	422	23	3	32

[a] $\chi^2=0.748$, df=3, $\alpha=0.05$
[b] $\chi^2=0.388$, df=3, $\alpha=0.05$
[c] $\chi^2=0.747$, df=3, $\alpha=0.05$

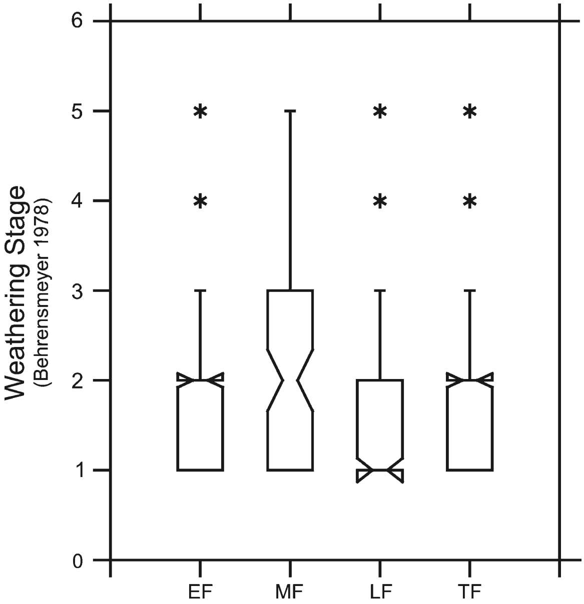

Fig. 2 Box plot of weathering stages by period at La Joya

When comparing batches of data, and thus generating more than one box plot, it is possible to test for statistical differences between distributions. The box plot is easily modified by adding "notches" which characterize the 95% confidence interval around the median. The notches are recognizable in that they give the box plot a characteristic hourglass shape. In some cases, a notch may extend beyond the hinge, appearing to fold back upon itself – this appearance does not change the interpretation of the graph (McGill et al. 1978:14; Scarry and Steponaitis 1997:113). If the notches of any two box plots do not overlap, then the medians of the two distributions are significantly different at about the 0.05 level (McGill et al. 1978:14; Scarry and Steponaitis 1997:113; Wilkinson et al. 1992:198). All of the notches in the box plots in Fig. 2 overlap, indicating a lack of statistical difference between the different time periods with respect to bone weathering. If we look at the distributions closely, however, we see that the range of values for the Middle Formative distribution is much greater than the other three periods; it appears that the Middle Formative assemblage exhibits a greater (though not statistically different) degree of weathering.

Taken together, these measures reveal little difference between La Joya's temporal occupations in terms of taphonomic bias. It appears that the bone assemblages from these periods are indeed comparable. The greater incidence of weathering in the Middle Formative sample, however, requires that we exercise caution in making such a comparison. This sample also has the lowest sample size of floral and faunal remains, small enough to warrant exclusion from my independent analyses of the data (VanDerwarker 2003, 2005, 2006) and the correspondence analysis presented below.

1.4 Summary of Independent Analyses of Plant and Animal Data

Independent analyses of the paleoethnobotanical and zooarchaeological data are presented in detail in VanDerwarker (2006). These analyses used multiple measures to assess changes in plant and animal diets at the site. In terms of the paleoethnobotanical data, measures include ubiquity, relative percentages, species richness and equitability, standardized counts, and comparative ratios. In terms of the zooarchaeological data, measures include animal class percentages, animal class ratios, species richness and equitability, aquatic taxa percentages, disturbance/edge fauna percentages, commensal taxa percentages, and large/small taxa ratios; all of these measures were calculated based on NISP, and most were calculated based on MNI and bone weight as well. Below I summarize some of the findings of these analyses to present an overall picture of subsistence at the site.

Most of the paleoethnobotanical samples from La Joya come from Early Formative and Terminal Formative contexts. Middle and Late Formative contexts yielded fewer samples, and as a result, lower samples sizes in general (Table 2). A greater number of taxa were identified in the Early and Terminal Formative assemblages – these assemblages are also characterized by a greater overall abundance of taxa than the Middle and Late Formative assemblages. Generally, maize, beans

Table 2 Counts of plant taxa by period[a] for La Joya

		EF	MF	LF	TF
Number of Samples		158	13	30	65
Plant weight		7.23	0.56	0.62	3.56
Wood Weight		6.57	0.26	0.42	1.59
FIELD CROPS					
Maize cupule	*Zea mays*	3			10
Maize kernel	*Zea mays*	91	5	6	153
Maize kernel cf.	*Zea mays* cf.	4			
Tepary bean cf.	*Phaseolus acutifolius* cf.	1			
Bean	*Phaseolus* sp.	6			22
Bean cf.	*Phaseolus* sp. cf.	1			5
Bean family	Fabaceae				1
Bean family cf.	Fabaceae cf.	5			
TREE CROPS					
Avocado	*Persea americana*	8	3	4	10
Avocado cf.	*Persea americana* cf.	5			
Coyol	*Acrocomia mexicana*	3	2		30
Sapote	*Pouteria sapote*	1			22
MISCELLANEOUS					
Trianthema	*Trianthema* sp.	1			
Achiote cf.	*Bixa orellana* cf.			1	
Unidentified		182	74	23	311
Unidentified seed		7	3	2	3

[a] *EF* Early formative, *MF* Middle formative, *LF* Late formative, *TF* Terminal formative

(*Phaseolus* sp.), avocado (*Persea americana*), coyol (*Acrocomia mexicana*), and sapote (*Pouteria sapote*) appear to be the most common plant food resources at the site. Despite the disparity in sample size and taxa representation between the different periods represented at La Joya, certain trends in the data are apparent. Maize is ubiquitous throughout the site's occupation; indeed it has the highest ubiquity value of any plant taxa during all time periods (VanDerwarker 2006:95). Box plots of standardized maize counts reveal no statistical differences in the distribution of maize through time, suggesting that residents of La Joya processed and consumed comparable amounts of maize throughout the Formative sequence (VanDerwarker 2006:Fig. 4.7). Thus, maize appears to have been the most important plant resource before the transition to year-round occupation of La Joya at the close of the Early Formative period.

Ratios of maize kernels to maize cupules decrease from the Early through Terminal Formative periods, indicating an increased focus on maize shelling at the site (VanDerwarker 2006:103). Before maize can be ground into flour, the kernels must first be removed from the cob, leaving the cobs and cupules as byproducts of the removal process. Because kernels represent the part of the maize plant meant for consumption and cupules represent processing discard, lower ratios of kernel counts to cupule counts would be indicative of elevated levels of maize processing (Scarry and Steponaitis 1997:117). I have argued elsewhere (VanDerwarker 2003, 2005, 2006) that increased shelling of maize at the site may be indicative of an increasing focus on infield cultivation. According to Killion's Infield/Outfield model of agricultural intensification, we can expect that people would have stored and processed maize at the houselot if infields were cultivated intensively (Killion 1987, 1990). Conversely, if outfields were cultivated intensively, then we can expect that people would have stored and shelled their maize in outfields, away from the houselot. Given this model, I have interpreted the decrease in kernel/cupule ratios at La Joya to signify a change in farming strategies toward a focus on infield cultivation. This shift in farming strategy represents an intensification of maize production in that people would have had to fallow land for shorter periods to maintain infield production; with shorter fallows, farmers would have had to invest more labor into their infield plots to produce sufficient yields – evidenced by field ridging identified in the Terminal Formative deposits at La Joya (see also Arnold 2000).

Ratios of tree crops (avocado, coyol, and sapote) to field crops (maize and beans) increased from the Early through Terminal Formative periods, indicating an increase in the harvesting and consumption of tree fruits through time (VanDerwarker 2006:108). I have argued elsewhere that this pattern represents the culmination of a millennium of human-directed agroforestry that was a direct outcome of the swidden farming system (VanDerwarker 2003, 2005, 2006). During the Early Formative period, people were residentially mobile, probably planting maize (and maybe beans) on a seasonal basis. At the end of the Middle Formative period, people were already sedentary, and began to focus more on agricultural production (see also McCormack 2002). Over time, as populations increased and Formative people became more invested in the swidden cycle, they created more gardens, more managed fallows, and more managed forests. This process would have culminated in an increase in the proportion of edible fruit trees (and economically useful plant species as a whole) through time (see also Peters 2000). Thus, by the end of the Formative sequence, people were literally harvesting the fruits of their labor to a greater degree because the fruits were more readily available. It is also interesting that the greatest increase in tree crops relative to field crops occurred during the Terminal Formative, after the major volcanic eruption at the close of the Late Formative. Volcanic ash fall would have destroyed maize crops and limited the short-term growth potential of new ones, but trees would have been less affected, rebounding more quickly (see Eggler 1948).

As the livelihood of Formative people became more embedded in a farming economy, they probably altered the manner in which they exploited the faunal resources around them. Given the gradual intensification of field and tree crops indicated by the plant data, I approached my analysis of animal data through the lens of garden-hunting. The garden-hunting model proposes that people dealt with new scheduling conflicts between farming and hunting by hunting/trapping animals inhabiting their fields and gardens (Emslie 1981:306; Linares 1976:331; Neusius 1996:276). Since many of these animals were crop pests, garden-hunting served the dual purpose of providing protein to the diet and protecting crops from competitors (Emslie 1981:306; Neusius 1996:276; Szuter 1994:60). Following this line of reasoning, Neusius (1996:276) argues that as farming became a more prominent subsistence activity, hunting, in turn, became a non-selective, opportunistic activity that increasingly occurred within the context of other subsistence-related tasks. This change in hunting patterns would be reflected archaeologically by an increase in types of prey that prefer disturbance habitats and a decrease in aquatic fauna (e.g., fish, waterfowl, and aquatic turtles) (Linares 1976:347; Neusius 1996:276).

A variety of measures reveal that the residents of La Joya appear to have increasingly focused on terrestrial taxa, and mammals, in particular, during the Early through Late Formative periods (Table 3). The percentage of mammals increased throughout this period (NISP and MNI), while the percentage of aquatic fauna

Table 3 Number of identified specimens (NISP) for La Joya by period[a]

Common name	Taxonomic name	EF	MF	LF	TF
FISH					
Alligator gar	*Lepisosteus spatula*				2
Sucker family	Catostomidae	1			1
Catfish family	Pimelodidae				6
Snook	*Centropomus* sp.	7	3		33
Jack	*Caranx* sp.	2			2
Snapper	*Lutjanus* sp.	3	1		2
Mojarra	*Cichlasoma* sp.	3		1	23
UID fish		57	20	8	389
AMPHIBIANS					
Toad	*Bufo* sp.	2	1	2	162
Frog	*Rana* sp.				
Toad/frog		2	1		33

(continued)

Table 3 (continued)

Common name	Taxonomic name	EF	MF	LF	TF
REPTILES					
Mexican giant musk turtle	*Staurotypus triporcatus*				7
Pond/box turtle family	Emydidae			7	
Slider	*Trachemys scripta*				49
UID turtle		8		17	9
Green iguana	*Iguana iguana*	4			158
Boa constrictor	*Boa constrictor*				262
UID snake		1		1	3
BIRDS					
Duck family	Anatidae	1			1
Muscovy duck	*Cairina moschata*				2
Duck	*Anas* sp.	2		1	1
Hawk	*Buteo* sp.	1			1
Falcon family	Falconidae	1		1	
Turkey/quail family	Phasianidae		1		
Wild turkey	*Meleagris gallopavo*	2		1	
Northern bobwhite	*Colinus virginianus*	1			1
Yellow-bellied sapsucker	*Sphyrapicus varius*	1			
UID bird		7	1	1	16
MAMMALS					
Opossum	*Didelphis* sp.	20		118	7
Nine-banded armadillo	*Dasypus novemcinetus*				4
Squirrel	*Sciurus* sp.	1			2
Hispid pocket gopher	*Orthogeomys hispidus*	30	7	9	8
Mouse/rat family	Muridae	2	2		13
Coues' rice rat	*Oryzomys couesi*	4	2		18
Hispid cotton rat	*Sigmodon hispidus*	2		3	18
Mexican wood rat	*Neotoma mexicana*				2
Mouse	*Peromyscus* sp.	8	7		72
Rabbit	*Sylvilagus* sp.	10	2	2	10
Domestic dog	*Canis familiaris*	5	6	11	51
Skunk/weasel family	Mustelidae				1
Ocelot	*Leopardus pardalis*	2			
Peccary family	Tayassuidae				1
Collared peccary	*Tayassu tajacu*	2			1
Deer family	Cervidae	8	16	7	11
White-tailed deer	*Odocoileus virginianus*	8	10	20	36
Red brocket deer	*Mazama americana*	1			1
UID mammal		468	135	322	507
Unidentified		80	23	19	275

[a] *EF* Early formative, *MF* Middle formative, *LF* Late formative, *TF* Terminal formative

decreased (NISP) (VanDerwarker 2006:154, 159). The high percentages of disturbance fauna (NISP, MNI, and presence) in the Early through Late Formative assemblages point to a focus on garden-hunting throughout this time (VanDerwarker 2006:162). Because most of the hunting took place in disturbed habitats near the settlement, people probably did not travel far to procure faunal resources. The decrease in species richness and evenness during this span of time also suggests that people became more selective about the animals they chose to exploit (VanDerwarker 2006:157). This increase in prey selectivity from the Early through Late Formative period may indicate that farming had become a more dependable and less risky venture.

During the Terminal Formative, however, these trends in faunal procurement reversed. At this time, the residents of La Joya began to exploit a wider range of habitats, procuring more animals from aquatic and primary forest habitats. An increase in species richness and evenness during the Terminal Formative, in addition to general increases in birds, reptiles, and fish, supports this pattern. This expansion of the hunting territory may have involved more time away from the houselot and fields. Nevertheless, an increase in food storage (see Arnold 2000) coupled with the plant data discussed above indicates that La Joya residents intensified maize production in infields at this time. Volcanic eruptions at the end of the Late Formative period would have affected the abundance of local fauna and may have limited the availability of good farmland during the subsequent Terminal Formative period (see Chase 1981; Eggler 1948). Residents of La Joya may have responded to these new subsistence limitations by focusing more intensively on fewer maize fields and widening their hunting range. Overall, these patterns suggest that the Terminal Formative residents of La Joya may have been faced with increasing subsistence risk, possibly related to local environmental catastrophe (volcanic eruptions and ash fall), in addition to potential tribute demands[1] by regional leaders in the face of local recovery from environmental catastrophe.

1.5 *Correspondence Analysis at La Joya*

Correspondence analysis is an ordination technique that uses nominal data (abundance data or presence/absence data) and calculates the chi-squared distances between the actual and expected values for both cases and units (Baxter 1994; Greenacre 1984; Shennan 1997; Statsoft, Inc. 2003). This technique analyzes simple two-way tables by measuring the degree of correspondence between columns (cases) and rows (units). While a simple chi-square statistic can be used to examine small tables, correspondence analysis allows for the simplification of large tables with many cases and/or units (Baxter 1994; Shennan 1997; Statsoft, Inc. 2003). The most common type of analysis uses the two-way frequency cross-tabulation table.

At La Joya, the columns/cases represent the pooled occupations for each time period; the rows/units are the plant and animal categories. The raw frequencies for cases and units are listed in Table 4. Sample sizes were too small for the Middle Formative period, and therefore this case is excluded. The analysis presented here uses only three cases – the Early, Late, and Terminal Formative periods. The plant categories include maize, bean, avocado, coyol, and sapote. These five taxa represent the most abundant and ubiquitous plant foods in the assemblage. The animal

Table 4 Frequency table of raw data for cases and units used in the correspondence analysis

	Early Formative	Late Formative	Terminal Formative	Row totals
Aquatic fauna	17	2	121	140
Arboreal fauna	5		420	425
Commensal fauna	16	5	270	291
Disturbance fauna	74	149	65	288
Domestic dogs	5	11	51	67
Forest/terrestrial fauna	4	1	8	13
Maize	98	6	163	267
Bean	13		28	41
Avocado	13	4	10	27
Coyol	3		30	33
Sapote	1		22	23
Column totals	249	178	1,188	1,615

species are grouped according to broad habitat preferences – categories include (1) terrestrial animals that prefer forested habitats, (2) arboreal fauna that prefer forested habitats, (3) aquatic fauna, (4) commensal fauna (i.e., mice and toads), (5) animals that prefer disturbed habitats, and (6) domestic dogs (*Canis familiaris*). Please refer to VanDerwarker (2006) for a detailed listing of habitat preferences by species. Table 5 standardizes the raw data such that the relative frequencies of all cells sum to a value of 1.0; this type of standardized frequency table shows "how one unit of mass is distributed across the cells" (Statsoft, Inc. 2003:2; see also Shennan 1997). Standardized row and column values are thus referred to as row mass and column mass, respectively.

The purpose of correspondence analysis is to identify the total variance from expected values; expected values are ones which display no relationship between row and column values (Baxter 1994; Greenacre 1984; Shennan 1997; Statsoft, Inc. 2003). The closer the actual computed values are to zero, the closer they are to the average expected value. For each row and column, we are interested in the variables that are most similar or different. We measure the departure of actual values from expected values as the total Pearson chi-square for the two-way table divided by the total sum of row and column values ($n=1{,}615$; see Table 4); this departure from expected values, or variance, is referred to as inertia (Baxter 1994; Greenacre 1984; Shennan 1997; Statsoft, Inc. 2003). In addition to identifying variance, correspondence analysis also determines how many dimensions, or components, can explain the variance. For each component, correspondence analysis computes an eigen value that represents "the proportion of inertia or variation explained by the associated component" (Baxter 1994:114–115). In terms of the analysis conducted for the La Joya data, the first component explains 80.9% of the variance, and the second component explains 19.1%; thus 100% of the variance is explained in two components (Table 6). The reason that two components explain the total variance is a technical one; in two-way tables, the variance will always be explained by the total number of columns minus one. That is, degrees of freedom (df) are calculated as $n-1$, where n represents the number of columns. In the La

Table 5 Row mass and column mass for La Joya units and cases

	Early Formative	Late Formative	Terminal Formative	Row totals
Aquatic fauna	0.010526316	0.001238390	0.074922601	0.086687307
Arboreal fauna	0.003095975		0.260061920	0.263157895
Commensal fauna	0.009907121	0.003095975	0.167182663	0.180185759
Disturbance fauna	0.045820433	0.092260062	0.040247678	0.178328173
Domestic dogs	0.003095975	0.006811146	0.031578947	0.041486068
Forest/terrestrial fauna	0.002476780	0.000619195	0.004953560	0.008049536
Maize	0.060681115	0.003715170	0.100928793	0.165325077
Bean	0.008049536		0.017337461	0.025386997
Avocado	0.008049536	0.002476780	0.006191950	0.016718266
Coyol	0.001857585		0.018575851	0.020433437
Sapote	0.000619195		0.013622291	0.014241486
Column totals	0.154179567	0.110216718	0.735603715	1

Table 6 Eigen values and % inertia by component

Component	Eigen value	% Inertia	Cumulative inertia
1	0.462805	80.9	80.9
2	0.108949	19.1	100

Joya table, there are only three columns – the Early, Middle, and Terminal Formative periods – and thus, degrees of freedom are calculated as 3−1, yielding two components.

The resulting component scores for the La Joya cases and units are listed in Table 7. Similar scores between two row or two column variables indicate a close relationship; conversely, disparate scores indicate a weak relationship. Component scores can be plotted in two-dimensional space as a visual representation of the relationship between row and column variables (Baxter 1994; Greenacre 1984; Shennan 1997; Statsoft, Inc. 2003). In such a representation, close spatial proximity indicates a close relationship; the greater the distance between the two variables, the weaker the relationship. Figure 3 plots the case results. The closer the values are to zero, where the two axes intersect, the closer they are to the average expected value (Baxter 1994; Greenacre 1984; Shennan 1997; Statsoft, Inc. 2003). The Early, Late, and Terminal Formative periods separate from each other rather markedly, both from the average expected value *and* from each other. If we plot the plant and animal groups onto this, we see three distinct clusters (Fig. 4). The Early Formative cluster includes terrestrial fauna that prefer undisturbed forests and the plant domesticates (maize, bean, and avocado). The Late Formative period is represented by animals that prefer disturbed habitats. The Terminal Formative cluster is composed almost entirely of wild resources; these include tree fruits coyol and sapote, and animals from a variety of different habitats. Domestic dogs also fall within the Terminal Formative cluster.

Table 7 Component scores for cases and units

	Component 1	Component 2
UNITS		
Aquatic fauna	–0.492444	–0.082085
Arboreal fauna	–0.774416	0.684005
Commensal fauna	–0.611844	0.421270
Disturbance fauna	2.017852	0.617517
Domestic dogs	0.081928	0.773896
Forest/terrestrial fauna	0.157383	–1.253145
Maize	0.033050	–1.878633
Beans	–0.166520	–1.583703
Avocado	0.820617	–2.302424
Coyol	–0.616833	0.096152
Sapote	–0.711272	0.448449
CASES		
Early Formative	0.811764	–2.19704
Late Formative	2.486972	1.374046
Terminal Formative	–0.542770	0.254615

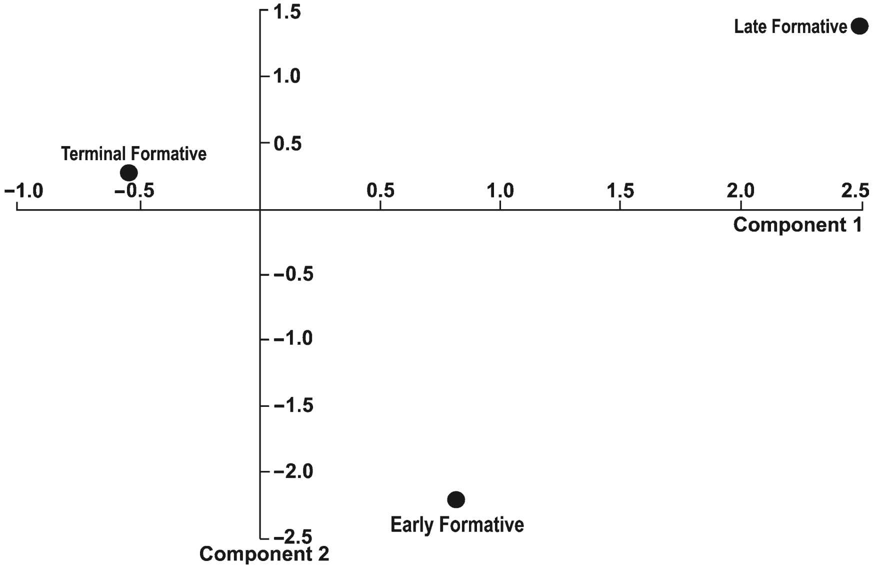

Fig. 3 La Joya cases plotted against two components

The results of the correspondence analysis indicate a clear relationship between plant domesticates, forest animals that prefer undisturbed habitats, and the Early Formative period. Early Formative residents of La Joya farmed maize and beans and actively tended avocado trees. The focus on undisturbed forest animals indicates that Early Formative people were not yet farming intensively – they still had not cleared enough land to significantly change the composition of the local fauna.

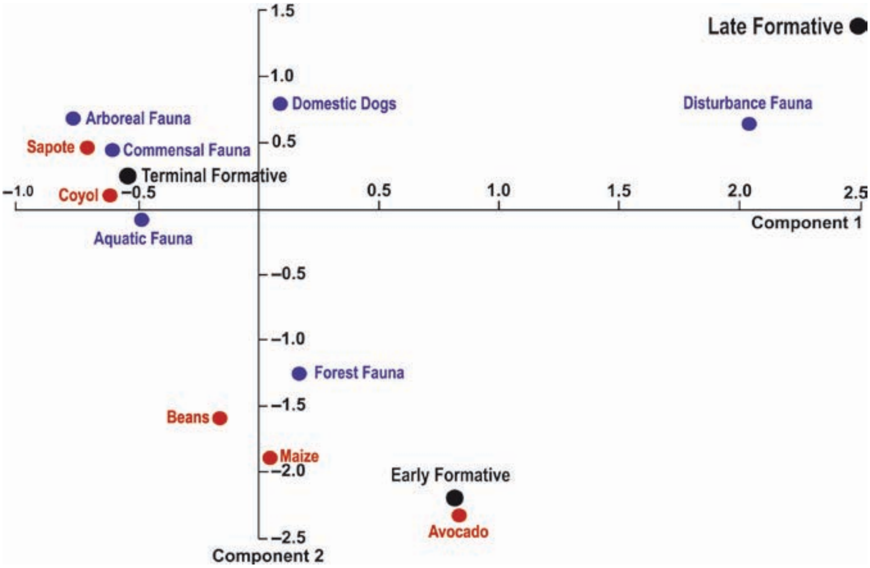

Fig. 4 La Joya cases and units plotted against two components

By the Late Formative period, however, people had altered the landscape such that disturbance fauna dominated the local environment. Similar scores for disturbance fauna and the Late Formative period support a close relationship between these variables. The fact that the Late Formative residents of La Joya focused their animal diet around disturbance fauna indicates their increased commitment to farming in two ways – (1) they were clearing more land for agricultural fields and (2) they were garden-hunting. This increased focus on farming is correlated with the region's political consolidation. After the volcanic eruption at the end of the Late Formative period, however, La Joya's residents shifted to a focus on wild resources, indicated by the cluster of similar scores for sapote, coyol, and the Terminal Formative period. La Joya's residents still cultivated maize and beans (as these variables are situated almost midway between the Early and Terminal Formative cases along component 1), but these domesticates were heavily supplemented by wild tree fruits, fish, waterfowl, turtles, and various arboreal animals. At this time, people may have also included animals in their diet that they previously did not choose to eat, such as mice, toads, and dogs.

The analysis presented here confirms my earlier interpretations of the plant and animal data from La Joya based on the independent analyses. From Early to Late Formative times, people increasingly focused their plant and animal foodways around farming. When faced with the consequences of environmental catastrophe, however, they diversified their subsistence portfolio to include a wider range of wild resources from a variety of habitats. Thus, the case presented here demonstrates the effectiveness of multivariate analysis for integrating paleoethnobotanical and zooarchaeological data. Indeed, a dual consideration of plant and animal data is absolutely critical for understanding how people organized and re-organized their subsistence systems in the context of farming and in the face of environmental risk. Ultimately, demonstrating the accuracy of this quantitative method on a relatively simple case through replication of the independent results allows for its use in more complex cases where independent analyses of the plant and animal data would be insufficient for exploring connections between these datasets. I discuss this in more depth below.

1.6 Discussion: Correspondence Analysis as an Integrative Tool

A primary goal of this chapter is the consideration of methods for integrating paleoethnobotanical and zooarchaeological data. Toward this end, I have presented a case study using correspondence analysis and have demonstrated that the analysis yields similar interpretive results as independent analyses of the same data. Accepting correspondence analysis as a valid method for integrating these data, however, requires more than a simple confirmation of the independent patterns from a single case study. Given the methodological differences between paleoethnobotanical and zooarchaeological data, namely preservation and sampling/recovery issues discussed in previous chapters ("On Methodological Issues in Zooarchaeology" and "On Methodological Issues in Paleoethnobotany"), is it valid and reasonable to combine abundance data from these datasets in the same quantitative analysis? I argue that it is. Correspondence analysis, by using a Pearson chi-square statistic, is essentially a measure of association. If we were simply considering the relationship between maize and deer through time, there would be no objections to using a simple measure of correlation. Considering the relationships among multiple variables, however, requires a more complex measure of association. Instead of running a two-way correlation over and over again until we have covered all the variables of interest, correspondence analysis can analyze many variables and examine multiple relationships at once.

The main methodological concern for running the correspondence analysis thus becomes quantitative in nature. That is, what is the most appropriate method(s) for quantifying the paleoethnobotanical and zooarchaeological assemblages for inclusion in a multivariate analysis? For example, should we use NISP or MNI to quantify the animal remains, or some other measure altogether? I choose simple taxon counts for both plant and animal datasets for two reasons. First, it seems preferable to quantify both types of data in the same way for purposes of integrating them; in doing so, we know they are comparable insofar as they are represented similarly as raw data. Secondly, the correspondence analysis standardizes the raw data, and thus, the taxon counts need not be standardized as ratios or percentages prior to the analysis. If one chose to standardize the plant and animal abundance data prior to running the analysis (e.g., plants counts/soil volume, animal NISP/faunal weight), then principal components analysis, not correspondence analysis, would be the appropriate multivariate technique to use (see Peres et al., this volume). It should be noted that in the course of the La Joya analysis, I also standardized the datasets (in the same manner as discussed in Peres et al., this volume) and conducted a PCA for comparison with the CA; the results in terms of the two-dimensional plot were virtually identical.

To gauge the interpretive value of the correspondence analysis with respect to my case study, I compared the integrative results to the patterns I identified through independent analyses of paleoethnobotanical and zooarchaeological datasets. My interpretation of the correspondence results reiterates my interpretation of the independent analyses. This begs the question: if the correspondence analysis simply confirms what I already knew from independent analyses, then why is it useful? The primary purpose of this chapter is to demonstrate that correspondence analysis is a valid method for integrating plant and animal data. In order to do so, it is imperative that I demonstrate replicability of results between CA and the independent analyses of the data. The only way to demonstrate replicability is to choose an example with few enough cases such that independent analysis on a case-by-case basis is actually feasible. Of course, correspondence analysis is not strictly necessary in the La Joya example; this is because we can use univariate measures to determine how plant and animal data co-vary without actual quantitative integration of the two. However, if we were dealing with many more cases and variables (for example, hundreds of features), it would be a difficult and time-consuming task to demonstrate animal/plant covariance relying on simple univariate analysis. Indeed, correspondence analysis was designed precisely to examine the relationship between multiple cases and variables. Thus, the significance of the replicability of results between the La Joya independent analyses and the La Joya correspondence analysis lies in the conclusion that correspondence analysis is a valid statistical technique for quantitatively integrating plant and animal datasets. Once issues of comparability (e.g., methodological and taphonomic) have been appropriately dealt with, correspondence analysis can be used to examine the covariation between plant and animal datasets that come from multiple analytical contexts.

2 Conclusion

As shown throughout this volume, there are a variety of ways that plant and animal data can be integrated, both qualitatively and quantitatively. Regardless of whether we choose to integrate our subsistence data using one of the techniques presented here or create a new measure for data integration, it is imperative that we first consider a suite of issues prior to operationalizing an integrative technique, including preservational/taphonomic histories unique to the dataset(s), recovery methods employed, and the appropriateness of the technique to the level of data (e.g., ensuring our data fit the assumptions of the statistical technique chosen). Moreover, once we have integrated these data, we must determine the interpretive value of the results in order to assess if our results are indeed meaningful. As demonstrated in this chapter and throughout this volume, with the appropriate level of caution, the integration of plant and animal datasets can provide fruitful results that allow us to push our interpretations and understandings of ancient subsistence forward.

3 Notes

1. At this point, a consideration of tribute is speculative. If a tribute economy was in place, however, tribute demands could have taken many forms, including labor (working fields, building mounds) and food transport (whether in the form of farm produce, or hunting/fishing surpluses).

Acknowledgments The National Science Foundation deserves recognition for funding the analysis of the plant and animal materials from the site of La Joya as part of a doctoral dissertation grant (#9912271). I also thank Katherine Spielmann and several anonymous reviewers for comments on earlier versions of this text. Finally, I have benefitted greatly from conversations with C. Margaret Scarry regarding methods and ideas for integrating plant and animal data.

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Part II
Case Studies

Microbotanical and Macrobotanical Evidence of Plant Use and the Transition to Agriculture in Panama

Ruth Dickau

Many studies over the past few decades have demonstrated the importance of using multiple lines of data when studying ancient plant use in a given region. This is especially true in the humid tropics, where plant taxonomic diversity is high and organic preservation is often poor due to accelerated rates of biological and chemical decay. The post-depositional preservation of each major type of botanical artifact – macrobotanical remains, phytoliths, pollen, and starch grains – is affected differently by human behavior and natural factors (see Wright, this volume). Therefore, using several techniques for identifying plant remains significantly improves the chances of reconstructing a more inclusive paleoethnobotanical record because the taxonomic assemblages generated by each technique can be considerably different.

1 Overview of Previous Paleoethnobotanical Research in Panama

Nearly half a century of paleoethnobotanical research in Panama underscores the value of multiple datasets. The first systematic paleoethnobotanical study was the palynological analysis of sediment cores from Gatún Lake (formerly, the Chagres River Valley) in the 1960s (Bartlett and Barghoorn 1973; Bartlett et al. 1969). These cores provided information on the vegetational history of the surrounding watershed since the Pleistocene and the introduction of certain domesticates. Piperno (1985a) later analyzed phytoliths from the same sediments, clarifying the nature and extent of human impact on regional forests. Subsequent reconstructions of the paleoenvironment in other Panamanian lake basins, such as La Yeguada (Piperno et al. 1991a, b), Monte Oscuro (Piperno and Jones 2003), and

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_6, © Springer Science+Business Media, LLC 2010

Cana (Bush and Colinvaux 1994), have relied on combined pollen and phytolith analyses on the same cores.

Paleoethnobotanists began identifying carbonized plant remains from Panamanian archaeological sites in the 1970s (Bird 1984; Galinat 1980; Smith 1980). Their results gave the impression that important cultigens, such as maize (*Zea mays*) appeared relatively late in the cultural sequence (after 1200 BC). Galinat's (1980:175) hypothesis that maize was of considerably greater antiquity on the Isthmus than the macrobotanical record indicated was soon confirmed by Piperno's analyses of phytoliths found in soils deposited at several lowland rockshelters (Piperno et al. 1985). Phytoliths also demonstrated the adoption of several other crops, including arrowroot (*Maranta arundinacea*), bottle gourd (*Lagenaria siceraria*), lerén (*Calathea allouia*), and squash (*Cucurbita moschata*), by 5800 BC (Piperno 1985b, 2004, 2006b; Piperno et al. 2000a; Piperno and Clary 1984; Piperno and Pearsall 1998). When starch grain analysis began to be used in the 1990s, it confirmed the antiquity of maize and revealed the pre-ceramic use of several other major crops in the central Pacific lowlands and foothills, including manioc (*Manihot esculenta*), yams (*Dioscorea trifida*), and chili peppers (*Capsicum* spp.) (Perry et al. 2007; Piperno 2006a; Piperno and Holst 1998, 2004; Piperno et al. 2000b). With the exception of possible manioc pollen in the Gatún Basin cores, these crops had previously been invisible in other paleoethnobotanical records. More recently, starch grain analysis has led to a revision of the nature and antiquity of plant use in another area of Panama, the western Pacific highlands. Pre-ceramic (6000–300 BC) inhabitants of the region, once believed to be exclusively hunter-gatherers, had in fact used cultivated plants like maize, manioc, and arrowroot by at least 5400 BC (Dickau et al. 2007).

2 Current Paleoethnobotanical Research in Panama

The above synthesis briefly illustrates how the use of only one particular botanical record can lead to a skewed view of pre-Columbian plant use in Panama. Many species are only visible via one or two signatures (e.g., pollen, phytoliths), or poorly represented in certain time periods due to the vagaries of preservation and human behavior. A more robust view of human-plant interaction is made possible through the integration of several datasets (Piperno 1995). In this chapter, I review existing macrobotanical, pollen, phytolith, and starch data for two regions of Panama that have provided the most complete paleoethnobotanical records: (1) *Central Panama*, extending from just east of the Canal to the Veraguas provincial border; and (2) *Western Panama* from the Veraguas border to Costa Rica (Fig. 1).[1] Since the Late Pre-ceramic period (6000–3300 BC), human groups living in these two regions have exhibited notable differences in material culture that allude to divergent social histories (Cooke 2005; Ranere and Cooke 1996). In addition to reviewing existing data, I also present new macrobotanical data from Western Panama. I then integrate the datasets from these two regions in order to draw conclusions about regional

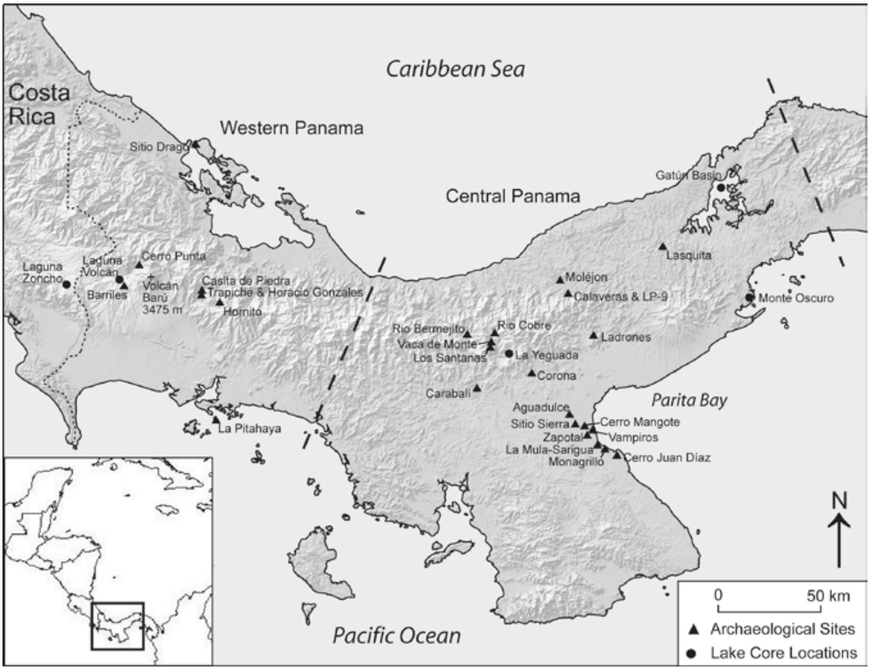

Fig. 1 Map of Western and Central Panama, showing archaeological sites and lake core locations discussed in the text

differences in the transition to agriculture. Due to the broad range of data, and the varying conditions of preservation, collection, and analysis, my attempt at integration in this case study is strictly qualitative, based on the concepts outlined in VanDerwarker and Peres' introductory chapter to this volume. I attempt to synthesize paleoethnobotanical data for specific plant use at archaeological sites (both microbotanical and macrobotanical) and paleoenvironmental data derived mainly from pollen and phytoliths in sediment and lake cores, in order to reconstruct plausible scenarios for the adoption of agriculture in each region. Some quantification is provided, but this is uneven among datasets, and therefore I feel the data can only support a comparative or qualitative level of integration. Quantitative integration should be a future goal, at least within individual sites that have been well-documented and analyzed.

2.1 Central Panama

2.1.1 Brief Chronology

Numerous archaeological sites in Central Panama document human occupation of the region from initial Paleoindian migration to Spanish conquest (before 9000

Table 1 Archaeological chronology of Central and Western Panama (after Cooke and Sanchéz 2004; Linares and Ranere 1980)

	Central Panama	Western Panama
Date BC/AD	Period	Period
AD 1500	Spanish Contact	Spanish Contact
AD 1000	Late Ceramic (AD 800–1500)	Ceramic (300 BC–AD 1500)
AD 1	Middle Ceramic (400 BC–AD 800)	
1000 BC	Early Ceramic (3300–400 BC)	Pre-ceramic (Boquete phase, 3000–300 BC)
2000 BC		
3000 BC	Late Pre-ceramic (6000–3300 BC)	Pre-ceramic (Talamanca phase, 6000–3000 BC)
4000 BC		
5000 BC		
6000 BC	Early Pre-ceramic (8500–6000 BC)	
7000 BC		?
8000 BC		
9000 BC	Paleoindian (11500–8500 BC)	
10000 BC		
11000 BC		
	?	
12000 BC		

BC–AD 1500) (Cooke and Ranere 1992a, b; Cooke and Sanchéz 2004) (Table 1). The first indisputable evidence of human activities in the region corresponds to the recovery of stone tools of the Paleoindian tradition (11500–8500 BC) and paleoenvironmental evidence of landscape modification in the Pacific watershed (Pearson 2003; Pearson and Cooke 2002; Piperno 2006b; Piperno et al. 1991a; Ranere 2000; Ranere and Cooke 2003). During the Early Pre-ceramic period (8500–6000 BC), the use of rockshelters intensified and ground-stone tools first appeared (Ranere 1992). Towards the end of the period, the first domesticated plants were introduced (Piperno 2006b; Piperno and Pearsall 1998). At the beginning of the Late Pre-ceramic (6000–3300 BC), settlement size and intensity of occupation increased considerably, stone tool technology changed to predominantly bipolar reduction, and a much broader range of resources began to be used, including coastal resources (Cooke and Ranere 1999; Piperno et al. 1985, 2000; Ranere and Cooke 1996).

It is during this period that human activities were detected in the Caribbean watershed, possibly reflecting the gradual movement of farmers from the Pacific slopes in response to increasing pressure on the landscape there (Griggs 2005).

The appearance of pottery (Monagrillo tradition) at the beginning of the Early Ceramic period (3300–400 BC) did not seem to be accompanied by any other changes in lithics, settlement patterns, or subsistence strategies (Cooke 1995; Griggs 2005; Willey and McGimsey 1954). By the beginning of the Middle Ceramic period (400 BC–AD 800), however, there was a notable shift in settlement on the Pacific slopes from the now mostly deforested foothills to the alluviated river valleys and coastal plains (Ranere and Hansell 1995; Weiland 1984). These settlements became nucleated into permanent villages supported by extensive agriculture, with the emergence of chiefly political organization (Hansell 1987). Settlements in the Caribbean watershed continued to grow in number and size (Griggs 2005). By the Late Ceramic period (AD 800–1500), the region was politically organized into several large chiefdoms, with paramount leaders controlling external trade networks, craft production, and large-scale agriculture (Cooke et al. 2003a, b; Cooke and Mayo 2005).

2.1.2 Macrobotanical Data

Although a considerable amount of macrobotanical remains have been recovered from Central Panamanian sites (Table 2), the data are somewhat disparate and uneven. Some sites, such as Aguadulce, Carabalí, and Vaca de Monte, have benefited from systematic recovery and analysis, whereas others have received only brief in-field or laboratory notations of identified remains. Sampling and recovery methodologies have varied between sites (e.g., *in situ*, dry screen, and wet screen recovery).[2] Many data remain unprocessed, unpublished, or available only in local publications. The majority of identifications from Pacific watershed sites were made by H. Cutler (personal correspondence with R. Cooke), R. McK. Bird (1984; unpublished notes), C. E. Smith (1987, 1988; unpublished notes), and K. Myiint-Hpu (n.d.), with recent analysis by the author (Dickau 2005). Data from sites on the Caribbean side come from recent work by J. Griggs (2005).

Carbonized palm endocarps were the most frequent macrobotanical remains recovered in Central Panama. Throughout the Pacific watershed, people harvested and processed corozo pacora (or coyol, *Acrocomia aculeata*), corozo gunzo (*Attalea butyracea*), and *Bactris* species, possibly including caña brava (*B. major*), at various sites from at least 6000 BC onwards. Other palm taxa were more restricted spatially and/or chronologically. Although the Neotropical oil palm (*Elaeis oleifera*) was recorded only at Aguadulce, it completely dominated the macrobotanical assemblage during all periods, from 8500 BC onwards (Fig. 2a).[3] It appears that intensive exploitation and processing of this palm for its oil may have been a major activity at the site (Cooke and Ranere 1992a:291). A species of *Astrocaryum* palm was identified in the Late Pre-ceramic (6000–3300 BC) deposits at Vaca de Monte in the more humid forests of the cordillera. This genus has many economically important species, but so far this is the only archaeological evidence of its use in Panama.

Table 2 Macrobotanical remains from Central Panama by time period

		Early Pre-ceramic (8500–6000 BC)		Late Pre-ceramic (6000–3300 BC)					
Common Name	Taxonomic Name	Aguadulce	Carabalí	Aguadulce	Carabalí	Corona	Ladrones	Vaca de Monte	Lasquita
Corozo pacora	*Acrocomia aculeata*			20/11 (e)				1 (e)	
Astrocaryum palm	*Astrocaryum* sp.							6 (e)	
Corozo gunzo	*Attalea butyracea*	/1 (e)		14/7 (e)	5 (e)				
Mangué	*Attalea allenii*								P (e)[a]
Caña brava	*Bactris* cf. *major*			1/16 (e)	3 (e)				
Bactris palm	*Bactris* sp.			1 (e)					
Oil palm	*Elaeis oleifera*	29 (e)		770/5 (e)					
Maize	*Zea mays*								
Amaranth	*Amaranthus* sp.							4 (s)	
Hogplum	*Spondias* sp.			/1 (p)					
Sandpaper tree	*Curatella americana*								
Legume family	Fabaceae			4 (c)				3 (c)	
Algarrobo	*Hymenaea courbaril*		1(sc)[b]	2/3 (sc)	52 (sc,re)			1 (sc)	
cf. Bean	cf. *Phaseolus* sp.							2 (c)[c]	
Corocillo	*Humiriastrum diguense*								P (p)[d]
Avocado	*Persea americana*							/2 (s)	
Nance	*Byrsonima crassifolia*			3/3 (s)			P	5 (s)	
Soapberry family	Sapindaceae							1 (s)	
Sapote family	Sapotaceae		1/7 (sc)	/1 (sc)	4 (sc)			30 (sc)	
Sterculia family	Sterculiaceae							P	

Table 2 (continued)

		Early Ceramic (3300–400 BC)						Middle to Late Ceramic (400 BC–AD 1500)						
Common Name	Taxonomic Name	Aguadulce	Carabalí	Ladrones	Corona	Los Santanas	Calavares	Sitio Sierra	Cerro Juan Díaz	Carabalí	Rio Bermejíto	Calav-ares	Molé-jon	LP-9
Palm family	Arecaceae	443/5(e)	10/3 (e)	9/1 (e)				2/3 (e)		30 (e)				
Corozo pacora	*Acrocomia aculeata*	56 (e)	11 (e)					P		56 (e)				
Corozo gunzo	Attalea butyracea	5/1 (e)	1 (e)					14(e)		1 (e)				
Mangué	*Attalea allenii*						P(e)						P(e)	
Caña brava	*Bactris* cf. *major*	10/3 (e)								1 (e)				
Oil palm	*Elaeis oleifera*	674 (e)	P (e)											
Grass family	Poaceae	/1 (s)				/1 (h?)				5 (st)				
Maize	*Zea mays*		8 (k)[e]					1000+(k,cb)[f]	100+(k,cb)[g]	147 (k)	9 (cb)			1(k)
Hogplum	*Spondias* sp.									8 (p)				
Poro-poro	*Cochlosp-ermum* sp.	1 (w)												
Squash family	Cucurbitaceae	1 (s)						/16 (r)						
Sandpaper tree	*Curatella americana*	1 (s)	1(s)	P										
Legume family	Fabaceae	1 (c)	2 (c)					/1 (c)		3 (c)	/3 (s)			
Algarrobo	*Hymenaea courbaril*	5 (sc)								1 (sc)				
Inga	*Inga* sp.					/2 (c)								

(continued)

Table 2 (continued)

		Early Ceramic (3300–400 BC)						Middle to Late Ceramic (400 BC–AD 1500)						
Common Name	Taxonomic Name	Aguadulce	Carabalí	Ladrones	Corona	Los Santanas	Calavares	Sitio Sierra	Cerro Juan Díaz	Carabalí	Rio Bermejíto	Calav-ares	Molé-jon	LP-9
Bean	*Phaseolus* sp.							1/1 (c)		1 (c)				
Corocillo	*Humiriastrum diguense*											5 (p)[h]		
Avocado	*Persea americana*										/3 (s)			
Nance	*Byrsonima crassifolia*	1/1 (s)[i]	5 (s)	11 (s)	2	1 (s)				3 (s)				
Cotton	*Gossypium* sp.								P (f)					
Sapote family	Sapotaceae			/6 (sc)		1 (sc)				2 (sc)	/4 (s)			
Cacao	*Theobroma cacao*					/1 (s)[j]					4 (pd)[k]			
Unid. fruit tissue		11		3				24						
Unid. tuber		1						/1						

Notes: Numbers indicate the count of fragments from a particular taxon. When counts were unavailable, "P" indicates "present". Numbers after a slash (/) represent tentative identifications. Letters in brackets represent the part(s) found: *c* cotyledon; *cb* cob; *ct* cast; *e* endocarp; *f* fiber; *h* husk; *k* kernel; *p* pit; *pd* pod; *r* rind; *re* resin; *s* seed; *sc* seed coat; *t* tuber; *w* wood

Sources: Aguadulce: Myiint-Hpu n.d., analysis by the author; Carabalí: Myiint-Hpu n.d., Smith unpublished notes, Cooke 1992, re-analysis by the author; Cerro Juan Díaz: Cooke et al. 2003; Corona: Valerio field notes; Ladrones: Cooke and Ranere 1992b, analysis by the author; Lasquita, Calavares, Moléjon, LP-9: Griggs 2005; Los Santanas: analysis by the author, anonymous notes; Rio Bermejíto, analysis by the author, anonymous notes; Sitio Sierra: Cooke 1979, Bird unpublished notes, Cutler unpublished notes, analysis by the author;. Vaca de Monte: Myiint-Hpu n.d., re-analysis by the author, Cooke and Ranere 1992a

Direct AMS dates:

[a] Lasquita, *Attalea allenii*; 4845–4710 BC (5920 ± 40 BP)

[b] Carabalí, *Hymenaea courbaril*; 10920–10110 BC/10080–10010 BC (10,480 ± 70 BP; Beta-202506; $\delta^{13}C = -28.9‰$)

[c] Vaca de Monte, cf. *Phaseolus* sp.; 4490–4050 BC (5470 ± 100 BP; Beta-202504; $\delta^{13}C = -27.4‰$)

[d] Lasquita, *Humiriastrum diguense*; 4720–4520 BC (5780 ± 40 BP)
[e] Carabalí, *Zea mays*; AD 1400–1480 (480 ± 50 BP; Beta-202505; $\delta^{13}C = -9.1‰$)
[f] Sitio Sierra, *Zea mays*; AD 395–635 (1560 ± 60 BP)
[g] Cerro Juan Díaz, *Zea mays*; AD 770-1170 (1070 ± 90), AD 415-710 (1470 ± 90 BP)
[h] Calaveras, *Humiriastrum diguense*; 3 pits dated: 420–355 BC/290–230 BC (2320 ± 50 BP), 415–350 BC/300–220 BC (2310 ± 50 BP), and 500–465 BC/425–360 BC (2330 ± 50 BP)
[i] Aguadulce, *Byrsonima crassifolia*; 2870–2800 BC/2770–2460 BC (4060 ± 60 BP; Beta-202503; $\delta^{13}C = -26.9‰$)
[j] Los Santanas, cf. *Theobroma cacao*; 1700–1520 BC (3330 ± 40 BP; Beta-201465; $\delta^{13}C = -24.8‰$)
[k] Rio Bermejíto, *Theobroma cacao*; AD 1310–1365/AD 1380–1445 (530 ± 50 BP; Beta-131428; $\delta^{13}C = -21.0‰$)

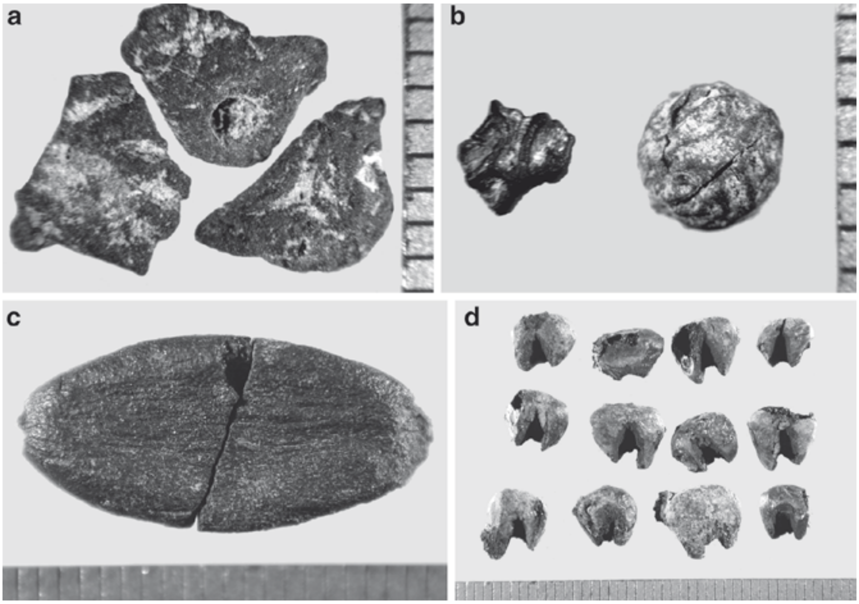

Fig. 2 Selected macrobotanical remains from Central Panama. (**a**) Neotropical oil palm endocarps from Aguadulce, (**b**) Nance pits from Aguadulce, (**c**) Possible cacao seed from Los Santanas, and (**d**) Maize kernels from Cerro Juan Díaz. Scale in mm

On the Caribbean side of the Isthmus, pre-Columbian inhabitants harvested mangué (*Attalea allenii*) palm nuts, beginning by 4700 BC (Griggs 2005).

The inhabitants of Central Panama exploited several other tree resources in addition to palms. These included fruits from nance (*Byrsonima crassifolia*) (Fig. 2b), hogplum (*Spondias* spp.), the Sapotaceae family (possibly *Pouteria* or *Manilkara* spp.), and at least two leguminous trees: *Inga* sp. and algarrobo (*Hymenaea courbaril*), both of which produce edible pulp around their seeds (Brücher 1988; Kainer and Duryea 1992). An algarrobo seed fragment from the base of the Carabalí excavations was AMS dated to 10,920–10,010 BC (10,480 ± 70 uncal BP; Beta-202506; $\delta^{13}C = -28.9‰$). In addition to consuming the pulp, people may have gathered the resin or "copal" produced by the tree and used it as incense, insect repellent, and/or in folk medicine as it is used today among some indigenous groups (Barrett 1994; Case et al. 2003; Kainer and Duryea 1992). Smith (unpublished notes) described a large amount of "resinous material" from Late Pre-ceramic (6000–3300 BC) periods of Carabalí that may belong to this taxon. Another tree species, corocillo (*Humiriastrum diguense*), was used by occupants of the Lasquita and Calaveras sites in the Caribbean slopes (Griggs 2005). It produces an edible pulp around the seeds and a fatty oil or resin within the exocarp and cavities of the seeds. This resin may have been among the several used in embalming practices in Panama (Cooke et al. 2003a).

Two domesticated tree species were tentatively identified. Carbonized fragments from what appear to be avocado pits (*Persea americana*) were found at Vaca de Monte between 6000 and 3300 BC and at the Rio Bermejíto rockshelter after 300 BC. Cacao (*Theobroma cacao*) pod fragments, directly dated to AD 1310–1445 (530 ± 50 uncal BP; Beta-131428; $\delta^{13}C = -21‰$), were recovered from the Rio Bermejíto site. Cacao was also likely available much earlier at Los Santanas, based on a tentatively identified seed (Fig. 2c) directly dated by AMS to 1700–1520 BC (3330 ± 40 uncal BP; Beta-201465; $\delta^{13}C = -24.8‰$). Several other wild species of *Theobroma* exist in Panama; however, they do not appear to occur naturally in the region where the seed was recovered (D'Arcy 1987). Both sites are located in the central cordillera between 450 and 900 m; while this is within the elevation and rainfall range tolerated by cacao, the tree prefers lower elevations and warm humid conditions. People may have been cultivating trees on the Caribbean coastal plain and transporting fruits and seeds along trade routes into the upland sites.

Macrobotanical remains of domesticated annuals were limited to the later ceramic periods. Maize was identified from kernels and cob fragments found at Sitio Sierra, Carabalí and Cerro Juan Díaz dating to the Middle to Late Ceramic periods (400 BC–AD 1500) (Fig. 2d). At Sitio Sierra, a cache of carbonized maize kernels directly dated to AD 395–635 (1560 ± 60 uncal BP) was associated with an adult male burial, probably as an intentional offering (Cooke 1984; Cooke and Ranere 1992b). At this site, maize dominated the macrobotanical assemblage. Maize was also identified at the site of LP-9 in the Caribbean foothills from a context dating to AD 1250–1420 (Griggs 2005). People ate common beans (*Phaseolus vulgaris*) at Carabalí and Sitio Sierra by at least 400 BC. Smith (1987) mentions an identification of beans at Ladrones, but does not mention their associated age. Partial seeds from Vaca de Monte directly AMS dated to 4490–4050 BC (5470 ± 100 uncal BP; Beta-202504; $\delta^{13}C = -27.4‰$) were identified as belonging to the sub-family Faboideae, and possibly from the Phaseolinae tribe, but they have not conclusively been identified as *Phaseolus* sp. (Kaplan, personal communication 2004). They may well represent a wild leguminous species. The use of cotton (*Gossypium* sp.) was probably widespread in Panama, but so far it has only been identified at Cerro Juan Díaz from fibers preserved within a gold pendant dating to AD 750–1050 (Cooke et al. 2003a). Lastly, Cucurbitaceae is represented by a seed fragment from an unidentified species at Aguadulce during the Early Ceramic (3300–400 BC), and by several possible rind fragments at the site of Sitio Sierra in the following period, but none of these remains were clearly from domesticated squash.

As will be discussed below, evidence from several different microbotanical records indicate that people adopted domesticated crops in Central Panama much earlier than this macrobotanical evidence would suggest. This may indicate possible changes in processing and preparation methods over time, or preservation biases against macrobotanical remains due to fragmentation through clay expansion and contraction, site compaction, microbial activity, or other factors.

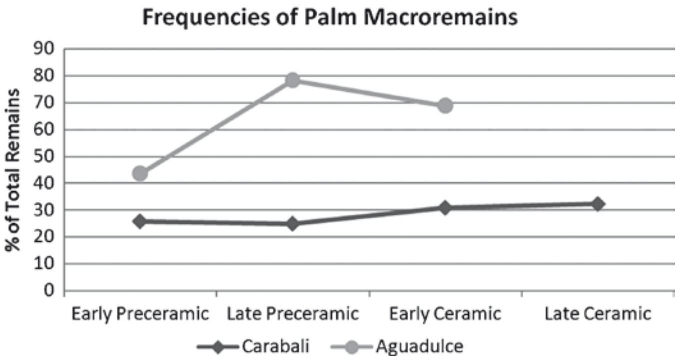

Fig. 3 Frequencies of palm macro remains over time from Aguadulce and Carabalí. Frequencies are expressed as a percent of the total count of macrobotanical remains recovered, including wood charcoal, from each time period

Although it is difficult to compare macrobotanical records between Central Panamanian sites due to differences in excavation methods and levels of analyses, some general trends can be observed. Palms were the most abundant remains at all Late Pre-ceramic and Early Pre-ceramic sites. Data from Carabalí and Aguadulce were comprehensive enough to permit comparison across different time periods. Frequencies were calculated by dividing the number of palm remains (all species) by the total remains for a particular time period (including wood and unidentified fragments) to arrive at a relative index for each period (Fig. 3). Such an index approach is far from ideal, but does attempt to compensate for preservation biases, particularly further back in time. Results show that palm use at Carabalí remained fairly constant from pre-ceramic into ceramic periods. There does not appear to be any significant decrease in use of palm after people adopted domesticated plants. The record at Aguadulce is more variable, however. This basic analysis was attempted on other taxa (see Dickau 2005:172–179) with mixed results; generally, other taxa were found in insufficient quantities to provide statistically reliable results. It is apparent, however, that tree crops, and particularly palms, continued to provide a certain measure of diet breadth even into later periods when subsistence was dominated by domesticated staple crops.

2.1.3 Microbotanical Data

Over the past two decades, Piperno and colleagues have recovered and analyzed microbotanical remains – pollen, phytolith, and starch grains – from sediments and artifacts from sites throughout Central Panama (Piperno 1985a, 1989, 2006; Piperno and Clary 1984; Piperno et al. 1985, 2000b; Piperno and Holst 1998, 2004; Piperno and Pearsall 1998). These data, along with more recent starch analysis conducted by Dickau (2005), are summarized in Table 3.

Table 3 Microbotanical remains from Central Panama by time period

		Early Pre-ceramic (8500–6000 BC)				Late Pre-ceramic (6000–3300 BC)							
Common Name	Taxonomic Name	Vampiros	Aguad-ulce	Corona	Carabalí	Aguadulce	Carabalí	Ladrones	La Yeguada	Los Santanas	Vaca de Monte	Rio Cobre	Gatun
Palm family	Arecaceae		ph					ph					
Ñampí	*Dioscorea trifida*					s							
Yam	*Dioscorea* sp.					s		s					
Arrowroot	*Maranta arundinacea*	ph	ph	ph	ph	s,ph		ph			ph		
Lerén	*Calathea allouia*		ph										
Calathea	*Calathea* sp.												
Maize	*Zea mays*		ph			ph,s		p,ph,s	ph	p,ph		s	p
Sweet potato	*Ipomoea batatas*												
Ipomoea	*Ipomoea* sp.												
Squash	*Cucurbita moschata*		ph										
Squash	*Cucurbita* sp.								ph				
Bottle gourd	*Lagenaria siceraria*		ph										
Manioc	*Manihot esculenta*					s							
Legume family	Fabaceae					s		s					
Chili pepper	*Capsicum* sp.					s							

Table 3 (continued)

Common Name	Taxonomic Name	Early Ceramic (3300–400 BC)							Middle to Late Ceramic (400 BC–AD 1500)						
		Aguadulce	Monagrillo	Zapotal	Ladrones	La Yeguada	Calaveras	Gatun	Cerro Juan Diaz	La Mula	Sitio Sierra	Ladrones	La Yeguada	Rio Cobre	Gatun
Palm family	Arecaceae	ph									ph				
Ñampí	*Dioscorea trifida*			s											
Yam	*Dioscorea* sp.			s	s					s					
Arrowroot	*Maranta arundinacea*			s								s			
Lerén	*Calathea allouia*														
Calathea	*Calathea* sp.									s					
Maize	*Zea mays*	p,ph	s	s	s,p, ph	ph	s	p	s	s		s	ph	s	p
Sweet potato	*Ipomoea batatas*	p													
Ipomoea	*Ipomoea* sp.														p
Squash	*Cucurbita* sp.										p,ph				
Bottle gourd	*Lagenaria siceraria*														
Manioc	*Manihot esculenta*		s	s						s				s	p
Legume family	Fabaceae														
Chili pepper	*Capsicum* sp.			s											

Notes: p pollen; *ph* phytolith; *s* starch

The data show that domesticated crops were first used in Panama between 7700 and 5800 BC. Piperno (1985, 1988; see also Piperno and Pearsall 1998:213; Cooke and Ranere 1992b:123) recovered phytoliths of arrowroot from Cueva de los Vampiros associated with a charcoal date of 7407–7828 BC (8560 ± 160 uncal BP), and in pre-5800 BC deposits at Carabalí, Corona, and Aguadulce. People were also growing squash, lerén, and bottle gourd before 5800 BC at Aguadulce (Piperno 2006b; Piperno and Pearsall 1998). Palm phytoliths are ubiquitous in the Early Pre-ceramic periods from several sites (Piperno and Pearsall 1998:217), and were particularly abundant at Aguadulce (Piperno 1988:196), echoing macrofossil data.

The adoption of maize into the horticultural system in Central Panama around 5800 BC is well-documented by three different microbotanical records: starch, phytoliths, and pollen. All three microfossil types record maize in the earliest occupation of Ladrones, 5800–5000 BC (Dickau et al. 2007; Piperno 2006b; Piperno et al. 1985) (Fig. 4a). Maize was identified at Aguadulce in the form of phytoliths from sediments that date to just before 5800 BC based on stratigraphic evidence (Piperno 2006b; Piperno et al. 1985; Piperno and Pearsall 1993, 1998). In addition, maize starch was extracted from a grinding tool associated with a date of 5800 BC (Piperno 2006; Piperno et al. 2000). Maize phytoliths were recovered in similarly aged contexts at Los Santanas (Piperno 1995:141). During the succeeding Middle and Late Ceramic periods, maize became one of the most prevalent and widespread crops, identified in starch and phytolith records at a majority of sites (Dickau 2005; Griggs 2005; Piperno 2006a; Piperno and Holst 1998; Piperno and Pearsall 1998).

Microbotanical data show that people first brought manioc into the region around the same time they adopted maize. Piperno et al. (2000b; Piperno 2006a) identified manioc starch on grinding tools at Aguadulce, dating to between 5800 and 5000 BC. Starch grains of ñampí or domesticated yam (*Dioscorea trifida*) on a tool from Aguadulce show that this tuber was being processed by 3300 BC (Piperno 2006). It was also consumed at Zapotal between 2500 and 1800 BC (Dickau 2005) (Fig. 4b). The starch of other *Dioscorea* species appears periodically at different Central Panamanian sites throughout pre-history, suggesting native yams were used alongside the introduced *D. trifida* (Dickau 2005; Piperno and Holst 1998) (Fig. 4c). Chili peppers were also an early addition to the ancient Panamanian diet, based on starch grains extracted from tools at Aguadulce and Zapotal (Perry et al. 2007) (Fig. 4d). Fabaceae starch was recovered from tools at both Aguadulce and Ladrones during the Late Pre-ceramic period; the particular species are unknown, but may represent people harvesting and processing wild legumes (Fig. 4e).

Ceramic periods (after 3300 BC) saw a continued presence of many of these crops in phytolith and starch records, including maize, manioc (Fig. 4f), legumes, squash, lerén, yams, and arrowroot. One new addition to the diet was sweet potato (*Ipomoea batatas*). Sweet potato pollen was recovered at Aguadulce in a level dating to 2800 BC (Piperno and Pearsall 1998:292–293). *Ipomoea* pollen was also seen in AD 200 level at Lake Gatun, but the investigators could not

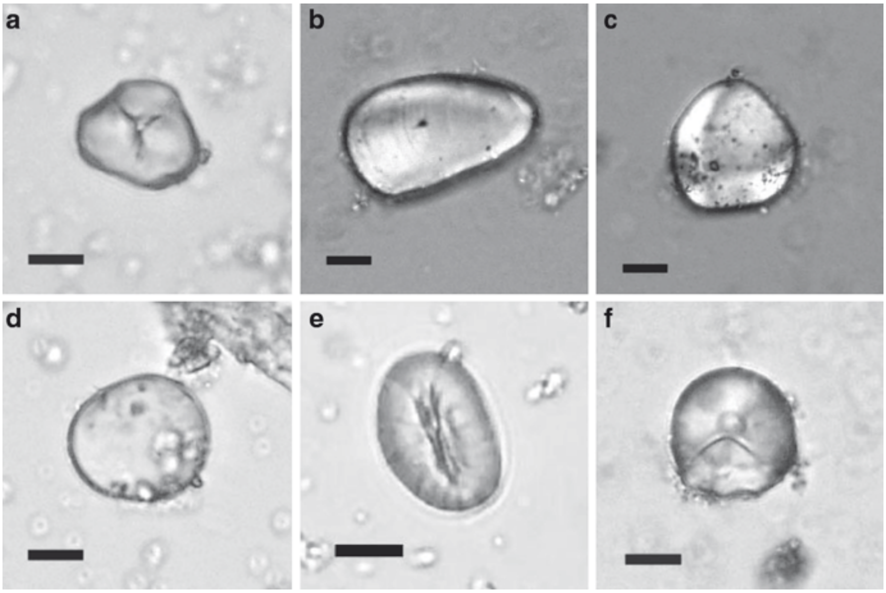

Fig. 4 Selected starch granules from Central Panama. (**a**) Maize from Ladrones, (**b**) Domesticated yam (*Dioscorea trifida*) from Zapotal, (**c**) Other yam species (*Dioscorea* sp.) from Aguadulce, (**d**) Chili pepper from Zapotal, (**e**) Legume from Ladrones, (**f**) Manioc from Zapotal. Scale bar = 10 μm

say for sure that it was *I. batatas* (Bartlett et al. 1969). Spanish soldiers who invaded the chiefdoms around Parita Bay between AD 1515 and 1522 often mentioned fields of "ajes" which Sauer (1966) interprets as sweet potatoes. They also commented on fields of squash, maize, and manioc lining the river banks (de Espinosa 1994).

2.1.4 Paleoenvironmental Data

While microbotanical data have provided information about when and at which sites people first started using specific domesticated crops, identifying the actual cultivation of these crops relies on proxy data from paleoenvironmental records that document human impact on regional vegetation over time. Paleoenvironmental data for Central Panama have been obtained from the analyses of sediment cores from three localities: the Chagres Basin (now under human-made Lake Gatún) (Bartlett and Barghoorn 1973; Piperno 1985), Laguna La Yeguada (Piperno et al. 1991a, b), and Monte Oscuro (Piperno and Jones 2003).

Cores from the Chagres Basin produced well-preserved pollen and phytolith records from 11,200 BC to AD 740. The initial part of the sequence is dominated by mangrove and associated taxa, suggesting that rising Holocene seas encroached on the coring locality. Freshwater swamp taxa replaced the mangroves after 6200 BC (Bartlett and Barghoorn 1973). Vegetation changes indicate the climate became drier between 6000 and 3000 BC. Bartlett et al. (1969) identified *Zea* pollen at 5800 BC; however, the first secure identification of domesticated maize is from phytoliths at 3620 BC (Piperno 1985b). This is associated with strong indications of agricultural clearing and slash-and-burn cultivation in the watershed. Agriculture was well established by 1600 BC based on the predominance of grass and weedy taxa, the disappearance of most arboreal pollen, and large amounts of phytoliths with carbon inclusions reflecting extensive burning.

In the Pacific foothills, the presence of montane taxa during the Pleistocene in cores from Lake La Yeguada and El Valle indicated a cooler and drier climate. Around 11,000 BC, an increase in lowland forest taxa reflected the increased precipitation and warmer temperatures of the Holocene transition (Piperno et al. 1991b). Evidence of burning, believed to be the result of human activities, was first visible at 11,000 BC at La Yeguada. Charcoal influx and disturbance indicators, such as *Heliconia*, reached their highest levels around 7700 BC in the lake's watershed (Piperno et al. 1991b). In addition, burnt arboreal and grass phytoliths began to increase substantially at this time, interpreted as the result of burning and small-scale clearing by early horticulturalists (Piperno and Pearsall 1998). There was a period of drying between 6000 and 3800 BC, similar to that seen at Gatún. When precipitation increased again around 3800 BC, arboreal phytoliths did not recover to pre-6000 BC levels at La Yeguada, suggesting people had taken advantage of the drier conditions to expand their clearing and cultivation activities. Agricultural pressure on the landscape continued into ceramic periods, with grass pollen peaking at around AD 1, associated with low presence of arboreal taxa, inferred to represent an anthropogenic savanna (Piperno et al. 1991b). After ca. AD 1, the agricultural pressure in the watershed seemed to lessen; frequencies of grass pollen started to decline, maize virtually disappeared, and some secondary growth taxa returned. This supports the apparent population (and corresponding economic) shift from the foothills to the coastal river valleys.

On the Pacific coastal plain, 150 km to the east of La Yeguada, the crater lake of Monte Oscuro was a dry lake-bed surrounded by a mix of tropical thorn-scrub and temperate shrubs during the Late Pleistocene (Piperno and Jones 2003). Warmer, wetter conditions around 10,500 BC facilitated the permanent inundation of the lake and the replacement of the open thorn-scrub vegetation in the watershed with deciduous tropical forest. After 6400 BC, the lake core showed evidence of increasing landscape disturbance and burning, likely the result of swidden cultivation (Piperno and Jones 2003). Between 3800 and 1300 BC, records show high levels of burnt phytoliths and particulate charcoal. Arboreal taxa appear to recover somewhat after 270 BC, but then decreased again around AD 1400, just before the arrival of the Spanish.

2.2 Western Panama

2.2.1 Brief Chronology

Although this area was archaeologically the best known in Panama during the early decades of archaeology (Cooke and Sanchéz 2004), systematic survey and excavation did not occur until the 1960s and 1970s, with projects in the highlands around Volcán Barú and coastal areas of the Caribbean and Pacific (Linares 1968; Linares and Ranere 1980). More recently, fieldwork has concentrated on Isla Colon on the Caribbean coast (Wake et al. 2004).

There is trace evidence of Paleoindian presence in the area (Ranere and Cooke 1996),[4] but the first stratigraphically excavated evidence for human occupation dates to the Pre-ceramic period (6000–300 BC) at several rockshelters and open-air campsites in the upper Rio Chiriqui Valley (Cooke 1977; Ranere 1980a). Based on lithic assemblages from these sites, the pre-ceramic period in the highlands of Western Panama is divided into two phases: the Talamanca phase (6000–3000 BC) and the Boquete phase (3000–300 BC) (Ranere 1980a).

Pottery did not appear in Western Panama until the first millennium BC (Linares 1980a; Shelton 1984). At this time, there was an influx of migrants into the fertile valleys west of Volcán Barú (Linares and Sheets 1980; Linares et al. 1975; Sheets 1980). By around AD 1, the valleys were densely occupied with numerous villages. One of these, Barriles, became an important regional center ca. AD 1–1250 (Rosenthal 1980; Stirling 1950). Interestingly, coastal settlement did not become visible until after AD 800. La Pitahaya on Isla Palenque in the Pacific Gulf of Chiriquí was a regional center comparable to Barriles in the highlands (Linares 1980d). Settlement of the Caribbean region occurred by at least AD 900 (Linares 1980c; Wake et al. 2004) and is likely to have been even earlier in view of recent discoveries of second and first millennium sites (BC) in Atlantic Costa Rica (Cooke 2005). Wake's (Wake et al. 2004) ongoing work at Sitio Drago on Isla Colon in the Bocas del Toro Archipelago suggests that the large site may have been situated on a major coastal trade route.

Varying amounts of macrobotanical remains were recovered from many of these sites. Starch grain analysis was conducted on tools from the highland pre-ceramic rockshelters. Phytolith and pollen data from these rockshelters, along with a lake core from Laguna Volcán, offer data on paleoenvironmental changes over time.

2.2.2 Macrobotanical Data

Like Central Panama, the most common macrobotanical remains recovered from pre-ceramic sites in Western Panama were durable remains from palms and tree fruits (Table 4). Corozo pacora and corozo gunzo palm fruits were the most frequently identified taxa. From the Talamanca phase, Smith (1980)

Table 4 Macrobotanical remains from Western Panama by time period and site

		Talamanca (6000–3000 BC)			Boquete(3000–300 BC)			Ceramic (300 BC–AD 1500)		
Common Name	Taxonomic Name	Casita	Trapiche	Hornito	Casita	Trapiche	Cerro Punta	Barriles	La Pitahaya	Sitio Drago
Palm family	Arecaceae			6 (e,s)			P (e)	10 (ct)	28 (e)	
Corozo pacora	*Acrocomia aculeata*	3 (k)			2 (k)		1 (e)	8 (ct)		
Corozo gunzo	*Attalea butyracea*		5 (k)		13 (e)				1 (k)	
cf. Attalea palm	cf. *Attalea* sp.			3 (e)						
Corozo palm	*Acrocomia* or *Attalea* sp.	186 (e)	109 (e)		100 (e)	36 (e)				
cf. Geonoma palm	cf. *Geonoma* sp.			29 (s)						
Raphia palm	*Raphea taedigera*									40 (k)
Maize	*Zea mays*						64 (cb)		P (cb,k)	
Annona	*Annona* sp.	P (s,c)								
Legume family	Fabaceae			2 (c)						
Algarrobo	*Hymenaea courbaril*	1 (s)	1 (s)		2 (s)		1 (s)			
Common bean	*Phaseolus vulgaris*						9 (s)			
Nance	*Byrsonima crassifolia*	21 (s)	24 (s)	4 (s)	3 (s)					
cf. Grape family	cf. Vitaceae									
cf. Cissus or Vitis	cf. *Cissus* or *Vitis* sp.			1 (s)						

(continued)

Table 4 (continued)

		Talamanca (6000–3000 BC)			Boquete(3000–300 BC)			Ceramic (300 BC–AD 1500)		
Common Name	Taxonomic Name	Casita	Trapiche	Hornito	Casita	Trapiche	Cerro Punta	Barriles	La Pitahaya	Sitio Drago
Canistel	*Pouteria* cf. *campechiana*	P (sc)								
cf. Amaranth or Chenopod family	cf. Amaranthaceae or Chenopodiaceae			1 (s)						
cf. Sweet potato	cf. *Ipomoea batatas*						1 (t)			
Unidentified				57 (s,sc,r)						

Notes: numbers indicate the number of fragments from a particular taxon. Letters in brackets represent the part(s) found: *c* cotyledon; *cb* cob; *ct* cast; *e* endocarp; *k* kernel; *r* rind; *s* seed; *sc* seed coat; *t* tuber; *st* stem; *P* present (count unavailable or unspecified)

Sources: Casita de Piedra and Trapiche: Smith 1980, analysis by the author; Hornito: Smith unpublished notes, Cooke 1977, analysis by the author; Cerro Punta and Barriles: Smith 1980, maize analysis by Galinat 1980, Sitio Drago: Wake 2006 identified over 300 fragments of endocarp or kernel from these species. During the following Boquete phase, the total was less, but these palms still dominated the assemblage. A small amount of palm endocarps recovered at Hornito may be corozo gunzo based on their thickness, but the fragments were too small to be securely identified. People at Hornito were also harvesting a small fruit that Cooke (1977) suggests might be a species of *Geonoma* palm. Subsequent analyses by both Smith (personal communication to R. G. Cooke 1984) and the author (Dickau 2005) have failed to resolve the taxonomic identification of these remains. Members of the genus *Geonoma* are most commonly used for their fronds in the Neotropics, for roof thatching (Henderson et al. 1995). However, there are some brief accounts of the small fruits being eaten by indigenous groups, including the Cabécar of central Costa Rica (Camacho-Zamora 1983; Macía 2004).

Palm remains were also reported from later ceramic period sites in the highlands and on the coast. Smith (1980:162) did not provide counts of the material at Cerro Punta or Barriles, but he did indicate that palms were the next most common taxa after maize and beans at Cerro Punta. He identified corozo pacora among the taxa represented. At La Pitahaya on the Pacific coast, corozo gunzo was among the palms used by the inhabitants (Smith 1980). Across the Isthmus on the Atlantic Coast, Wake identified numerous raphia palm (*Raphea taedigera*) kernel fragments at Sitio Drago, two of which were directly AMS dated to AD 880–1050 (1010 ± 60 uncal BP) and AD 900–1170 (1050 ± 60 uncal BP) (Wake 2006:14).

Other tree fruits were eaten and their seeds preserved through carbonization, primarily at the highland pre-ceramic sites. Nance pits were ubiquitous throughout the deposits, and while algarrobo seed fragments were identified, they were relatively uncommon (Smith 1980). New excavations at Casita de Piedra by the author in 2007 yielded additional macrobotanical data. Analysis is ongoing, but at least two new species can be added to the list of tree fruits used in the region during the pre-ceramic: *Annona* spp. seeds were found at the back of the shelter in levels dating from 3800 to 1250 BC (Fig. 5a) and fragments of the durable seed coat of *Pouteria* spp. (Sapotaceae) were recovered from all levels of the site. Based on the thickness and reconstructed dimensions of the hilum scar, at least some of these appear to be from canistel (*Pouteria campechiana*) (Fig. 5b). Remains from wild herbaceous plants were much less common than palm and tree fruits. These are restricted to a Cheno/Am seed and a possible grape (Vitaceae) seed recovered at the site of Hornito (Dickau 2005:150). Thus far, macrobotanical remains of domesticated annuals have only been found at ceramic age (post-300 BC) sites in Western Panama. Maize dominated the assemblage at Cerro Punta (Smith 1980). Galinat (1980) identified 64 maize cobs dating to AD 200–400 as belonging to the Nal-tel/Chapalote complex. Maize was also found on the coast at La Pitahaya, dating to approximately AD 800–1100. Both cob remains and charred masses of kernels were found; one mass appears to have had a maize leaf imprinted on it during carbonization (Smith 1980:165). Common beans were recovered from Cerro Punta (Smith 1980), but were absent

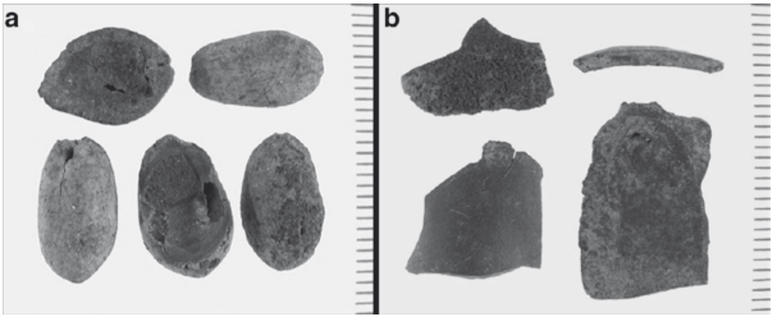

Fig. 5 Selected macrobotanical remains from Casita de Piedra, Western Panama. (**a**) *Annona* spp. seeds and cotyledons, (**b**) *Pouteria* sp. seed coats; the lower right fragment shows the top portion of the hilar scar, and may be from canistel (*Pouteria campechiana*). Scale in mm

at Barriles 15 km to the southwest, as was maize. Smith (1980) suggests that this may be a result of the unusual preservation at Barriles (casts of specimens: i.e., voids filled in by volcanic ash and preserved), in addition to small sample size. A charred tuber fragment found at Cerro Punta was tentatively identified by Smith (1980:162) as sweet potato on the basis of its bubbly and glassy nature, suggesting high sugar content.

2.2.3 Starch Grain Data

Starch analysis was undertaken on stone tools from the pre-ceramic sites of Casita de Piedra, Trapiche, and Hornito in 2004–2005 by the author. The results yielded a completely different list of taxa than macrobotanical analysis, including native starchy roots, legumes, and perhaps most surprisingly, exogenous domesticates (Dickau et al. 2007) (Table 5).

Among the native resources identified thus far, granules consistent with *Zamia* spp., possibly from cuna (*Z. skinneri*), were recovered at Hornito (5000 BC), and tentatively at Casita de Piedra in later times. Occupants of Trapiche and Casita de Piedra processed at least two or three species of native yams (*Dioscorea* spp.) from 4200 BC onwards. In particular, a chopper tool from Trapiche yielded a number of yam starches belonging to at least two species, one of which was tentatively identified as *Dioscorea urophylla*. Another tuberous resource, *Calathea* sp., was used during the Boquete phase at Casita de Piedra. A small number of legume seed starches were found on tools at Casita de Piedra in both pre-ceramic phases. They are morphologically similar to *Phaseolus* sp., but they may be from a wild species rather than domesticated beans, since wild *Phaseolus* still grows near the site today. People may have also been gathering and grinding wild grass seeds from the area, based on starch grains recovered from grinding tools. Some of these appear to belong to the Pooideae subfamily. Systematic collection and testing of grasses from the area may provide more secure determinations.

Table 5 Starch grains from Western Panama by time period

		Talamanca phase (6000–3000 BC)			Boquete phase (3000–300 BC)	
Common Name	Taxonomic Name	Casita	Trapiche	Hornito	Casita	Trapiche
Zamia	*Zamia* cf. *skinneri*			x		
cf. Zamia	cf. *Zamia* sp.	x		x	x	
Grass family	Poaceae	x	x	x	x	
Maize	*Zea mays*	x	x	x	x	
cf. Maize	cf. *Zea mays*	x	x	x	x	x
Arrowroot family	Marantaceae		x			
Arrowroot	*Maranta* cf. *arundinacea*	x	x			
Calathea	*Calathea* sp.				x	
cf. Calathea	cf. *Calathea* sp.			x		
Yam	*Dioscorea* sp.		x		x	
Yam	*Dioscorea* cf. *urophylla*		x			
cf. Yam	cf. *Dioscorea* sp.	x	x			x
Legume family	Fabaceae	x			x	
Manioc	*Manihot esculenta*	x			x	
Possible root starch[a]		x				

[a] Simple starch with eccentric hila, longer than they are wide

In addition to these local resources, starch analysis showed that people used several exogenous domesticates. The recovery of botanical evidence for manioc and arrowroot is not overly surprising, since Ranere (1980b) hypothesized that root crops contributed to the diet in the Boquete phase. However, starch analysis revealed that both species were also available during the earlier Talamanca phase. Arrowroot was identified in the earliest levels of Casita de Piedra, as well as at the 5000 BC site of Hornito. People processed manioc at Casita de Piedra by at least 3600 BC (Dickau et al. 2007).

Perhaps more unexpected than the recovery of these root crops was the identification of maize at the site of Hornito (5000 BC), and its tentative identification in the initial cultural levels of Casita de Piedra at 5400 BC. Until this discovery, maize was thought to be a relatively late introduction into Western Panama, based on the macrobotanical evidence from Cerro Punta dating to only AD 200. Starch data now show that it was present in the region four to five millennia earlier than previously thought.

2.2.4 Paleoenvironmental Data

Piperno (1988:135–136) undertook pollen and phytolith analyses on sediments from Casita de Piedra (750 m above sea level), and another nearby rockshelter, Horacio Gonzales, in the 1980s. She found that pollen was poorly preserved, but the presence and analysis of phytoliths allowed a diachronic view of the local environment around the sites. Although phytolith counts were low for some levels, certain general trends were visible. During pre-ceramic periods (the Casita de Piedra sequence from 5400 to 1000 BC), there was little apparent change in the local vegetation of the upper Chiriqui Valley. Arboreal phytoliths remained consistently high throughout the sequence, with no indication of clearing or disturbance. However, the phytolith sequence at Horacio Gonzales showed that beginning around 300 BC, there was a marked increase in Poaceae and Heliconiaceae phytoliths, typical of human disturbance. These weedy taxa increased even more in later periods.

Forty-five kilometers to the west on the other side of Volcán Barú, a core from Laguna Volcán (1500 m above sea level) extended back to 1000 BC (Behling 2000). The core contained high levels of Poaceae and herbaceous taxa in the basal levels, along with high carbon influx, indicative of human disturbance of the surrounding forest for agriculture. However, maize pollen did not appear in the core until AD 210 (Behling 2000). Across the border in Costa Rica, a core from Laguna Zoncho (1190 m above sea level) contained both maize pollen and evidence of large-scale forest disturbance at the base of the organic levels dating to 1160 BC. This evidence suggests that clearing was extensive and well established by the time of lake formation, and that maize agriculture may have occurred nearby prior to 1200 BC (Clement and Horn 2001).

Clary (1980) conducted pollen analysis on a core from the edge of a small estuary, approximately 100 m from the site of La Pitahaya on Isla Palenque. Unfortunately, no dates were obtained from the core, but she suggests the oldest levels were contemporaneous with the initial occupation of La Pitahaya around AD 800. She identified both maize and manioc pollen in the basal levels. Other potential economic taxa were also identified, including Arecaceae and Annonaceae; however, it is not clear if their presence was the result of intentional cultivation nearby, or merely a reflection of the surrounding vegetation.

3 The Transition to Agriculture in Central and Western Panama

Integrating information from carbonized macrobotanical remains, starch grains, phytoliths, and pollen provides paleoethnobotanists with a secure platform for reconstructing histories of human impact on vegetation, plant species utilization, and the transition to agricultural economies in pre-Columbian Panama. By necessity, due to the broad nature of the data discussed above, the following attempt at integration is qualitative and comparative in nature. However, it provides valuable insight into the patterns of plant use, human-environmental interaction, and the origins of food production in two neighboring regions.

The presence of remains from domesticated plants in the archaeological record is the marker most often used to infer cultivation and the beginning of food production. Some of the earliest evidence of food production in the Neotropics has been identified in Central Pacific Panama. Four cultigens – arrowroot, lerén, bottle gourd, and squash – were identified in phytolith records from several sites dating from 7700 to 5800 BC. Their appearance in archaeological deposits coincides with significant evidence of forest clearing and burning at two lake catchments: La Yeguada and Monte Oscuro. These disturbance indicators are interpreted to have resulted from the opening and cultivation of horticultural plots. Vegetational history at La Yeguada indicates clearing continued to intensify until 5800 BC, by which time evidence for the introduction of maize into the region is clear, based on the ubiquity of pollen, phytolith, and starch grains at several sites. People also began growing manioc, ñampí, and chili peppers between 5800 and 3600 BC. The degree of deforestation indicated in the La Yeguada core suggests people were already practicing swidden cultivation in the Pacific foothills, where the deciduous vegetation and dry season winds would have facilitated clearing and burning of the forest. There are also indications that the climate between 6000 and 3800 BC was drier or more markedly seasonal on both sides of the Isthmus. In the Chagres watershed on the Caribbean side, indicators of forest disturbance did not appear until 3700 BC, suggesting that human penetration and agricultural activities were delayed in this more humid region.

On both sides of the cordillera in Central Panama, phytoliths and pollen from lake-core sediments indicate that anthropogenic clearing continued into ceramic periods (after 3300 BC). Around 2800 BC, people added sweet potatoes to their mix of cultivated crops, based on pollen from Aguadulce on the Pacific plain. By 1600 BC, vegetation composition around La Yeguada indicates that clearing in the Pacific foothills was so extensive that even secondary forest taxa declined due to shortened fallow periods. Monte Oscuro also shows signs of agricultural expansion with a sharp increase in charcoal influx and weedy taxa.

Shortly after 1300 BC, there was a shift in archaeological settlement patterns. Some inland rockshelters and sites were used less frequently or abandoned altogether. Populations appear to have nucleated, with the first permanent villages emerging on the Pacific coastal plain around 500–200 BC. The predominance of carbonized maize remains at sites like Sitio Sierra, and *metates* laden with large amounts of maize starch at La Mula-Sarigua and Cerro Juan Diaz (Piperno and Holst 1998) suggest that the people living in these villages relied on extensive maize agriculture. Measurements of maize macro remains by Robert McK. Bird (unpublished notes) indicated mostly 8–10 row varieties, perhaps derived from South American types. Beans, squash, manioc, and sweet potatoes were also grown.

Throughout this time people exploited and consumed numerous wild or local resources along with adopted crops. Palm remains were found at almost every site during all time periods. Ancient inhabitants of Central Panama also harvested and consumed numerous tree fruits, including tree legumes (algarrobo and *Inga* sp.), nance, Sapotaceae species, hogplum, corcillo, cacao, and possibly avocado. Native tuberous resources like yams, *Calathea* sp., and possibly *Canna* sp. provided additional diet breadth.

Determining the relative importance of these resources and whether this importance changed over time is difficult. Diachronic analysis of palm frequencies at three sites spanning the Late Pre-ceramic and Early Ceramic periods did not show any decline associated with the adoption of cultigens and succeeding horticultural expansion (see Fig. 3). However, at other sites from the Middle and Late Ceramic periods, particularly Sitio Sierra, palm frequencies were quite low compared to maize. The frequencies of other resources are more difficult to track. It does appear that despite the adoption of domesticates and their increasing prevalence, people in Central Panama used a wide range of native plants for food. Native plants may have declined in importance by the Late Ceramic period, but many were still used. Collected herbaceous resources and tree fruits would have provided important vitamins and minerals, and perhaps just as importantly, variety in the diet.

Based on the available data, Western Panama seems to follow a different trajectory towards agriculture. Starch analysis provides direct evidence that maize and arrowroot were available by at least 5400 BC, and manioc was available by 3600 BC, at small rockshelters and campsites near the cordillera. Like Central Panama, these domesticates were supplemented by a wide range of local resources throughout the pre-ceramic period, including palms (predominantly corozo pacora and corozo gunzo), several tree fruits (*Annona* sp., *Pouteria* sp., nance, and algarrobo), native roots and tubers (yams, *Calathea* sp., and *Zamia* cf. *skinneri*), and wild legume and grass seeds. Several of these taxa are adapted to humid forest, such as *Zamia* sp., and were likely collected from the surrounding environment. Other species may have been tended, transplanted, and even cultivated alongside the new crops. Presently, there are not enough data to statistically assess change over time in the frequency or ubiquity of these resources; however, general observation of taxonomic diversity suggests that local resources were important throughout the pre-ceramic but declined during the ceramic periods when there was a pronounced and rapid expansion of agricultural activities.

Unlike Central Panama, the adoption of domesticated crops by 5400 BC in Western Panama is not associated with any evidence of forest clearing. Unfortunately, this is based on somewhat limited paleoenvironmental data since no lake cores dating earlier than 1200 BC are available. However, phytoliths in sediments at Casita de Piedra and nearby Horacio Gonzalez show that levels of arboreal taxa remain high throughout the entire Pre-ceramic. Evidence of forest clearing for agricultural activities did not occur until after 300 BC, when arboreal phytoliths declined and weedy taxa increased. If crops were being cultivated around the sites, it was at a level so low that it did not register in the phytolith record.

The lack of evidence for early forest disturbance in Western Panama compared to Central Panama during the initial adoption of domesticates may be partly related to differences in human demography (as inferred from settlement patterns) between the two regions. There is virtually no evidence of human occupation in Western Panama until 5400 BC, and in the succeeding pre-ceramic period, habitation is recorded only at a handful of small sites until 300 BC. In contrast, the Paleoindian period is well-documented in Central Pacific Panama, and the region exhibits strong patterns of population growth and expansion, beginning 5800 BC with a sevenfold increase in the number of sites, as well as an increase in the average site size (Ranere, personal communication). Environment may have also been an important factor. The humid montane forest around the Chiriqui sites in Western Panama would have been more difficult to clear and burn than the seasonally dry, deciduous forests of Central Pacific Panama. The delay between the initial appearance of domesticates and the evidence of swidden cultivation in Western Panama is comparable to that seen in the Gatún Basin (Bartlett and Barghoorn 1973; Piperno 1985a), which shares a similar humid environment.

An alternative explanation for the delay in evidence of forest clearing in the upper Chiriquí valley is that crops were being grown elsewhere and transported to the sites. Farming of maize, manioc, and arrowroot would have probably been easier at lower elevations with more suitable conditions. The annual fruiting cycles of several of the tree fruits and other native resources suggest that Hornito and the rockshelters were mainly used during the dry season, perhaps as seasonal collecting stations by people who spent the rainy season growing crops elsewhere. Unfortunately, no other pre-ceramic sites have been identified in Western Panama. An extensive archaeological survey along the Gulf of Chiriquí coast yielded no evidence of occupation earlier than AD 800 (Linares 1968). Nor have any pre-ceramic sites been found in the interior coastal plain (Ranere 1980a), although more extensive systematic survey is needed in this region. The archaeological evidence of people clearing forests and intensively farming on the coastal lowlands before 300 BC has not yet been discovered.

Like Central Panama, large, permanently settled villages did not appear in Western Panama until several millennia after the initial adoption of food production. The highland valley of Cerro Punta was first settled around 400 BC, perhaps as a result of the development of new varieties of maize that were tolerant of the cooler, more humid highland environments (Cooke 2005; Galinat 1980). Changes in cultigen varieties, processing techniques, or taphonomic conditions allowed maize and beans to finally be preserved in the macrobotanical record. *Manos* and *metates* also appeared for the first time. Pollen data from Laguna Volcán indicate that agriculture expanded rapidly and clearing became extensive in the highlands (Behling 2000). Ceramic technology was introduced in the region (Linares 1980a; Shelton 1984), and flaked stone tool technology underwent significant changes (Ranere 1980b; Ranere and Cooke 1996). All these factors suggest that there was some sort of influx of people into the highlands during the first millennium BC (Haberland 1962, 1984; Linares 1968, 1977, 1980b). Many of the Cerro Punta inhabitants left the valley around AD 800, perhaps relocating as far away as the Caribbean and Atlantic coasts. To the southwest, the village of Barriles continued to grow, eventually becoming a major political center in control of a large territory and supported by extensive agriculture.

4 Integrating Macrobotanical, Microbotanical, and Paleoenvironmental Data

Without the use of all available lines of paleoethnobotanical data, the preceding reconstruction and comparison of plant use and environmental change between Central and Western Panama would be far less comprehensive. Use of only one paleoethnobotanical record in isolation would lead to considerable difference in interpretation. For example, viewing ancient plant use solely through the lens of the macrobotanical record would fundamentally alter our perspective on resource use and agricultural origins. Macrobotanical remains of domesticated annuals, specifically maize and beans, do not appear until after 400 BC in Central Panama and AD 200 in Western Panama. Before this time, carbonized remains in both regions consist almost entirely of tree resources. Therefore, reliance on the macrobotanical record would lead to the conclusion that ancient Panamanians exclusively ate wild plant foods like palm nuts and tree fruits throughout much of pre history, and did not begin farming until quite late, only a millennia or so before the arrival of the Spanish. Moreover, we would be missing any botanical evidence for the consumption of domesticated and native root crops, and therefore be severely restricted in our ability to evaluate the role these plants played in the diet. Information from microbotanical analyses at archaeological sites shows that people were using maize several thousand years earlier than the macrobotanical evidence would indicate: by 5800 BC in Central Panama and 5400 BC in Western Panama. Moreover, phytolith, pollen, and especially starch grains reveal processing – and by extension, cultivation – of numerous major root crops, including arrowroot, lerén, manioc, yams, and sweet potato. Some of these were being grown as far back as 7700 BC in Central Panama and 5400 BC in Western Panama. Microbotanical evidence demonstrates that people were practicing food production long before they began nucleating in permanent villages supported by extensive field-based agriculture.

The exclusive use of any one particular microbotanical record results in a limited basis for paleoethnobotanical interpretation. Each type of microfossil has its particular strengths and weaknesses (for a discussion, see Pearsall 2000; Piperno 1995; Piperno and Holst 2004), and in Panama, many economic species were visible in only one or two records. In Central Panama, phytoliths from archaeological sediments were often well-preserved and provided the earliest evidence of domesticated plants like squash, bottle gourd, lerén, and arrowroot. But documenting other major domesticates like manioc, chili peppers, and yams, required the use of starch analysis. The presence of sweet potato at an archaeological site was only seen via pollen. Other domesticates like maize were represented in all three microbotanical records, providing multiple lines of evidence that reinforce the early availability of this crop. In Western Panama, starch grains demonstrated that several exogenous domesticates were used before 1200 BC. Starch grains also revealed that people consumed numerous native resources, including tubers and legume seeds, previously undocumented.

Despite the major insights from the recovery of starch grains, phytoliths, and pollen during the past several decades in Panama, the exclusive use of microbotanical results without consideration of the macrobotanical record would also lead to a biased perspective. Most noteworthy would be the lack of information regarding the importance of tree resources, particularly palms. Palm phytoliths were identified in many pre-ceramic contexts in Central Panama, but it is only through macrobotanical remains that we can identify particular species and observe interesting patterns like the prevalence and uniqueness of oil palm use at Aguadulce. Likewise, other tree resources would not have been identified without the study of macroremains, and therefore an entire component of dietary breadth, landscape use, and subsistence strategies would have remained unseen.

Recovery of plant remains from archaeological sites, both macrobotanical and microbotanical, tell us which economic species were used where and when. Paleoenvironmental data, primarily from phytolith and pollen fossils in lake cores and sediment columns, are the proxies for actually documenting human clearing and cultivation activities, and the keys to examining the processes and effects of the transition to agriculture. Three paleoenvironmental records from Central Panama show a clear trend of agricultural intensification after the initial introduction of domesticated plants. The data from Western Panama are limited, but seem to indicate a more gradual shift to agriculture. The interpretations here remain somewhat tentative until more columns and cores can be collected and analyzed.

Integrating vegetational history from paleoenvironmental records with multiple lines of archaeological evidence for the human use of particular plant species, both wild and domesticated, provides the foundation for reconstructing subsistence patterns and the transition to agriculture. From this foundation, we can begin to assess differences between regions and investigate the social and environmental factors that affected the pathways people followed towards fully agricultural economies.

5 Summary and Conclusions

Decades of research have provided abundant macrobotanical and microbotanical data on pre-Columbian plant use and human-environment interactions in Panama. Comparisons of macroremains, starch grains, phytoliths, and pollen show that each contributes important information on the use of specific taxa and paleoenvironmental changes not always visible in other records. The integration of these multiple lines of data, therefore, greatly improves our ability to reconstruct ancient subsistence strategies and address broader questions of economic change and the impacts on environment and social organization. Integration of paleoethnobotanical data within Western and Central Panama reveals differences and similarities in the adoption of food production and the transition to agriculture.

The initial appearance of domesticates occurs quite early in both regions. Several cultivars were used between 7700 and 5800 BC in Central Panama, followed shortly by the appearance of maize and manioc around 5800 BC. In Western Panama, maize and root crops were used by at least 5400 BC. However, the two regions differ in how quickly cultivation expanded and impacted the landscape. In Central Panama, the arrival of domesticates corresponds with clear indications of deforestation and burning. In Western Panama, however, evidence of clearing does not occur for approximately 4,000 years after the first evidence of crop use. The transition to swidden cultivation seems to have occurred at a slower pace here, perhaps as a result of lower population density or a more humid, less seasonal environment. An alternative scenario is that crops were being grown elsewhere in Western Panama and transported to the sites by travelers or seasonal occupants, a hypothesis that can only be tested through the recovery of additional paleoenvironmental and settlement data.

Despite these differences, some similarities also exist. In both regions, collected resources such as palms, tree fruits, and native tubers contributed to diet breadth throughout pre history. Many of these taxa continued to be part of the diet even after more productive foreign crops were adopted. It is not until approximately 400 BC in both regions that we see the emergence of a fully sedentary agricultural economy, with permanently settled villages reliant on maize and other staple crops. The integration of all classes of paleoethnobotanical data, as well as information on settlement patterns and climate, shows that ancient Panamanians followed different pathways in the transition from foraging, to initial adoption of food production, to complete reliance on agriculture. A complex interplay between crop productivity, wild resource availability, population density, and environmental factors directed the nature and pace of this transition.

6 Notes

1. During the last two millennia of the pre-Columbian period, “Central Panama” corresponded to the cultural area of Gran Coclé, defined on the basis of shared stylistic traits in pottery, stone, and metal, and other evidence of close cultural interaction. Likewise, “Western Panama” (the provinces of Bocas del Toro and Chiriquí, and the Comarca Ngöbe Bugle) formed part of Gran Chiriquí during later ceramic periods, along with the southwestern portion of neighboring Costa Rica. There is evidence that some sort of cultural boundary existed between

these two subregions as far back as the Late Pre-ceramic period (6000–3300 BC) (Ranere and Cooke 1996). I prefer, however, to use the more geographic terms of "Central Panama" and "Western Panama" in this paper since the definitions of Isthmian culture areas are variable in time and space (e.g., see Cooke and Sanchéz 2004).

2. Water flotation has been attempted at several sites over the years, but has never been successful. For unknown reasons, carbonized remains at many sites in Central Panama simply do not float efficiently, even light material such as wood, charcoal, and seeds (Cooke, personal communication 2002). This may be the result of translocation and penetration of the remains by water-soluble minerals, but this has not been examined. Chemical flotation has not yet been attempted.
3. Cooke and Ranere's (1992b) report of the use of oil palm (*Elaeis oliefera*) at Carabalí during this period, as well as Cooke's (1992) report of Early Pre-ceramic use of corozo pacora (*Acrocomia aculeata*), Astrocaryum palm (*Astrocaryum* sp.), and Bactris palm (*Bactris* sp.) at Carabalí, have been revised after the recent re-examination of the macrobotanical material. *Elaeis oliefera* has only been confirmed at Aguadulce; it has not been identified at Carabalí in any period. Corozo pacora and *Bactris* cf. *major* were found in Late Pre-ceramic deposits of Carabalí, however, palm endocarps from the Early Pre-ceramic period at the site could not be identified to a particular species. Astrocaryum palm has not been identified at the site in any time period.
4. The only indication of a Paleoindian presence in Western Panama thus far is a chalcedony biface fragment surface collected on the Universidad de Panama campus in the city of David, on the Pacific coastal plain (Ranere and Cooke 1996).

Acknowledgments My research was funded by the Social Sciences and Humanities Research Council of Canada (SSHRC), the Smithsonian Institution, and the National Science Foundation (NSF). Staff of the Smithsonian Tropical Research Institution (STRI), Panama, and Temple University, Philadelphia, provided assistance during laboratory analysis. Recent investigations at Casita de Piedra were made possible by a SSHRC post-doctoral fellowship, and the help of Eduardo Bejerano, Rueben Guerra, Anthony Ranere, and the communities of Casita de Piedra and Quebrada Seca, Panama. I am grateful to Sonia Zarrillo for helpful suggestions during lab analysis and on the manuscript. Above all, I would like to thank Anthony Ranere, Richard Cooke, and Dolores Piperno for their guidance and comments, and for trusting me with their data. However, any mistakes in this paper are my own.

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Waitui Kei Vanua: Interpreting Sea- and Land-Based Foodways in Fiji

Sharyn Jones and Rhonda Quinn

We outline a method that both incorporates quantitative and qualitative elements and positions ethnoarchaeological analogy at the center of analysis and interpretation. Exploring ethnographic analogs provides models that assist in the articulation of disparate data, such as paleoethnobotanical and zooarchaeological remains, and frameworks for interpretation of stable isotopic results. Our approach is meaning-focused, with the goal of understanding the social life of people in the past through their foodways. This method is illustrated with data from Jones' ethnoarchaeological research in Fiji's Lau Island Group and Quinn's laboratory-based stable isotope analysis of human bone. We argue that food and customs associated with eating are mechanisms for the definition and maintenance of meaningful social structures and cultural identities that are accessible to archaeologists through interdisciplinary approaches. In this case study, we reconstruct a holistic view of subsistence and foodways using zooarchaeological and stable isotopic data, interpreted through a framework of ethnoarchaeological analogs.

This chapter is written from the perspective of a practicing zooarchaeologist and ethnoarchaeologist (Jones), and a bioarchaeologist and geochemist (Quinn). The results from zooarchaeological and related archaeological human stable isotope analyses are described here and provide information about the entire Lauan diet, including marine and terrestrial plant and animal foods consumed over the pre-European occupation of the study sites. We envision the perfect study of subsistence as one that incorporates both zooarchaeological and paleoethnobotanical lines of evidence; in the absence of available plant data, this can be effectively achieved via ethnoarchaeology and tested with isotopic analysis of human bone. Ultimately, we aim to conduct research that will bring zooarchaeology closer to the anthropology of foodways, illuminating lifeways and meaning in the past.

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_7,

1 Background and Studies on Human Exploitation of Plants and Animals in the Pacific Islands

The Pacific Island region is vast, therefore we limit our description of previous research to the smaller region of Remote Oceania (Fig. 1), including the islands of Vanuatu, New Caledonia, Fiji, Micronesia, and Polynesia. The origins of Pacific Island food systems appear to be a combination of cultivation technologies and domesticated food items from Southeast Asia [domestic pig (*Sus scrofa*), domestic dog (*Canis familiaris*), domestic chicken (*Gallus gallus*), and yams (*Dioscorea* spp.)] and New Guinea [sugar (*Saccharum officinarum*) and bananas (*Australimusa* spp.)], as well as marine resource exploitation. The Lapita peoples were the ancestors of most of the modern occupants of the islands of Remote Oceania. The Lapita culture complex is recognizable by distinctive dentate stamped pottery and associated stone and shell tool assemblages, the archaeological signature of the "seafaring pottery making farmers" who first inhabited Remote Oceania (Lilly 2006:5).

Until recently, relatively few archaeologists who work in Remote Oceania have incorporated the study of animal and plant remains in a single publication (but see Ambrose et al. 1997; Kirch 1997; Kirch et al. 1995; 2003; Leach et al. 2003; McGovern-Wilson and Quinn 1996; Valentin et al. 2006). One of the most heated

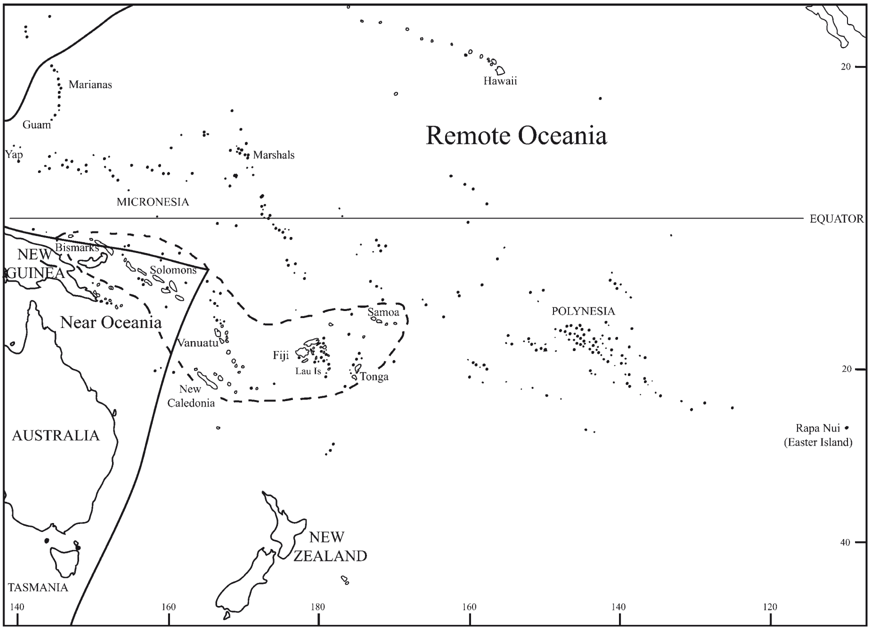

Fig. 1 Map of the Pacific Islands with Remote Oceania indicated. The *hatched line* indicates the extent of the known Lapita sites

debates regarding the Lapita peoples is centered on the issue of whether they practiced horticulture or if they were “Oceanic strandloopers,”[1] living primarily on marine resources, lacking a horticultural mode of subsistence, and having a preference for coastal settlements adjacent to lagoons (Davidson and Leach 2000; Groube 1971). Green (1979, 1982) and Kirch (1979) have challenged the strandlooper hypothesis and elaborated a phylogenetic model based on a historical anthropology that incorporates data from biological anthropology, archaeology, historical linguistics, and comparative ethnology (Kirch and Green 2001). Using multiple lines of evidence, they convincingly argue that the Lapita peoples utilized a system of horticultural production in addition to their extensive exploitation of reefs, lagoons, and open oceans (Kirch and Green 2001:121). As Leach et al. (2003:34) have pointed out, this strandlooper debate could have been resolved years ago using data generated from stable isotopic analysis of human bone from Tonga and Fiji. Additional support for the horticultural economy of the Lapita peoples comes from Horrocks and Nunn (2007:739), whose starch residue, pollen, and phytolith analyses from the site of Bourewa, Fiji, provide an eastward extension “of the direct evidence of Lapita horticulture in Remote Oceania.”

Due to the nature of the archaeological remains and an abundance of rich ethnographic literature and linguistic data, archaeologists working in Remote Oceania have a history of relying on indirect evidence of plant use and consumption by prehistoric peoples. The extensive middle to late prehistoric period dryland and irrigated wetland agricultural field systems of Fiji and Polynesia have been mapped, excavated, and analyzed in detail (Earle 1978; Kirch 1994; Parry 1987). These elaborate structures provide ample evidence that full-blown agriculture was a critical element of the subsistence economy in the middle to late period prehistoric sites (e.g., in Fiji ca. 100 BC–AD 1800). Moreover, comparative ethnographies provided many clues about subsistence practices in the past, based on the present and the historical period (e.g., AD 1791 in Fiji) (Bell 1931; Thompson 1940; Yen 1974). The field of historical linguistics has also contributed to archaeological interpretations in Remote Oceania that support the idea that the people of this region have a long history of cultivating root crops and maintaining both horticultural and agricultural economies (Kirch and Green 2001; Ross et al. 1998).

The staple carbohydrates exploited for food in the Pacific Islands include roots and tubers, supplemented by tree crops such as breadfruit (*Artocarpus altilis*), coconut (*Cocos nucifera*), and bananas (*Musa* spp.). The most commonly consumed taxa include yams (*Dioscorea* spp.), taros (*Colocasia esculenta* and other members of the Araceae family), sweet potatoes (*Ipomoea batatas*), and manioc or cassava (*Manihot esculenta*). Until the 1990s standardized methods for the identification of roots, tubers, and nuts were lacking (Hather 1992). The direct examination (using microscopic thin sections) of plant remains from archaeological sites became increasingly common with the work of Hather, Kirch (Hather and Kirch 1991; Kirch 1989), and Allen (1989); up until this point, few floral assemblages were intensively examined, and those that were analyzed are dominated by charred nutshell fragments (Gosden 1989; Green and Davidson 1974; Rosendahl and Yen 1971; Spriggs 1984).

Researchers working on plant materials from Remote Oceania have made great progress toward the regular identification of charred remains of wood, nutshells, small seeds, and tissue from roots and tubers. Pollen, starch grain, and phytolith studies are also becoming more frequent; however, the majority of plant foods consumed by Pacific Islanders do not produce pollen (Flenley and King 1984; Horrocks 2005). Recent studies include research based on Easter Island (Horrocks and Wozniak 2008); New Zealand (Horrocks et al. 2000; Horrocks and Barber 2005; Horrocks and Lawlor 2006; Horrocks et al. 2007); the Marshall Islands (Horrocks and Weisler 2006); Hawaii (Athens and Ward 1997); and Fiji (Horrocks and Nunn 2007).

The terrestrial fauna of Fiji and most of Remote Oceania consists of indigenous lizards (Scincidae), birds (Aves), and fruit bats (*Pteropus* spp.), as well as prehistoric human introductions including pigs (*Sus scrofa*), dogs (*Canis familiaris*), chickens (*Gallus gallus*), and rats (*Rattus exulans*, *R. praetor*). Cattle (*Bos taurus*), goats (*Capra hircus*), and horses (*Equus caballus*) arrived on the island as European introductions in the late 1800s. Currently, the majority of animal foods consumed on the islands include bony fishes, shellfish, and other invertebrates [including coconut crabs (*Birgus latro*); lobsters (*Panulirus* spp.) and other crustaceans; sea cucumbers (Holothuoidea); cephalopods, especially octopus (*Octopus* spp.); seasonal annelid sea worms (*Eunice viridis*); bivalves; and gastropods], turtles, chickens, pigs, and cows. Animals that contribute small and irregular portions to the diet include seabirds, ducks (Anatidae), and bats. Pigs, chickens, and cows are reserved for consumption on special occasions.

2 The Lau Group: A Case Study in Ethnoarchaeology

By using ethnoarchaeological analogs, it is possible to link the interpretation of plant and animal remains in order to understand subsistence in a more holistic manner as discussed in this volume's introductory chapter (see VanDerwarker and Peres, this volume). The integration of multiple lines of evidence provides for broad-based reconstructions. By stating ethnographic analogies, archaeologists may produce models that articulate different types of data, such as plants, vertebrates, and invertebrates. Moreover, in order to avoid some of the problems associated with equifinality, it is advisable to work with multiple lines of evidence, including historical, archaeological, and ethnographic (Lyman 1994). Exploring different behaviors that could result in the same archaeological signature will reduce the possibility of falling into the pitfall of equifinality. In contexts with historical continuity between the past and the present, this task may be relatively straightforward. For example, Yvonne Marshall's (1987) study of freshwater eel (*Anguilla* spp.) fishing and weir construction aimed to generate a model for eel fishing in prehistory in the "absence of direct archaeological evidence for prehistoric mass capture eel fishing, in the form of substantial eel bone middens or durable artefacts" (Marshall 1987:74). Marshall used contemporary and ethnohistoric accounts as a "lens through which to view prehistory" (Marshall 1987:74).

She gave special attention to documenting material and economic changes that occurred as a result of the Historic period (post-AD 1765) in New Zealand, with the goal of controlling for some of the post-European influences. Marshall argued that food, technology (especially nets of natural fiber), and customs associated with the collection of eels and their preparation and consumption, act as mechanisms for the definition and maintenance of social structures and cultural identity (Marshall 1987:75). Using ethnoarchaeology, Marshall was able to hypothesize about the role of both animals and plants in this subsistence practice prehistorically.

Ethnoarchaeology is one means we employ to understand long-term trends in foodways. Doing ethnoarchaeology involves articulating analogs generated in a contemporary or ethnohistoric setting, which can then be tested with archaeological data. Like many subfields within archaeology, ethnoarchaeology has primarily developed within regional specialties without a general set of methods and theoretical principles. What all ethnoarchaeological research has in common is the application of, and a concern with, analogies. According to Wylie (1985:93–94) analogy can be defined as

> …the selective transposition of information from source to subject on the basis of a comparison that, fully developed, specifies how the "terms" (elements) compared are similar (positive components), different (negative components) or of unknown likeness (neutral components) …An argument by analogy, proper, involves the claim that given the similarities and differences specified in the premises, some specific aspects of the neutral analogy may also be assumed to be similar or, to comprise further points of positive analogy.

Making analogical inferences is a fundamental part of doing archaeology, whether the analogy is blatantly stated or couched in scientific terms. However, ethnoarchaeologists are generally cautious about analogical forms of reasoning, in an attempt to avoid affirming the consequent (Ascher 1961; Cunningham 2003; Trigger 1978, 1989; Wylie 1985). These realizations have led some researchers to place emphasis on understanding the underlying causal mechanisms behind observable ethnoarchaeological patterns (Bowser 2000; Cunningham 2003; Wiessner 1983; Wylie 1982, 1985).[2]

Direct historical analogy, or homology, is an analogy based on observations of contemporary peoples who have a direct historical link through common ancestry with the archaeological populations and their materials under study. Relying on homology, the "direct historical approach" was practiced by North American archaeologists including Wedel (1938) and Steward (1942). These researchers were interested in extending the short-term view of ethnohistory and ethnography by combining them with archaeological data in an effort to expose long-term cultural trajectories. More recently, increased attention has been given to this form of analogy in archaeology because homology is assumed to allow a closer and more accurate reading of archaeological materials (Agorsah 1990; Kirch and Green 2001; Trigger 1998).

While homology might be the strongest form of analogy, generating inferences with blatant links between the past and present, there are a number of valid criticisms of this type of approach. An obvious potential problem inherent in the application of homology is the fact that similarities in material, or any aspect of culture, may result from contact, borrowing, coincidence, or descent (homology). Additionally, Gould and Watson (1982:359) have claimed that both general and historical analogues are subject to the same level of empirical testing in order to confirm acceptable interpretations. A warning should accompany homologically derived interpretations, because the lifeways of modern peoples cannot simply be understood as one-to-one equations for the prehistoric past. Taking these criticisms into account, it can be said that homology and historical continuity offer an increase in the likelihood that the same causal processes unite modern and archaeological contexts.

In Oceania multiple lines of evidence often accompany the application of homology, making for strong ethnoarchaeological inferences and interpretations based on multiple data sets, including archaeology, linguistics, and ethnographic information. Kirch and Green (2001:51) posit that "interpretations of archaeological data typically have deep roots within ethnology, as is evident in Polynesia where the transition from one data set to another is virtually seamless." Numerous factors support the application of the direct historical approach in Oceania. In particular, strong evidence for continuity is provided by well-dated and connected local archaeological chronologies that exhibit change over time, but little or no evidence of population replacement. Kirch and Green (2001) consider Oceanic archeological sequences as an independent line of evidence that may be used to cross-check and test linguistic and ethnographic constructions of the past. In situations where homology exists, ethnographic analogies provide especially strong modes to understanding the past. This is the case in Fiji's Lau Island Group where the modern population is descended from the people who occupied the archaeological sites.

To illustrate our approach we use data from the Lau Group. Lau was first inhabited about 3,000 years ago by the Lapita peoples (Best 2002; Clark et al. 2001), the ancestors of the modern occupants of all of Remote Oceania. The Lau Group is an archipelago of 80 islands, 29 of which are inhabited (Fig. 2). The Lau islands are made up of volcanic and coralline limestone substrates and they are located relatively close together. These islands support extensive reef systems that are rich in marine faunal resources, yet they are naturally depauperate in land mammals. The ancestors of contemporary Fijian populations introduced pigs, dogs, and rats to Remote Oceania (Kirch and Green 2001).

Jones' ethnographic data are the result of 6 months of participant observation on the island of Nayau and an additional 5 months of work on the nearby islands of Lakeba, Aiwa Levu, and Aiwa Lailai (see Fig. 2). This research aimed to document socioeconomic behaviors associated with rank and gender in qualitative and quantitative detail in order to facilitate comparisons between ethnographic data and prehistoric archaeological households in Fiji. Women's roles and associated material phenomena were recorded, especially food remains and debris, and were traced through three levels of analysis, including ethnographic (modern lifeways), ethnoarchaeological (modern consumption, deposition, and disposal), and archaeological (based on faunal analysis, stratigraphy, and examination of archaeological features).

Most of this ethnographic work focused on the island of Nayau. Nayau (18.4 km^2) is topographically and geologically varied, with limestone regions, large areas of volcanic soils, and bedrock outcrops. People on Nayau maintain extensive

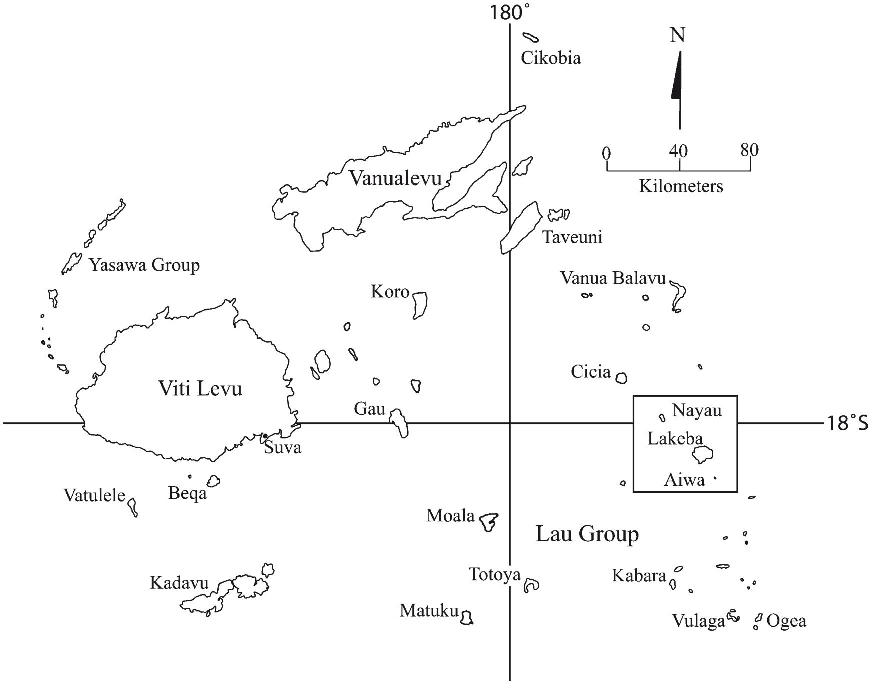

Fig. 2 Map of Fiji with the study sites indicated in the square

dryland and wetland agricultural crops, including taro, cassava, sweet potato, and yam. Table 1 presents a roster of important crops consumed in the study area, and provides a baseline for the interpretation of archaeological and isotopic data. Both male (offshore) and female (inshore) directed fishing expeditions were also recorded (Appendix A).

Modern households were investigated with attention to food-related activities. Through participant observation and formal interviews Jones documented household food preparation, consumption, distribution, and refuse disposal, individual preference, and household spatial patterning. The items most commonly used in the preparation of food are traditionally made of wood and other plant materials; these are listed in Table 2, along with important food items and categories. Data collected included information on which plant and animal foods were consumed each day, how much was consumed, the relative proportions of starch to meat, and individual consumption patterns within households.

Finally, 23 archaeological sites and households in the study area were excavated in an effort to understand patterned distribution of food remains and material culture. Archaeological work has generated a basic chronology of human occupational history on these islands (Jones 2007; Jones et al. 2007; O'Day et al. 2003). The study sites span a range of occupation for the Fiji region. The dates suggest an early settlement of Nayau by about cal. 580 ± 40 years BC, and extend to about cal.

Table 1 Modern Lauan staple plant foods: their sources and uses

Food	Scientific name	Source	Preparing	Serving	Notes
Taro	*Colocasia esculenta*	Family garden (interior of island)	Peeled and boiled, baked or pudding	Collective meals, for guests, gifts, tribute	A favorite field-crop, important in feasts and ritual eating
Elephant ear taro and Giant swamp taro	*Alocasia macrorrhiza* and *Cyrtosperma chamissonis*	Family gardens and feral (at base of hill slopes on coastal terraces and interior)	Peeled and boiled, baked or pudding	Collective meals, for guests, gifts, snacks	Enjoyed, but less important and less valued than taro
Cassava	*Manihot dulcis* and *M. esculenta*	Family garden (interior)	Peeled and boiled, baked or pudding	Collective meals, snacks	European introduction; is now eaten daily due to fast growth and relative ease of production
Sweet potatoes	*Ipomoea batatas*	Family garden (interior)	Peeled and boiled or baked	Collective meals, gifts, tribute, snacks	This crop is highly valued
Flour/Bread		Local store	Mixed with water or coconut milk and baked, boiled, or fried	Collective meals and snacks	European introduction, but Pacific islanders have long made starches, flours and meals
Coconut palm	*Cocos nucifera*	Coastal strand	Raw, grated, boiled, emollient	Collective meals, snacks, gifts	A staple food, used daily as an ingredient in the preparation of other foods
Rice	*Oryza* sp.	Local store	Boiled	Collective meals	This is a European introduction
Wild yams	*Dioscerea nummularia*	Interior forests	Boiled or pounded and mixed with water; the leaves are also consumed	Meals, collective meals, snacks	The leaves are collected at least 1-2 times a week and incorporated into meals

Breadfruit	*Artocarpus altilis*	Village gardens and hill slopes	Baked, mixed with water and fermented, made into puddings	Meals, collective meals, snacks, gifts	
Yams	*Dioscerea alata* and various *Dioscerea*, *Dioscorea* spp.	Family garden (interior)	Peeled and boiled or baked	Collective meals, for guests, gifts	Highly valued and important in communal feasts and as tribute
Bananas	*Musa* spp.	Family garden (interior)	Raw or peeled and boiled	Snacks and some meals	

Table 2 Lauan terms for food and food-related preparation objects

Object	Lauan term	Material	Functions and comments	Permanent (use or preservation)	Temporary/disposable
Bowl	*Peseni*	Wood or coconut shell	Specifically, *peseni lailai* (small bowl) or *peseni levu* (large bowl)	x	
Bowl	*Kumete*	Hardwood	Large, and usually oblong, wooden bowl for mixing and for use as a general basin	x	
Earth oven	*Lovo*	Stone, wood, charcoal, leaves	Reused in the same general area for many years (generations)	x	
Grater	*Sakalo or lotuma*	Wooden stool with shell grater	Used for grating flesh of coconuts	x	
Grater	*Sakalo* or *coroga*	Wood or a branch of coral	Used for grating starches, sugar cane, or kava (*yaqona*)	x	
Scraper	*Kuku*	Mangrove mussel shell	Used for scraping corms, tubers, fruit, and pandanus fronds in mat making	x	
Basket	*Kato*	Palm fronds	Refers to the baskets made of coconut frond used for carrying food from the garden or firewood		x
Pots	*Kuro*	Clay or metal	Pottery or metal pots for cooking and serving	x	
Spoon	*Taki*	Wood and/or coconut shell	A dipper and item for stirring	x	

Cup	*Bilo*	Wood or coconut shell	May function as a bowl, cup, or general scoop		x (Shell may preserve)
Coconut water	*Bu*		Specifically, a young coconut fit for drinking		x
Vegetables	*Boro*		Starch and leafy, but in common usage refers to root crops	x (Starch grains, seeds)	x (Flesh)
Flesh foods	*I coi*		Carries the connotation of accompanied food items (likely due to the cultural preference for eating flesh foods with a starch)	x (Bones and shells)	x (Flesh)
Starchy crops	*Ka kana dina*		Literally, “true food”, including cassava, bananas, taro, yams, breadfruit, etc.	x (Starch grains, seeds)	x
Pudding	*Vakalolo* or *galu*		Many kinds, pounded root crop, mixed with coconut cream and baked in the earth oven	x (Starch residue)	x
Bread	*Madrai*		Modern usage, refers to bread of flour and yeast, traditionally the term applies to Fijian bread of starch, buried in the ground to ferment	x (Starch residue)	x
Fish	*Ika*			x (Bones)	x (Flesh)
Shellfish	*Vivili or kai*			x (Shells)	x (Flesh)

(continued)

Table 2 (continued)

Object	Lauan term	Material	Functions and comments	Permanent (use or preservation)	Temporary/disposable
Seabirds	*Manumanu ni wasa*			x (Bones)	x (Flesh)
Chicken	*Toa*			x (Bones)	x (Flesh)
Beef	*Bulumakau*		Generally referred to as "cow," a European introduction	x (Bones)	x (Flesh)

1300–1400 AD in the excavated sites. On Aiwa Levu and Aiwa Lailai, 11 AMS dates provided evidence of over two millennia of human activity and occupation, extending from cal. 710 BC until the present, with most of the dates suggesting site occupations before cal. AD 1500 (Jones et al. 2007). Nayau has been continuously occupied since Lapita times, and Aiwa was occupied prehistorically but is currently only used as a temporary fishing camp.

The excavated sediment was screened through nested sieves of 1/2-in. (12.7 mm), 1/4-in. (6.35 mm), 1/8-in. (3.175 mm), and 1/16-in. (1.6 mm) mesh; shell, bone, pottery, lithics, non-local rock, and any other artifacts were collected. Bulk sediment samples were taken for additional analysis in the future. Jones extracted sediment from each stratum and feature at each site in order to provide samples potentially containing botanical remains that may be identified by a specialist. Ultimately, we expect to produce cross-sections of paleoethnobotanical data from sites spanning the human occupation of the Lau study area.

2.1 Ethnographic Patterns

A series of generalizations and ethnographic analogies may be drawn from Jones' participant observation and informant interviews. This ethnographic work provides useful information for comparison with the archaeological data, and some of the interpretations may ultimately be tested with isotopic analysis. The following points are pertinent to understanding the subsistence system and foodways of Lauans as a whole.

Starches dominate contemporary Lauan cuisine; they are eaten with every meal and as snacks throughout the day. These items are highly valued and sought after as well, playing an important role in social interactions, exchange, feasts, and communal meals (see Table 1). Thus, root crops are a critical part of everyday eating, ritual feasting, and exchange. Inshore fishes and other marine-associated resources such as shellfish, turtles, and seaweeds provide the marine portion of the diet; these are occasionally supplemented by larger bony fish caught offshore (see Appendix A). Domestic animals contribute a much smaller portion to the diet than bony fish (cows, pigs, and chickens contribute less than 10% of the overall animal protein consumed in most modern households). People typically eat domestic animals such as pig or chicken once a week or less, and during special occasions. Shellfish make up an even smaller portion of the diet, being consumed in very limited quantities and primarily as snacks.

The inshore area is exploited on a daily basis. Adult women between the ages of 16 and 60 are the main collectors of inshore marine resources, which form the primary animal protein portion of the Lauan diet, as is obvious from the list of important food fishes listed in Appendix A. Unmarried men and adolescents may join the women inshore, or groups composed of two to twelve men occasionally go out together with spears, nets, and motor boats on the inshore or off shore reef edge. Men of all ages fish on the outer reef edge with a mask and snorkel and a multi-pointed spear; this is usually done individually. It is uncommon for families, including parents and children, to fish together.[3]

Fisherpeople collect species in each of the following families on a daily basis using fishing nets and occasionally spears: parrotfish (Scaridae), tangs (Acanthuridae), emperorfish (Lethrinidae), groupers (Serranidae), and wrasse (Labridae). Tangs (especially *Acanthurus triostegus*) often occur in schools and may be caught in large numbers. Emperorfish are a favored food of Nayau's inhabitants; species in this family typically inhabit the shallows around inshore seagrass beds and sandy bottoms adjacent to coral reefs, either in small schools or alone.

Tubers are eaten with every meal and people, especially women and children, often snack on root crops throughout the day. Plant items not only contribute a large portion of the foods consumed daily (about two-thirds of the daily caloric intake), but material culture made from plant products forms a critical part of everyday domestic items (see Table 2). Jones' ethnographic study reveals that Lauans use plant items for multiple purposes, which certainly affects deposition of items into domestic areas and middens. For example, a coconut may first be used as a beverage. Then, the inside of the shell will be scraped, and the coconut meat will be grated and used for cooking (coconut meat and oil is an important emollient in the cuisine of the Pacific Islands). Finally, the cleaned coconut shell may be used as a cup or spoon and kept for years until it is finally discarded in the fire, hearth, or trash pile. This example illustrates that an understanding of traditional kitchen items (as well as their uses and material origins) may assist in interpreting the meaning of archaeological remains.

Unfortunately, plant foods and material culture made of wood and plant fibers are less likely to preserve over the long term due to taphonomic processes. However, archaeological excavations might be expected to uncover some of this domestic material culture, including both food remains and food preparation objects that are frequently used in modern Lauan kitchens. Many traditional utilitarian domestic and kitchen-related material culture items are either unknown to archaeologists or neglected for the more common study of ceramics and pot sherds, as is frequently the case in Fiji and other areas of Oceania.

2.2 Archaeological Findings

Although the archaeological sample from the 23 excavated sites has yielded only preliminary results, the data from Lau may be compared to the ethnographic analogs listed above and thus provide an alternative perspective on subsistence and foodways (Tables 3–6). Additionally, a long-term view of subsistence practices may be derived from the combination of archaeological and ethnographic data. An analysis of the plant remains and residues from the archaeological sites excavated in Lau has not yet been conducted. From the ethnoarchaeological data presented here it is impossible to adequately understand prehistoric uses of plant materials and the plant component of the diet.

Table 3 Family-level summary of fish bones from 12 Mid–late Period prehistoric archaeological sites on Nayau, Lau Group, Fiji

Family	MNI (%)	NISP (%)
Acanthuridae	20	32
Scaridae	12	8
Serranidae	12	13
Balistidae	11	17
Labridae	7	2
Lethrinidae	5	4
Diodontidae	5	15
Carangidae	4	1
Muraenidae	4	1
Mullidae	3	1
Lutjanidae	2	0.3
Pleuronectidae	2	0.4
Ostraciidae	2	0.6
Belonidae	2	1
Siganidae	2	1
Carcharhinidae	1	0.3
Exocoetidae	1	0.3
Holocentridae	1	0.3
Mugilidae	1	0.4
Scombridae	1	0.6
Tetraodontidae	0.5	0.1
Coryphaenidae	0.5	0.3

However, Lauans in the past undoubtedly consumed many plant foods, especially tubers, and we plan to continue to explore this issue in the future.[4] Here we integrate interpretations from faunal and isotopic analyses, alongside ethnoarchaeological data, to provide as broad a picture of subsistence as possible. We focus on the fish bones, as fishes are the most common component of the zooarchaeological assemblages by all measures (weight, count, MNI, and biomass), making up 67–90% of the total fauna at any given site. Four patterns are visible in the zooarchaeological fish data.

- First, remains of tangs (Acanthridae), parrotfish (Scaridae), groupers (Serranidae), triggerfish (Balistidae), emperorfish (Lethrinidae), and porcupinefish (Diodontidae) are common in all the Lauan assemblages analyzed (see Tables 3–5). There is much overlap in the identified fishes from all the sites, on each island, and across chronological periods; in rank order of abundance, tangs, parrotfish, and groupers consistently contribute the greatest frequency to the fish assemblage (MNI, NISP, and weight). Inshore marine resources, including bony fishes and to a lesser extent invertebrates, formed the largest animal protein portion of the prehistoric diet according to the zooarchaeological remains. Inshore fishes contribute two-thirds or more of the total NISP and MNI to the zooarchaeological assemblages (see Table 6).

Table 4 Family-level summary of identified fish bones from excavation on Aiwa Levu and Aiwa Lailai, Lau Group, Fiji

Family	MNI (%)	NISP (%)
Acanthuridae	18	26
Scaridae	14	20
Serranidae	10	13
Balistidae	9	11
Labridae	10	8
Diodontidae	5	7
Lethrinidae	8	4
Mullidae	2	2
Carcharhinidae	3	1
Holocentridae	3	1
Muraenidae	3	0.9
Lutjanidae	3	0.8
Siganidae	2	0.8
Carangidae	2	0.7
Pomacentridae	2	0.7
Haemulidae	0.5	0.5
Scrombridae	0.5	0.3
Mugilidae	0.5	0.3
Ostraciidae	0.5	0.3
Sphyraenidae	1	0.3
Kyphoside	0.5	0.1
Dasyatidae	0.5	0.1
Belonidae	0.5	0.1
Gerreidae	0.5	0.1
Tetraodontidae	0.5	0.1
Belonidae	0.5	0.1
Exocoetidae	0.5	0.1

Table 5 Family-level summary of identified fish bones from excavations at the Lapita site of NaMasimasi on Nayau, Lau Group, Fiji

Family	MNI (%)	NISP (%)
Acanthuridae	19	14
Serranidae	12	14
Diodontidae	3	10
Scaridae	9	10
Exocoetidae	5	9
Balistidae	5	9
Mullidae	3	7
Labridae	7	6
Belonidae	2	4
Muraenidae	2	3
Mugilidae	3	3
Siganidae	2	2

(continued)

Table 5 (continued)

Family	MNI (%)	NISP (%)
Pomacentridae	3	2
Scombridae	2	0.9
Holocentridae	2	0.9
Sphyraenidae	2	0.7
Carangidae	2	0.7
Ostraciidae	2	0.5
Dasyatidae	3	0.4
Lethrinidae	3	0.4
Carcharhinidae	2	0.4
Monacanthidae	2	0.4
Albulidae	2	0.2
Gerreidae	2	0.2
Lutjanidae	2	0.2
Haemulidae	2	0.2

– Second, greater than 80% of the recovered faunal remains, by all measures, were collected from archaeological cooking features (earth ovens, hearths, and/or other cooking areas) in the Mid-prehistoric to Contact period sites (cal AD 1450 to present). The composition of principle fish taxa in the various fish assemblages is remarkably similar across sites.

– Third, the overall size of the fish exploited throughout prehistory is relatively small. Measurements of more than 2,500 fish vertebral centra[5] from sites on Nayau, Aiwa Levu, and Aiwa Lailai reveal a mean fish size of about 24 cm in total length (TL) (and generally <35 cm TL) based on comparisons to modern fish specimens from Lau (Table 7). A surprising finding is that the fishes collected at this early Lapita occupation were smaller than those consumed later in prehistory; this finding goes against expectations based on optimal foraging theory, which predicts that large-bodied fauna will be preferably exploited. The Lapita site of Na Masimasi also produced the broadest range in the sizes of fishes with vertebral centra measuring 0.61–20.2 mm, although the vast majority of fish vertebrae are small overall. Mid–late period sites on Nayau (cal. 1400–1720 AD) produced a smaller range in the sizes of fishes exploited, with a mean vertebral centra size of 4.3 mm. The fish remains from Aiwa exhibit less dramatic variation in size over time (the mean 4.65-mm centra width at the Early period [cal 760–610 BC] sites, and 4.85 mm in the Mid-late period sites).

– Fourth, the taxonomic composition of the identified fish fauna is highly varied but ranges from 22 to 27 different families identified from each of the time periods (the mid–late Period sites from Nayau have 22 taxa; Na Masimasi has 26; and the Aiwa sites have 27). Furthermore, the average body size of consumed fishes, as indicated by measurements of fish vertebral centra, is small. These findings indicate that either a variety of methods was used prehistorically for fish collection (such as hook and hand-line, cast net, spear, and gill nets), and/or inshore nets

Table 6 Summary of faunal data from archaeological sites on Aiwa and Nayau (sites listed from early to late periods)

Site(s)	Island	Age[a]	Site type	NISP	MNI	Dominant fish families	Reference
Aiwa 1(units 1–4, III–IV), Dau RS, Cave 2	Aiwa Levu and Lailai	Early (cal. 500 BC–1040 AD)	Rock shelters	3,138	110	Acanthuridae (Tang), Scaridae (Parrotfish), Labridae (Wrasse), Serranidae (Grouper)	Jones et al. (2007)
NaMasimasi; Sites 196 and 197 (Lakeba)	Nayau, Lakeba	Early (cal. 760–610 BC)[b]	Beach site/Lapita occupation	7,570	59	Tang, Grouper, Diodontidae (Porcupinefish), Parrotfish	O'Day et al. (2003), Best (1984, 2002)
12 sites	Nayau	Mid-late (cal. 1400–1720 AD)	Fortified sites and rock shelters	3,054	175	Tang, Balistidae (Triggerfish), Grouper, Parrotfish, Lethnrinidae (Emperorfish)	O'Day et al. (2003), Jones et al. (2007)
Aiwa 1(units 1–4, I–II and all of units 5–6), Goat Rockshelter	Aiwa Levu	Late (cal. 1450–1720 AD)	Rockshelters	1,665	86	Tang, Grouper, Parrotfish, Triggerfish, Emperorfish	Jones et al. (2007)

[a] Age estimates based on AMS Radiocarbon dates with OxCal cal. BP correction

[b] The quantified measures only include data from the Jones, not material from Lakeba that was analyzed by Best (1984); Lakeba's earliest dates are 900–600 BC (Best 2002:33)

Table 7 Fish vertebral centrum widths (mm) from early and mid–late period occupations on Nayau, Aiwa Levu, and Aiwa Lailai

Provenience	*N*	Mean	Range	Standard deviation
Early Nayau	1,432	2.98	0.61–20.2	1.76
Early Aiwa	281	4.65	1.5–13.0	2.05
Mixed Aiwa	174	4.2	1.7–14.3	2
Mid–late Nayau	464	4.3	3–18.7	3.9
Mid–late Aiwa	165	4.85	2.04–13.33	1.9
Total	2,516	4.2	0.61–20.2	–

were the primary fishing technology employed. The use of inshore nets is the most parsimonious explanation for both the wide variety of inshore fishes and their overall small-body size (as indicated from the vertebral centra measurements and observations of the general size of the fish bones). Likely, people relied on nets to procure the majority of their fish, but also employed other technologies such as spear and hook and hand-line occasionally, just as they do today.

In sum, the zooarchaeological data suggest that the indigenous inhabitants of central Lau relied heavily on a suite of relatively small-bodied inshore fishes for food and likely used a combination of technologies (nets, hook and hand line, and spears or gill nets) to collect these animals. The most commonly identified taxa include tangs, parrotfish, groupers, triggerfish, emperorfish, and porcupinefish. These fishes are all frequently identified in Pacific Island archaeological sites (Davidson and Leach 2000; Jones et al. 2007) and comprise some of the most abundant living reef vertebrates in the Central Pacific (Myers 1991). Small-bodied inshore fishes were collected and consumed at the earliest occupied sites and throughout the archaeological period.

3 Stable Isotopes From Fiji's Lau Group: A Comparative Analysis

Ethnographic data indicate that the diets of most people throughout the world are composed of more plant than animal resources; yet, archaeologists have had difficulty determining the relative proportions of the two major food classes due to preservational and taphonomic biases. Alternatively, stable isotope analysis provides diet information of individuals, where both plant and animal components of the diet are incorporated into skeletal tissues preserved in archaeological contexts.

The organic phase of bone (primarily collagen) provides information on the protein fraction of the diet, and the inorganic or mineral phase (bioapatite) records whole diet (Ambrose and Norr 1993). Collagen remodels approximately every 10 years (Libby et al. 1964), while apatite is thought to have a higher remodeling rate due to ease of dissolution (Ruben 1989). Bone turnover rates vary by skeletal element (Marotti 1976) and may be dependent on metabolic rates (Tieszen et al. 1983). Increased levels of dietary protein may speed rates of collagen turnover up to three times that of low protein plant foods; as a result, marine isotopic signals quickly replace previous plant food isotopes, representing a seasonal or yearly diet rather than decadal averages (Parkington 1991). Nutritional stress may also speed fractionation rates from food to tissues, resulting in quicker turnover and shortened intervals represented in tissue isotopes (Hobson and Clark 1992). In sum, isotopic values of human bone represent diet averaged over approximately the last 4–10 years of an individual's life.

Isotopic values are reported in delta (δ) notation in parts per thousand (per mil, ‰) with the corresponding chemical species in the following equation: $\delta = [(R_{\text{sample}}/R_{\text{standard}})-1]\times 1{,}000$ where $R = {}^{13}C/{}^{12}C$, ${}^{15}N/{}^{14}N$ (Faure 1986). This equation calculates the ratio of heavy to light isotopes and compares that ratio to a known material, Pee Dee Belemnite (PDB) for carbon isotopes and air for nitrogen isotopes, for data standardization.

Stable carbon isotopic (${}^{13}C/{}^{12}C$) ratios represent the photosynthetic pathway of ingested plant material: Calvin–Benson (C_3), Hatch–Slack (C_4), or crassulacean acid metabolism (CAM) (Ehleringer 1989; Tieszen 1991). C_3 plants (e.g., yam, banana, breadfruit) strongly discriminate against the heavier isotope, ${}^{13}C$, and result in low $\delta^{13}C$ values. Alternatively, C_4 plants (e.g., sugar cane, maize) accommodate some heavy isotopes resulting in significantly higher $\delta^{13}C$ values. CAM plants are succulents (e.g., *Pandanus*) and switch from the 3- to 4-carbon cycles due to diurnal requirements. The result of the delta notation calculation typically maps measured $\delta^{13}C$ values in negative space. For instance, when an individual consumes C_4 plants, the higher or more negative $\delta^{13}C$ values are incorporated into body tissues including bone, whereas one who eats C_3 plants incorporates lower or less negative $\delta^{13}C$ values. Marine resources yield similar $\delta^{13}C$ values to those of C_4 plants (Schoeninger and DeNiro 1984; Sealy and van der Merwe 1985, 1988). CAM $\delta^{13}C$ values span the C_3–C_4 isotopic range, and thus pose a problem for differentiating diet groups. Notably, carbon isotopic analysis does not discriminate between an individual ingesting a particular plant from an individual ingesting an animal that fed on a particular plant.

Trophic level information is recorded in nitrogen isotopic (${}^{15}N/{}^{14}N$) ratios expressed as $\delta^{15}N$ values. The lighter isotope, ${}^{14}N$, is more easily incorporated into metabolic processes such as excretion, resulting in loss of ${}^{14}N$ and enrichment of body tissue in ${}^{15}N$. At the base of the food chain, nitrogen-fixing flora such as legumes are typically low in ${}^{15}N$, approaching a $\delta^{15}N$ value of 0‰ (Shearer and Kohl 1986). There is a stepwise increase in $\delta^{15}N$ values of approximately 3‰ each trophic level (Koch et al. 1994). Additional trophic spaces in marine ecosystems result in higher $\delta^{15}N$ values relative to terrestrial and freshwater ecosystems; thus, relative proportions of sea- and land-based foods may be estimated.

Utilizing $\delta^{13}C$ and $\delta^{15}N$ values in concert resolves several dietary groups. Browsers and grazers are separated by $\delta^{13}C$ values (Thackeray et al. 1993; Cerling et al. 1999), whereas δ^{15}N values further differentiate carnivores feeding on browsers from those feeding on grazers (Schoeninger and DeNiro 1984). Marine mammals and fishes are separated from terrestrial carnivores of grazer prey due to additional trophic spaces and therefore display higher δ^{15}N values (Norr 1995; Schoeninger et al. 1983). Humans are commonly mixed feeders and are located between these distinct dietary groups. Equifinality poses a difficult problem for mixed feeders, since the combination of many different diet end members may result in the same single isotopic value.

Ethnoarchaeological and zooarchaeological information inform interpretation of isotopic values and present likely diet combinations. Alternatively, interpretations based on ethnographic analogies and archaeological data may be tested with data derived from human bone isotope analysis. No single method provides a complete reconstruction of diet, but together, these independent lines of evidence are useful to test different assumptions or hypotheses, acknowledging the risk of tautology. For the purposes of this chapter, we emphasize the use of stable isotope analysis as a tool for testing hypotheses and conclusions derived from archaeological and ethnographic evidence. Specifically, this tool enables the identification of a broad spectrum of dietary resources that were consumed in the past, and assists in the estimation of their relative contributions to the overall diet. Less than a dozen isotopic studies have been conducted on human bone from archaeological sites in the southwest Pacific islands. Furthermore, only one study has been published on material from the Fijian islands (Valentin et al. 2006). Thus, additional research incorporating isotope analysis is needed in the region. Here, we present a preliminary isotopic dataset from human collagen samples from three of the Lau Group islands (Nayau, Aiwa Levu, and Aiwa Lailai) and are currently conducting additional analyses of human bone apatite and faunal bone collagen/apatite from the sites. We compare our results to human, non-human faunal, and floral isotopic data reported in Ambrose et al. (1997) and Valentin et al. (2006).

Quinn extracted collagen from nine human bone specimens following the methods of DeNiro and Epstein (1981) and analyzed 200–300 µg of bulk collagen on a GV Instruments Isoprime stable isotope mass spectrometer combined with a Eurovector elemental analyzer (continuous flow) housed at the Stable Isotope Laboratory in the Department of Earth and Planetary Sciences at Rutgers University. Quinn standardized all results against three National Institute of Standards and Technology (NIST) reference materials: NBS-1 (solid), NBS-3 (solid), and NBS-22 (oil).

In order to compare our human bone collagen results to plant and animal foods in the region, we utilized isotopic data from Ambrose et al. (1997) and compiled by Valentin et al. (2006). We implemented Valentin et al.'s (2006) four diet categories: C_3 vegetal diet (δ^{13}C: −27.2 ± 1.8‰, δ^{15}N: 3.5 ± 2.2‰), pelagic fish diet (δ^{13}C: −16.0 ± 1.8‰, δ^{15}N: 12.5 ± 2.3‰), marine shellfish diet (δ^{13}C: −15.0 ± 2.8‰, δ^{15}N: 6.9 ± 2.1‰), and reef fish diet (δ^{13}C: −12.6 ± 0.4‰, δ^{15}N: 7.9 ± 0.2‰). Following Ambrose et al. (1997) and Valentin et al. (2006), we corrected the mean values of each diet category to represent the δ^{13}C and δ^{15}N values for an individual ingesting 100% of that diet. We assume +5‰ for δ^{13}C values (Lee-Thorp et al. 1989) and +4‰ for δ^{15}N values (Ambrose and DeNiro 1986) for archaeological bone samples, and an additional +1.5‰ for δ^{13}C values to account for the fossil fuel effect in modern floral and faunal samples (Freyer and Belacy 1983).

From the four 100% diet categories, we calculated three line equations for each of the following diet groups: C_3 vegetal – pelagic fish diet: $y = 0.80x + 24.13$; C_3 vegetal – reef fish diet: $y = 0.30x + 13.74$; C_3 vegetal – marine shellfish diet: $y = 0.28x + 13.27$. Although the y-intercepts display variation due to the range of isotopic values in C_3 plants, we expect diets with the same two end members will have similar slopes (after Valentin et al. 2006). We modeled diet with least squares fit linear regressions (trend lines) of the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006). From the contexts of the archaeological and ethnohistorical findings, we test whether our dietary assumptions are supported or refuted with the stable isotopic results.

The ethnoarchaeological analogs or hypotheses include: (1) people relied on tubers (C_3 plants) and marine fishes as their primary food sources throughout prehistory; (2) small-bodied fishes that inhabit the inshore area make up the majority of consumed animal flesh; and, (3) pelagic fishes constituted a minor portion of the diet. Although our bone collagen sample is small (9 individuals from 3 Lau Group islands), the results significantly contribute to the previous published bone collagen datasets from the region (33 individuals from 4 islands). Our results also considerably expand the previously measured range of isotopic values and thus have implications for reconstructing diet breadth and marine foraging behaviors of peoples in Remote Oceania.

3.1 Isotopic Results

Nine individuals from the Lau Group yielded well-preserved collagen for isotopic analysis with C:N values between 2.9 and 3.6 (Table 8; after Ambrose 1990, 1993). δ^{13}C values ranged from –18.7‰ to –13.9‰ averaging –16.3‰, and δ^{15}N values ranged from 8.0 to 10.6‰ averaging 9.4‰ (Table 9). Analyses of variance (ANOVA) with post hoc Tukey comparisons performed on data from Valentin et al. (2006) and Ambrose et al. (1997) show significant differences between our δ^{13}C data and those from Rota and Saipian (Table 10, Fig. 3). The Lau Group δ^{13}C values are markedly higher. In δ^{15}N values, the Lau Group data are similar to all groups but Saipan, which shows lower values relative to all other groups (Table 11, Figs. 3 and 4). The Lauan individuals display a moderate to weak positive correlation between δ^{13}C and δ^{15}N values that is not significant at the 0.05 level (Pearson: $R^2 = 0.41$; $p = 0.6$; Table 12, Fig. 5). These results are similar to those of Saipan and Cikobia. Rota and Guam, alternatively, display strong positive and significant correlations (Ambrose et al. 1997). Least squares fit linear

Table 8 Lau Group human bone specimen archaeological site information, skeletal elemental identification, C:N ratio, and collagen isotopic ($\delta^{13}C$, $\delta^{15}N$) values (per mil, ‰)

FS #	Island	Site	Unit	Layer/level	Skeletal element	C:N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
N15	Nayau	Na Masimasi	D8	II/8	Humeral frag	3.1	−16.7	9.7
N10	Nayau	Na Masimasi	D8	II/7	Rib frag	3.0	−17.5	8.0
N13	Nayau	Na Masimasi	G6	I/3	Cranial frag	3.2	−16.2	9.8
A3	Aiwa Lailai	Dau Rockshelter	3	I/3	R scapular frag	3.1	−13.9	10.4
161	Aiwa Levu	Coastal Rockshelter	1	I/1	Long bone frag	3.1	−16.5	9.3
33	Nayau	Qara ni lulu	1	I/2	L cuneiform	3.6	−18.7	9.1
59	Nayau	Ulunikoro	1	I/2	Tibial frag	3.5	−14.8	10.6
–	Nayau	Nukutubu Rockshelter 2	1	III/4	Rib frag	2.9	−15.6	8.5
48	Nayau	Korovatu Rockshelter 2	1	I/2	R scapular frag	3.1	−17.0	9.3

Table 9 Summary statistics for the Lau Group human bone collagen isotopic (δ^{13}C, δ^{15}N) values (per mil, ‰)

	δ^{13}C (‰)	δ^{15}N (‰)
Sample size	9	9
Mean	−16.3	9.4
Median	−16.5	9.3
Std error	0.5	0.3
Std dev.	1.4	0.8
Variance	2.1	0.7
Minimum	−18.7	8.0
Maximum	−13.9	10.6
Range	4.8	2.6

Table 10 Results of analysis of variance (ANOVA) and Tukey post hoc test of δ^{13}C values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006)

Analysis of variance (ANOVA)					
Source	Type III SS	df	Mean Sq.	*F*	*p*
Model	22.945	4	5.736	6.205	**0.001**
Error	34.205	37	0.924		
Total	57.151	41			
Tukey post hoc test					
Group 1	Group 2	Mean diff.	SE	*q*	*p*
LAU	**ROTA**	**1.718**	**0.312**	**5.500**	**0.003**
	GUAM	1.048	0.379	2.764	0.308
	SAIPAN	**2.024**	**0.320**	**6.314**	**0.001**
	CIKOBIA	0.835	0.320	2.605	0.366
ROTA	GUAM	−0.670	0.372	1.799	0.709
	SAIPAN	0.306	0.312	0.978	0.957
	CIKOBIA	−0.883	0.312	2.828	0.286
GUAM	SAIPAN	0.976	0.379	2.573	0.378
	CIKOBIA	−0.213	0.379	0.563	0.994
SAIPAN	CIKOBIA	−1.189	0.320	3.710	0.087

trend line of the Lau Group has a low inclined slope of 0.37, which is similar to those of diets composed of C_3 vegetation and either marine shellfish or reef fish. Alternatively, Guam and Rota slopes approximate the slope of a C_3 vegetal and pelagic fish diet (Fig. 6).

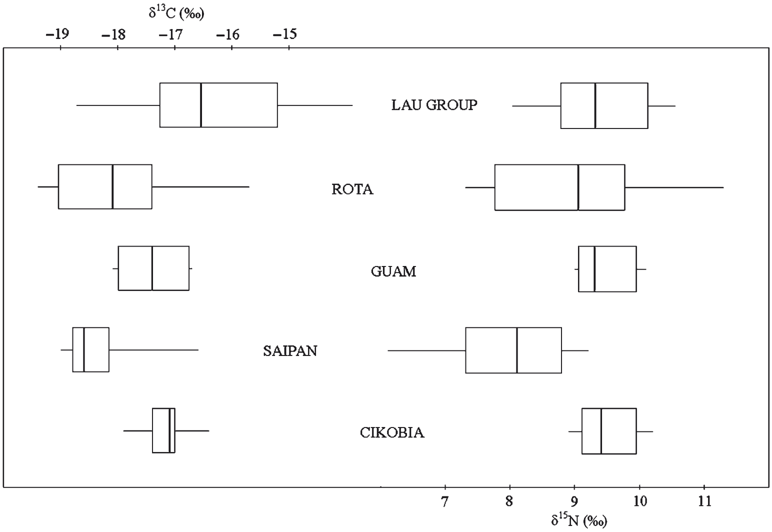

Fig. 3 Boxplots of human bone collagen δ^{13}C and δ^{15}N values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006)

Table 11 Results of analysis of variance (ANOVA) and Tukey post hoc test of δ^{15}N values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006)

Analysis of variance (ANOVA)					
Source	Type III SS	df	Mean sq.	*F*	*p*
Model	13.851	4	3.463	4.010	**0.008**
Error	31.950	37	0.864		
Total	45.802	41			
Tukey post hoc test					
Group 1	Group 2	Mean diff.	SE	*q*	*p*
LAU	ROTA	0.405	0.302	1.342	0.876
	GUAM	−0.055	0.367	0.149	1.000
	SAIPAN	**1.416**	**0.310**	**4.573**	**0.020**
	CIKOBIA	−0.084	0.310	0.270	1.000
ROTA	GUAM	−0.460	0.360	1.278	0.894
	SAIPAN	1.011	0.302	3.349	0.147
	CIKOBIA	−0.489	0.302	1.619	0.782
GUAM	**SAIPAN**	**1.471**	**0.367**	**4.014**	**0.053**
	CIKOBIA	−0.029	0.367	0.079	1.000
SAIPAN	**CIKOBIA**	**−1.500**	**0.310**	**4.843**	**0.012**

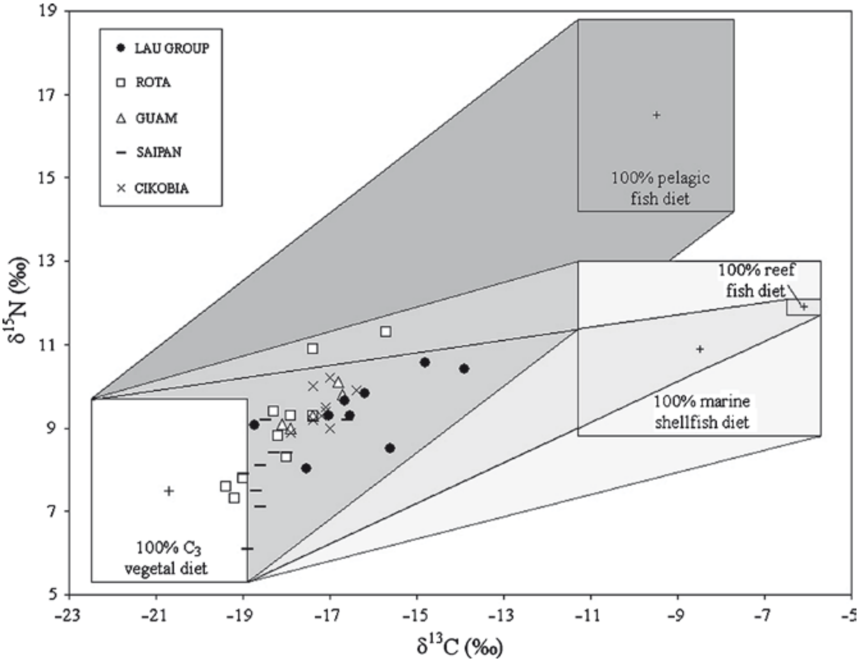

Fig. 4 Bivariate plot of human bone collagen δ^{13}C and δ^{15}N values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006). *Boxes* represent diet end members after Valentin et al. (2006). *Plus signs* equal mean values; *large boxes* represent one standard deviation

Table 12 Results of Pearson correlations of human bone collagen δ^{13}C and δ^{15}N values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006)

	Correlation matrix (R^2)	t-Statistic	Correlation significance (p)	Slope
LAU	0.41	2.22	0.06	0.37
ROTA	0.82	6.00	<0.00	1.12
GUAM	0.86	4.30	0.02	0.70
SAIPAN	0.39	2.09	0.08	0.85
CIKOBIA	0.25	1.53	0.17	0.56

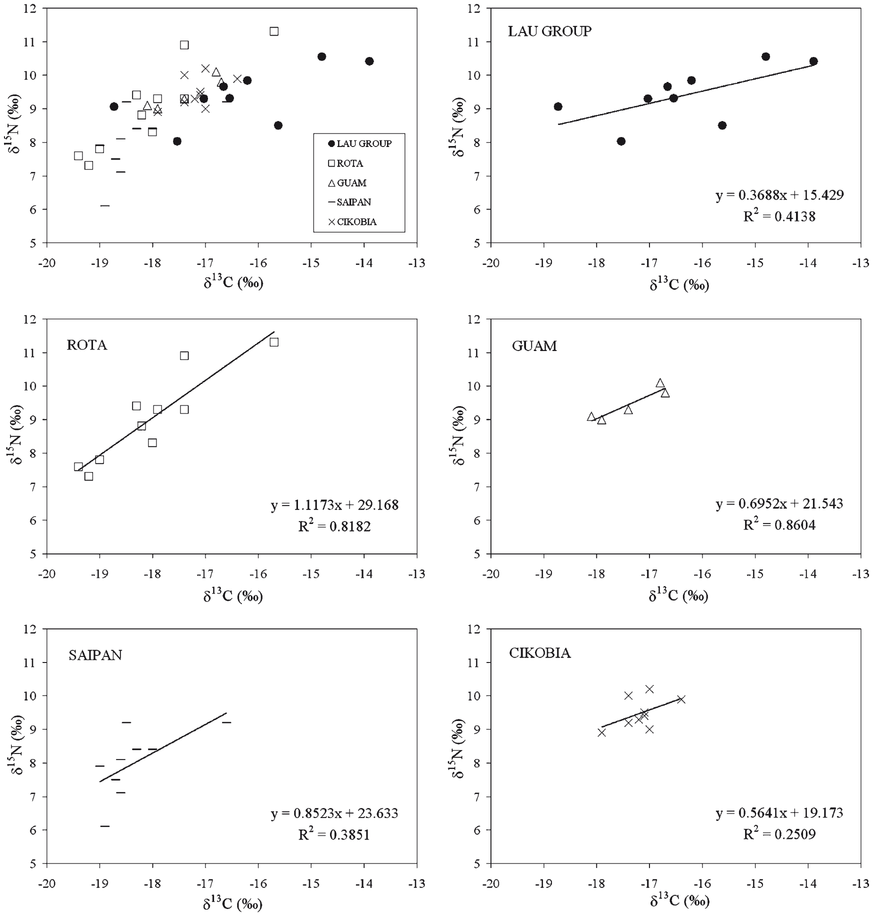

Fig. 5 Least squares fit linear trend lines, line equations, correlation matrices (R^2), and slopes of human bone collagen δ^{13}C and δ^{15}N values from the Lau Group (this study), Rota, Guam, Saipan (Ambrose et al. 1997), and Cikobia (Valentin et al. 2006)

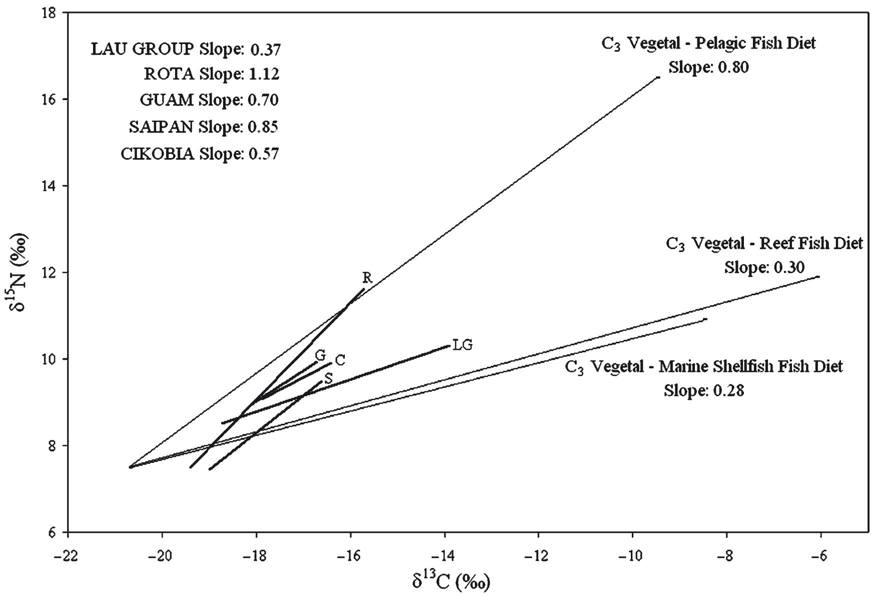

Fig. 6 Least squares fit linear trend lines of human bone collagen δ^{13}C and δ^{15}N values from the Lau Group (LG, this study), Rota (R), Guam (G), Saipan (S) (Ambrose et al. 1997), and Cikobia (C) (Valentin et al. 2006). Mean values of diet end members after Valentin et al. (2006)

4 Summary and Discussion

Complex meanings are undoubtedly associated with food and food-related activities of both the past and the present. The social correlates of the archaeologically identified patterns may be better understood by comparing these findings to ethnographic and stable isotopic data. Our approach is focused on exploring and interpreting Lauan foodways in the past through ethnoarchaeological homology, and testing these interpretations with stable isotopic analysis of human bone. We aim to reconstruct a holistic view of diet as well as some of the more complicated aspects of subsistence, including the technologies used for production, the most important food items, eating behaviors, and more generally, the meanings of common archaeological food-associated remains. In this case study we integrate zooarchaeological and ethnographic data with proxy plant data, specifically stable isotopic information regarding plant consumption.

4.1 Ethnoarchaeological Interpretations

Small-bodied inshore fishes are the most common component of the zooarchaeological assemblages by all measures; these fishes also make up the most significant animal portion of the diet. In a contemporary setting, small-bodied fishes are not only eaten daily, but they are also valued as a food source. That is, women target some types of small inshore fishes, including tangs, groupers, emperorfish, and parrotfish. There is a great deal of overlap between the types of fish exploited in the past and in the present. Inshore invertebrates are also collected and consumed, but form a much less important component of both the zooarchaeological remains and the modern diet.

The data suggest that net fishing and/or a combination of methods were employed in the inshore area as the primary mode(s) of fish capture in the past. If patterns of gendered labor division in the past were similar to those in the present and those documented in the early historic period, then women, children, and adolescents likely collected the inshore marine resources that are common in Lauan archaeological assemblages. Moreover, it appears that small inshore fishes contributed the most significant animal protein portion to the diet across time and throughout the excavated sites.

The ethnographic data may also assist in explaining why faunal remains are abundant in and around certain types of cooking features, such as earth ovens and hearths. Men and boys frequently sit around earth oven features and dispose of animal bones and shells on which they are snacking. Earthovens are male-associated structures that are dug into the ground some distance away from the kitchen, and used for cooking specific types of flesh foods, including pigs and cows. Conversely, hearths are features typically used by women for boiling foods, which are located in the kitchen and/or in central domestic spaces; these features are reused (as are earth ovens) and also have accumulations of domestic rubbish associated with them, such as coconut shells and broken utensils.

Contemporary data indicate that tubers and starches make up approximately two-thirds of the diet. The proportion of starch to animal foods consumed in the past may be better understood through isotopic information. Additionally, in the future our roster of modern plant foods may be compared to data derived from the identification of archaeological starch grains, residues, carbonized floral materials, and uncarbonized seeds. The ethnographic data may be used to address many archaeological questions and, even more importantly, it may expand the range of possible interpretations of the archaeological data (Binford 1978). Ethnographic analogs suggest a framework for the interpretation of plant and animal remains, beyond relatively simple behaviors that might be evidenced from archaeological patterns alone.

4.2 Isotopic Interpretations

The average diet of the nine Lauan individuals analyzed in this study contained a food source with an elevated $\delta^{13}C$ value. Our mean $\delta^{13}C$ values are significantly higher than Rota and Saipan, with two Lau individuals exceeding −15‰. We interpret the high $\delta^{13}C$ values to indicate that these Lauans were likely consuming different food resources than people from Rota and Saipan, since the majority of plant foods on the

Lau islands utilize the C_3 photosynthetic pathway, and therefore, have low $\delta^{13}C$ values; another source of high $\delta^{13}C$ values is required to explain the results. Sugar cane, a C_4 plant, is one known exception in the region that could have contributed to high $\delta^{13}C$ values in the diet (see Ambrose et al. 1997); however, ethnohistorically, sugar cane was not ingested in large quantities (Kirch and Green 2001; Sahlins 1962). Ingestion of the fruits of *Pandanus*, a succulent (CAM) in the region, could also have resulted in high $\delta^{13}C$ values; however, samples from the Cook Islands have been reported to have values in the C_3 range (Antón et al. 2007). The consumption of reef fish and marine shellfish, which have high $\delta^{13}C$ values exceeding those of pelagic fish (Fig. 4), is supported by both the archaeological and ethnohistorical evidence.

Lauan $\delta^{15}N$ values do not exceed those of individuals from Cikobia or the Marianas Islands, which have been interpreted to have had diets composed of 25–27% marine protein with the remaining derived from C_3 plant foods (Ambrose et al. 1997; Valentin et al. 2006). C_3 plant foods measured on Pacific Islands and utilized here have at most 5% protein, whereas marine animal flesh is composed of approximately 85% protein (Ambrose et al. 1997); therefore, even a low amount of marine protein would have increased $\delta^{15}N$ values markedly.

Based on the archaeological and ethnographic data, we can assume that protein was derived primarily from marine animal resources (i.e., pelagic fish, reef fish, or marine shellfish) and not from C_3 plant foods. We calculated the amount of protein in the diet from $\delta^{13}C$ values between C_3 vegetation (0% protein) and each of the three marine animal resources (100% protein) after methods of Ambrose et al. (1997) (Table 13). A diet of 100% C_3 plants would produce a $\delta^{13}C$ value of −20.7‰, and a diet of 100% pelagic fish would produce a $\delta^{13}C$ value of −9.5‰ (a difference of 11.2‰); therefore, each 1‰ increase from the C_3 plant value equals an added 8.9% of protein in the diet when consuming pelagic fish. The difference between C_3 plants and marine shellfish (−8.5‰) is 12.2‰, resulting in 8.2% protein for every 1‰ increase. Finally, the difference between C_3 plants and reef fish (−6.1‰) is 14.6‰, resulting in 6.9% protein for every 1‰ increase. Table 13 lists the percentage of dietary protein for each Lauan individual analyzed based on the three diet groups. Percentages range from 14% to 61% and give three averages of 39%, 36%, and 30% depending on marine animal flesh diet end members. These averages are similar but slightly higher than those of Cikobia (Valentin et al. 2006) and the Marianas (Ambrose et al. 1997). Based on the ethnohistorical findings, root crop species, such as taro and yam, comprise a large portion of the modern Lauan diet. These vegetal sources of protein are higher in both $\delta^{15}N$ value (up to 4–5‰, Ambrose et al. 1997) and protein content (5–7% of total calories; FAO 1990) than other C_3 plants and may further reduce our estimation of animal protein in the diet.

Ambrose et al. (1997) predicted a strong positive correlation between $\delta^{13}C$ and $\delta^{15}N$ values for a diet of C_3 flora and marine animal resources. Rota and Guam individuals demonstrate this pattern with steeply sloped linear trend lines (see Fig. 5), indicating a C_3 vegetal – pelagic fish diet (see Fig. 6). The slope of the least squares regression of Lau Group values is positive but with a low incline compared to the other island individuals (see Fig. 5), illustrating the significantly higher $\delta^{13}C$ values compared to the other groups, but with comparable $\delta^{15}N$ values. We interpret

Table 13 Percentages of marine protein in the Lau Group diet for each individual

$\delta^{13}C$ values (‰)	Percentage of protein (C_3 vegetal – pelagic fish diet)	Percentage of protein (C_3 vegetal – marine shellfish diet)	Percentage of protein (C_3 vegetal – reef fish diet)
−13.9	60.7	55.8	46.6
−16.7	36.1	33.2	27.7
−17.5	28.3	26.0	21.7
−16.2	40.1	36.9	30.8
−16.5	37.1	34.1	28.5
−17.0	32.8	30.1	25.2
−15.6	45.4	41.7	34.8
−18.7	17.6	16.2	13.5
−14.8	52.7	48.4	40.5
	39.0 (Mean)	**35.8** (Mean)	**29.9** (Mean)

Estimations are based on methods after Ambrose et al. (1997) and mean values of diet category end members after Valentin et al. (2006)

this low slope to indicate a C_3 vegetal – reef fish and/or marine shellfish diet, rather than C_3 vegetal – pelagic fish diet (see Fig. 6). Consequently, we favor the lower percentages of protein (30–36%) in the diet derived from reef resources. Future analyses of human bone apatite will test these interpretations.

Modern Lauans eat relatively few pelagic species in a contemporary context, and archaeological evidence supporting a pattern of intensive offshore exploitation is lacking. We interpret our stable isotopic data to support these findings. The nine Lauan individuals analyzed here, similarly, ingested reef fish and shellfish with minimal dietary contributions from pelagic species. Vegetal species (C_3) comprised the largest portion of the protein fraction of the diet and likely that of the whole diet. Our interpretations are somewhat different than Valentin et al. (2006:1404) who state that, "… the proportion of marine fish was at most 25% whereas shellfish or sea mammal flesh do not seem to have constituted an important part of daily food" (Valentin et al. 2006:1404). Cikobia individuals were elite-status individuals who likely had slightly different diets than non-elites. Although we have not yet definitively determined the status of the Lau Group individuals, we assume there are several lower-status individuals, or commoners, represented. Thus, it is not surprising that the marine protein portion of the Cikobian diet yielded isotopic values suggesting that pelagic fish were consumed more frequently than reef and inshore fishes; high-status individuals from this region often consume more offshore fishes than lower-status people (O'Day 2004).

The conclusions of Valentin et al. (2006) raise issues of taphonomic changes that might occur between the deposition of food remains and the subsequent excavation and recovery of food refuse. Since stable isotopic analysis of human bone provides a direct measure of what people ate, this approach offers a complement to zooarchaeological, paleoethnobotanical, and ethnographic data. Importantly, the identified fishes from this Cikobia site all primarily inhabit inshore habitats rather than pelagic environments (Valentin et al. 2006:1404–1405). However, Valentin et al. interpret the Cikobia isotopic values as suggesting that the majority of the consumed fishes inhabited pelagic environments. The difference between the zooarchaeological data and stable isotopic data is marked and the question remains: what happens to the fish catch before it ends up in the archaeological record? This is an issue that can be addressed by using ethnographic information. A better understanding of food processing, consumption, and discard will enable archaeologists to illuminate the foodways of Fijians as well as other peoples.

4.3 Testing Our Interpretations

The archaeological and ethnographic data suggest that: (1) Lauans were targeting, collecting, and eating substantial amounts of inshore reef fishes and other reef resources though prehistory and into modern times; (2) tubers account for a large portion of the diet; and (3) pelagic fishes constituted an insignificant portion of the diet. Our isotopic data concur with the archaeological and ethnographic data. When compared to other Remote Oceania populations, Lauan bone collagen shows high δ^{13}C values relative to δ^{15}N values. This pattern is consistent with a diet composed of C_3 plants and reef resources rather than pelagic fishes. Future isotopic analysis of human bone apatite samples will determine whether Lauans were consuming C_4 plants. Based on collagen results, we estimate no more than 30–36% of the diet consisted of protein derived from reef fish and shellfish, with the remainder (64–70%) of the diet composed of C_3 plants. Our stable isotopic analysis is only the second such study conducted in the Fiji islands, and thus our findings contribute important information toward building a larger comparative baseline of dietary isotopic data for Fiji and Remote Oceania. Moreover, our data suggest that homological comparisons in the Fiji islands can be a powerful source for interpretation, which has implications for the archaeology of the Pacific Island region in general.

5 Conclusion

When research focuses on one type of data and its quantification, one can easily lose sight of the meaning of the archaeological material under analysis. Indeed, a focus on transforming data through equations sometimes results in the complete separation of floral and faunal information through specializations as sub-fields within archaeology. On a collaborative multinational or multi-institutional project, for example, the person conducting zooarchaeological research might not even discuss his or her research with the person conducting paleoethnobotanical analysis. This separation and compartmentalization is detrimental to overall interpretation and understanding of subsistence and economic systems. Increased collaboration between researchers, and more researchers who practice floral, faunal, and stable isotopic analysis, would contribute much to the anthropological study of foodways and subsistence systems in the past.

Interdisciplinary collaboration holds great potential for illuminating a broad holistic view of subsistence and foodways. Humans need proteins, carbohydrates, and essential vitamins and minerals to live healthy lives. As anthropologists and archaeologists, however, we should seek to understand all aspects of subsistence systems in order to obtain a more encompassing picture of the past. Only in light of multiple lines of evidence can archaeologists hope to adequately interpret prehistoric diets and foodways. To understand how paleoethnobotanical data articulate with zooarchaeological and stable isotopic data, ethnographic analogy is either implicitly or explicitly employed in all interpretations.

Finally, since researchers may not share theoretical goals or even a common theoretical base, an emphasis on methods is critical. If standardized analytical methods are applied at a basic level then archaeologists will be in a position to make cross-cultural, deep time, or large-scale comparisons, and to ultimately synthesize knowledge and enhance the meaning and significance of our research. With attention to methods, it is possible to collect data that are applicable to various theoretical approaches. Ultimately, this should create a dialogue and exchange of information that cut across theoretical approaches. Both formal theory (evolutionary, ecological, economic) and historical or social approaches would benefit from this discourse that may advance our knowledge about the past and the complex relationships between humans, plants, and animals.

Notes

1. Groube (1971) originally suggested that the intensive shellfish exploitation and coastal settlement of the earliest occupants of Tonga (the Lapita peoples) indicated that they were “oceanic strandloopers,” explorers who settled islands in advance of people who practiced horticulture or agriculture. While this Lapita maritime, lagoon-based economy allowed for rapid occupation of islands, it was the development or introduction of horticultural systems that enabled the Lapita peoples to prosper and expand east. The descendents of the Lapita peoples practiced full-blown agriculture with elaborate irrigated dryland and wetland field systems.
2. Hodder (1986) and Conkey (1989), among others, have suggested a shift away from ethnoarchaeology toward material culture studies, focusing on how people construct their material worlds. In this scenario, culture and material culture are understood in relation to meaning. Hodder suggests that material culture can only be understood by placing it within a cultural and historical context.
3. The exception to this is found in two villages on the island of Lakeba, Nasaqalau, and Vakano. In these villages communal fishing is done 2–3 times each week, and extended families are involved. Women direct these expeditions, as they do with all inshore fishing activities.

4. Horrocks and Nunn (2007) recently published findings from starch residue, pollen, and phytolith analysis that were carried out on coralline deposits from a Lapita site at Bourewa, Viti Levu, Fiji. Starch grains, calcium oxalate crystals, and xylem cells of Lapita-introduced taro and yam were identified. These data provide an eastward extension of direct evidence for Lapita horticulture in Remote Oceania. Jones is currently conducting a detailed study of the fauna from Bourewa.
5. The anterior width of complete vertebral centra from both the identified and unidentified fish remains was measured for comparative purposes and to estimate the average weight and size of fishes in the assemblages. This procedure is based on the assumption that both the identified and unidentified fish vertebrae represent a cross-section of the species present in the assemblage (Newsom and Wing 2004).

Acknowledgments The authors gratefully acknowledge the late Na Gone Turaga Na Tui Lau, Tui Nayau Ka Sau ni Vanua ko Lau, The Right Honourable Ratu Sir Kamisese Mara, and his family for allowing our team to work on Lakeba, Nayau, and Aiwa. We thank the Fiji Museum and especially Sepeti Matararaba for their important assistance. We are grateful to the people of Nayau and Lakeba for welcoming and facilitating this research, in addition to providing us with a wealth of local knowledge. Vinaka vakalevu Tui Liku, Tui Naro, Jack, Sera, Caka, Meli, Mote, Sina, Semeti Guvaki, Colati, and Rusila. We also thank the Florida Museum of Natural History for use of multiple laboratories and comparative collections; Heather Walsh-Haney of Florida Gulf Coast University for identifying the human remains submitted for radiocarbon dating; and Joseph Ortega for assistance with the illustrations. We thank Linda Godfrey and Jim Wright at the Stable Isotope Laboratory in the Department of Earth and Planetary Sciences at Rutgers University for assistance with isotopic analyses. This research was partially funded by a National Geographic Research and Exploration Grant and UAB-NSF ADVANCE grants to Sharyn Jones.

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Integrated Contextual Approaches to Understanding Past Activities Using Plant and Animal Remains from Kala Uyuni, Lake Titicaca, Bolivia

Katherine Moore, Maria Bruno, José M. Capriles, and Christine Hastorf

For pragmatic reasons, separate specialists usually analyze plant and animal remains recovered from archaeological sites. Animal bones and charred plant remains are the products of very different organisms and tissues, fragment differently, and are identified using very different characters (see Peres, this volume; Wright, this volume). Even so, a primary concern of the Taraco Archaeological Project (TAP) has been to integrate these archaeobiological datasets to better understand aspects of ancient lifeways in the Lake Titicaca Basin of the Andes.

The collaboration between TAP zooarchaeologists and paleoethnobotanists has contributed to a greater understanding of the Titicaca Basin economy based on farming, pastoralism, and fishing[1] (Bruno and Moore 2008; Capriles Flores et al. 2007), as well as food practices (Miller et al. 2008). However, prior to exploring these broader cultural patterns we had to consider the depositional processes that produced the patterns we encountered in both datasets.

In the first stage of our research, Moore and Hastorf (2000) conducted a pilot study of flotation samples, in which plant and animal remains were compared, looking for coincidences and correlations in their attributes. Here, we establish a more detailed framework for recording burning, weathering, and disturbance of archaeobiological remains. In the contexts we examine from highland Bolivia, the only plant remains that preserve are carbonized. A detailed visual assessment of the remains themselves allows us to suggest a variety of contextual conditions associated with burning events. Similarly, bone fragments reflect their taphonomic history, including the intensity and timing of heat treatment. All bone fragments in midden are assumed to have experienced cooking. Much bone, even after cooking, has no visible signs of heat treatment, so it can serve as a record of activities where heat treatment was less intense, and where plant remains may be missing because of decomposition or no contact with fire.

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_8, © Springer Science+Business Media, LLC 2010

With these two sets of observations, we approach each sample as a record of site activities including heat treatment, weathering, and post-depositional disturbance. For this phase of research, we use experimental and ethnoarchaeological observations to more tightly connect our archaeological remains with a range of possible prehistoric behaviors. These observations were made over a period from 1999 to 2006, including interviews with local residents, observations and excavations of abandoned and weathered structures and features, and experimental cooking and firing using traditional materials and features.

This approach offers specific evidence for the range of activities at archaeological sites and highlights the different pathways by which plant and animals remains are deposited. We argue that broader cultural interpretations of plant and animal remains should not be undertaken until the conditions of burning and differential preservation can be established for a particular site.

1 Archaeological Setting

The Taraco Peninsula of Bolivia extends as a narrow finger into the shallow southern part of Lake Titicaca (Fig. 1). Located in the Andean *altiplano*, the vegetation and animal life of the area are strongly affected by the high altitude (approximately 3830 m asl), with cool-adapted cereals and tubers grown along the lakeshore and extensive pasture for cattle (*Bos taurus*), sheep (*Ovis aries*), pigs (*Sus scrofa*) and

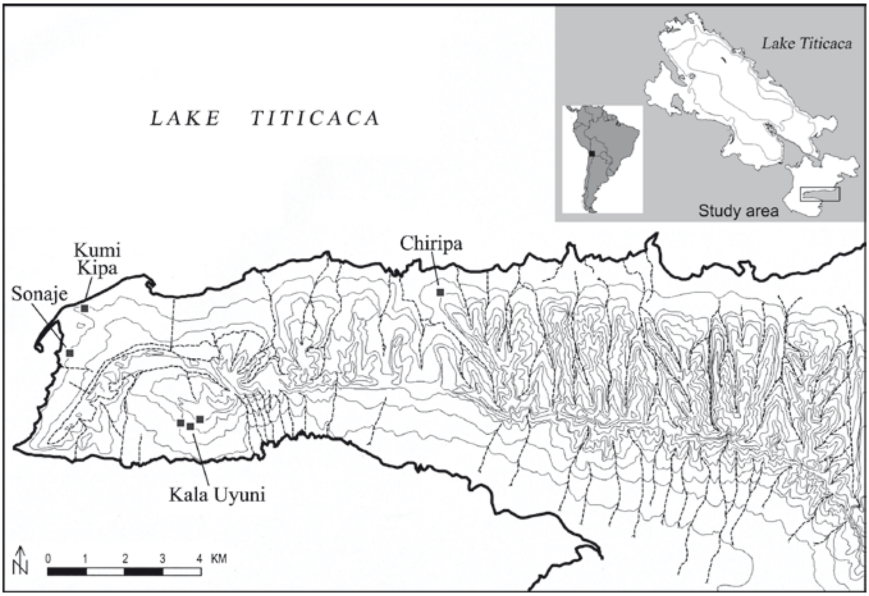

Fig. 1 Study area showing location of sites

native alpacas (*Lama alpaca*) and llamas (*Lama lama*). The Formative period (ca. 1500 BC–AD 500) sites of the Taraco Peninsula are well known based on excavations at the early ceremonial center of Chiripa on the northern shore of the Peninsula (Bennett 1936; Browman 1978, 1989; Hastorf 1999a; Kidder 1956). At the site of Chiripa, TAP instituted a comprehensive program to recover archaeobiological remains, and established a preliminary understanding of early plant cultivation and pastoralism, hunting, and gathering for the region (Bruno and Whitehead 2003; Hastorf 1999b; Moore et al. 1999; Whitehead 1999, 2006). A comprehensive survey of the Taraco Peninsula (Bandy 2001) guided the selection of further sites along the eastern and southern shore of the peninsula for excavation from 2003 to 2005 by TAP (Bandy and Hastorf 2007). Excavations at the site of Kala Uyuni took place in 2003 and 2005; the samples discussed in this paper were excavated during the 2003 season. Kala Uyuni is a multi-component site with deposits and structures dating from the Early Formative (Early and Middle Chiripa phases, 1500–800 BC), Middle Formative (Late Chiripa phase 800–200 BC) and Late Formative (Tiwanaku I and III phases, 200 BC–AD 500) (Bandy 2007). A prominent hilltop, called Achachi Coa Kkollu (AC), contained the remains of two stone-lined sunken courtyards, one with a carved stele still in place in the center (Cohen and Roddick 2007). On the basis of radiocarbon dates and ceramics, these structures date to the Late Chiripa phase. The presence of decorated and specialized ceramics led to the suggestion that the AC sector was the site of public ritual, including food consumption events like feasts or drinking parties (Steadman 2007). The AC structure was built over an earlier Early and Middle Chiripa phase component that appears to be domestic midden deposits with non-decorated ceramics.

On the slope below the AC structure is the Kala Uyuni (KU) sector of the site. The distribution of Late Formative (250 BC–AD 250) ceramics indicates that this would have been a substantial settlement of more than 15 ha (Bandy 2001:101). In the excavations, we encountered a series of Late Formative structures and prepared surfaces that post-date the sunken courts of AC (Paz Soría and Fernandez 2007). These structures and features appear to be of smaller scale and have some domestic aspects, but have also yielded a distinctive decorated and elaborate ceramic assemblage, suggesting a ceremonial role or perhaps elite occupation (Steadman 2007).

The Ayrampu Qontu (AQ) sector, an earlier settlement to the west of the KU sector, dates to the Early and Middle Formative periods. We have no evidence for structures from AQ but there are stratified midden deposits (Bruno 2007). In contrast to the contemporaneous AC area, the AQ deposits contained undecorated utilitarian ceramics suggesting this area represents a domestic occupation (Steadman 2007).

In addition to the KU samples, we chose one flotation sample identified as a possible hearth at the site of Sonaji, excavated in 2004, and a sample identified as the remains of *in situ* burning at the site of Kumi Kipa, also excavated in 2004. Excavations at the large site of Sonaji, on the eastern end of the peninsula, consisted primarily of Late Formative structures and features such as pits and middens (Bruno et al. 2006; Ulloa Vidauree and Killackey 2005). Excavations at the site of Kumi Kipa on the northeastern tip of the peninsula, revealed Late Formative walls, burials, and pits (Fernandez Murillo et al. 2005).

Unmixed archaeological deposits were screened through 6.35 mm (1/4 in.) mesh. This method provided a representative sample of large animal remains, and a highly biased sample of bird, rodent, and fish remains (see Peres, this volume, for a discussion of recovery biases). In addition, flotation samples were taken from every context, which we refer to as a locus, and processed using a modified SMAP machine with a 1 mm mesh insert to collect the heavy fraction (see Watson 1976). The light fractions of the flotation samples were the sole source for charred plant materials; the heavy fractions of the flotation samples were an unbiased sample of the animal remains with respect to fragment size, including remains to 1 mm, which recovered the teeth of the smallest cricetine rodents.

All of the excavated sites presented ample evidence for the use of fire. In addition to abundant carbonized plant remains, there was evidence of burned bone and ceramics. The fires creating these carbonized remains likely came from a variety of sources and contexts: cooking, firing ceramics, cleaning, ritual, or accidental. As part of understanding the function of these sites, we attempt to determine the types of fires that produced the excavated deposits through careful examination of the plant and animal remains. In particular, we hope to differentiate fires used for food preparation versus the disposal and burning of garbage. In addition, we hope to understand the ritual or ceremonial role of burning. We are aware that there may be mixtures of several different kinds of behavior as the result of site maintenance, reconstruction and fill of structures, weathering and bioturbation. We hope to reconstruct some of this depositional history, keeping in mind that decomposition and burning altered and removed a significant part of the plant material and some of the animal remains. In this study, we examine 33 flotation samples that represent 29 contexts from the five sites described above (Table 1). The samples represent a range of contexts from adobe wall fall to pits with high concentrations of carbon and bone. In Table 1, we present the excavators' descriptions of the contexts (hearth, ash lenses, etc.). These descriptions influenced our selection of samples as we hoped to examine a range of contexts, particularly those that possibly represented the direct use of fire. In this analysis, however, we are able to refine some of these interpretations through our careful examination of the plant and animal remains.

2 Ethnoarchaeology of Burning and Fires

In modern farming villages on the Taraco Peninsula, there are many contexts in which plants come into contact with fire and get deposited in soil (Table 2) (Bruno 2008:205–208). Indoors, people use plants as fuel for cooking. While cooks today frequently use a gas burner, they still use clay hearths for cooking soups, tubers, and other boiled dishes. The most common fuels are *Eucalyptus* wood (including branches, leaves, and nuts) and cattle dung, which contains seeds from various plants. Camelid dung would certainly have been a source of carbonized seeds in the archaeological record (Hastorf and Wright 1998; see also Pearsall 1988). In the past, local shrubs and native trees could have been used as fuel, as well as llama dung.

Table 1 Summary of flotation sample data

Flotation sample characteristics						
Flot #	Locus	Area	Excavator's description of context	Ceramic phase	Deposition discrete	High burning
13035	5065	AQ	Midden, high density	Late Chiripa		
13050	5070	AQ	Midden with ash	Late Chiripa		x
13055	5075	AQ	Midden, medium density	Late Chiripa		
13090	5079	AQ	Wall fall	Late Chiripa		
13105	5081	AQ	Wall fall	Late Chiripa		
13122	5086	AQ	Midden, high density with charcoal	Late Chiripa		x
13131	5088	AQ	Midden, high density	Late Chiripa		
13140	5091	AQ	Midden, high density	Late Chiripa		
13128	5137	AC	Clay floor inside structure	Late Chiripa	x	x
13137	5141	AC	Pit fill, ash	Late/Middle Chiripa	x	x
13120	5178	AC	Pit with fish bone	Late Chiripa	x	
13123	5178	AC	Pit with fish bone	Late Chiripa	x	
13115	5180	AC	Fill over floor	Late Chiripa		
13143	5183	AC	Ash on upper floor of lower court	Late Chiripa	x	x
13144	5183	AC	Ash on upper floor of lower court	Late Chiripa	x	x
13156	5192	AC	Pit with fish bone	Late Chiripa	x	
13169	5193	AC	Pit with fish bone	Late Chiripa	x	
13175	5193	AC	Pit with fish bone	Late Chiripa	x	
13177	5193	AC	Pit with fish bone	Late Chiripa	x	
13163	5229	AC	Pit with clay fill	no ceramics	x	
13159	5230	AC	Pit fill, ash	Tia I/III	x	x
13166	5233	AC	Midden, medium density, primary context	Middle Chiripa		
13167	5234	AC	Midden, medium density, primary context	Middle Chiripa		
13200	5238	AC	Midden with ash, high density, secondary context	Middle Chiripa		x
13204	5240	AC	Midden with ash, primary context	no ceramics		x
13245	5305	KU	Midden, high density	Tia I		
13249	5307	KU	Pit fill, ash	Tia III	x	x
13359	5317	KU	Midden, high density	Tia I		
13339	5363	KU	Hearth	Tia I	x	x
13319	5370	KU	Hearth	Tia I	x	x
13351	5431	AC	Ash deposit, building collapse	Late Chiripa	x	x
14284	6125	SN	Hearth	Tia I?	x	x
14192	6590	KK	Fill between floors, possible hearth	Tia I?	x	x

(continued)

Table 1 (continued)

Charred plant material: light fractions						
Flot #	Density of charred fuel (g/l), deposit	Density of charred food (g/l)	Condition of seed coat, 0–5	Preservation of seed, distortion, 0–4	Fragmentation of seed, 0–3	Firing condition, 0–6
13035	0.02273	0.01073	4	3.5	3	2
13050	0.00689	0.00211	4	3	3	3
13055	0.00467	0.00167	4.5	3	3	1
13090	0.00011	0	1	1	1	3
13105	0.00744	0.00089	3	3	2	2
13122	0.01989	0.00600	4.5	3	3	2
13131	0.02550	0.00820	3	3.5	3	3
13140	0.05944	0.04744	3	3	3	3
13128	0.12040	0.00240	3	3	3	2
13137	0.20344	0.06056	2	2	2	1.5
13120	0.01620	0.01110	3	2.5	2	3
13123	0.01280	0.00720	2	2	3	2
13115	0.01333	0.00533	3	2	3	3
13143	0.02760	0.00600	4	4	2	3
13144	0.03371	0.01157	3	3	2	3
13156	0.01770	0.01100	2	2	2	2
13169	0.01910	0.01300	3	2.5	3	3
13175						
13177						
13163	0.03133	0.01100	3	2.5	2.5	2
13159	0.06150	0.00200	2	2	2	2
13166	0.06340	0.00460	3	3	3	3
13167	0.00670	0.00190	3	2	3	2.5
13200	0.21070	0.04490	3	2	3	2
13204	0.14400	0.06480	2	3	3	2.5
13245	0.01222	0.00311	2	2	2	3
13249	0.14970	0.04290	3	3	3	3
13359	0.07844	0.04144	4	3	2.5	3
13339	0.02640	0.00470	3.5	2.5	2	3
13319	0.00700	0.00244	3	2.5	2	3
13351	0.09850	0.05900	2	1	1	2
14284	0.16110	0.06960	1	2	1	2
14192	0.00620	0.00080	2	2	2	2

(continued)

Table 1 (continued)

Animal bone: heavy fractions

Flot #	Density all bone, unburned (g/l)	Density mammal bone, charred (g/l)	Density fish bone, charred, (g/l)	Density mammal bone, calcined (g/l)	Density fish bone, calcined (g/l)	Bone weathering and splitting, 0–5	Trampling and rounding, 0–3	Fragmentation, 0–1
13035	4.238	0.499	0.064	0.016	0.000	2	0	0.29
13050	2.332	0.034	0.200	0.000	0.011	3	0	1.00
13055	1.100	0.052	0.089	0.009	0.000	3	0	0.34
13090	0.448	0.009	0.008	0.000	0.000			0.29
13105	1.428	0.038	0.018	0.001	0.001	4		0.04
13122	3.719	0.132	0.130	0.020	0.000	3		0.19
13131	4.381	0.346	0.075	0.000	0.001	3	1	0.09
13140	3.584	0.407	0.129	0.017	0.000	1	2	0.33
13128	0.576	0.111	0.094	0.000	0.004	1	0	0.12
13137	0.224	0.354	0.088	0.032	0.007	2	0	0.13
13120	8.188	0.071	0.064	0.015	0.000	3	0	0.90
13123	2.555	0.265	0.044	0.007	0.001	4	2	0.23
13115	0.558	0.087	0.031	0.003	0.000	2	1	0.81
13143	2.292	0.080	0.060	0.001	0.000	1	0	0.09
13144	1.630	0.709	0.139	0.000	0.000	3	0	0.13
13156	4.289	0.121	0.267	0.039	0.002	5	3	0.21
13169	3.091	0.109	0.974	0.001	0.113	5	3	0.36
13175	5.266	0.106	1.546	0.007	0.002	2	0	0.23
13177	3.085	0.109	0.968	0.002	0.113	4	3	0.36
13163	1.447	0.017	1.070	0.000	0.003	0	0	1.00
13159	2.325	0.120	1.520	0.000	0.000	3	0	1.00
13166	5.059	0.021	0.035	0.001	0.000	5	0	0.15
13167	0.611	0.027	0.003	0.005	0.000	3	0	0.20
13200	14.886	1.201	1.651	0.060	0.000	0	0	0.09
13204	1.930	1.085	0.207	0.213	0.001	1	0	0.43
13245	0.892	0.088	0.004	0.011	0.000	4	3	0.60
13249	0.415	0.427	0.058	0.032	0.000	4	3	0.46
13359	5.106	1.090	0.163	0.009	0.000	3	3	0.05
13339	3.889	0.462	0.138	0.004	0.006	0	0	0.54
13319	0.194	0.499	0.022	0.002	0.000	0	0	0.42
13351	0.443	0.777	0.074	0.118	0.001	1	0	0.10
14284	0.454	0.098	0.013	0.178	0.000	0	0	0.81
14192	0.677	0.341	0.025	0.022	0.001	0	0	0.45

(continued)

Table 1 (continued)

	Other indications of context				
Flot #	Partial burning present	Eggshell present	Small rodents present	Burned earth, relative amount	Glassy slag abundant
13035			x	x	
13050		x	x	x	
13055		x		xx	
13090				x	
13105					
13122		x	x	xx	
13131		x			
13140	x			x	
13128					
13137					
13120					
13123			x	x	
13115		x		x	
13143	x	x	x		x
13144		x		x	
13156					
13169			x	xxx	
13175				x	
13177					
13163			x		
13159				x	
13166			x		
13167	x			xx	
13200		x	x		
13204	x	x		x	
13245		x			
13249					
13359	x	x			
13339		x		xx	
13319					
13351		x			
14284	x	x		x	x
14192		x		x	

Table 2 Domestic activities involving burning: plants and animals

Cooking/burning	Plant density	Seed distortion	Seed fragmentation	Weathering	Effect on animal remains
Stews and porridges	Residues on ceramics only				Residues on ceramics; no burned boned produced
Toasting seeds	High density of food plant	Low distortion	Low fragmentation		
Pit cooking (*Watia*)	High densities of fuel, some food	Low distortion	Low fragmentation	Rake out spreads fuel and burned earth beyond pit	No burned bone from cooked meat; Heat in pit chars bone in underlying deposits
Plants as fuel for open cooking fires	High densities of fuel plants	High distortion	Moderate fragmentation	Increasing fragmentation if open	Light charring with “grilling,” heat from cooking chars bone in underlying deposits
Site maintenance, trash burning	Variable densities	High distortion	Low fragmentation	Increasing fragmentation if open	Charring, calcined bone produced with repeated burning in trash fire and underlying deposits
Field clearance	Low density, high ash		High fragmentation		Little effect

After cooking, accumulated ashes from the fire are usually swept into a bucket and dumped in fields as fertilizer. In excavations of one house abandoned in the 1970s, however, we encountered a hearth approximately 50 cm in diameter with layers of ash and charcoal 30 cm thick. While some abandoned hearths still maintain part of the clay or stone structure, some are visible only as reddened surfaces on floors and the adobe wall directly above.

Outside of the house, plants are burned for other purposes. Some cooking can be done outdoors, particularly the method of pit roasting called *watia*. A small pit is dug in a field, and clumps of clay and stones are gathered to make a shelter over the pit. Wood, dung, and grass are placed inside and set on fire. The fire is maintained until the surrounding earth has absorbed enough heat to cook food. Cooks clean out the fire and then place tubers and meats inside, and cover them completely. After some time, the earth is cleared away and the food picked out. A similar pit-cooking technique seen for larger meals is when rocks are heated in a separate wood fire, then cleaned off and laid in a prepared pit. Meat and vegetables are placed on top of the hot rocks. The food is then covered to keep it clean, and soil is piled on top to insulate it while the food steams and cooks. In this case, the fire and the process of cooking are separated by several meters.

No ceramics are manufactured in our study area today, but Tschopik (1950) recorded that Aymara potters used grass, dung, and wood to fire pots in open, aboveground kilns, renewing the fuel supply as it burned away. Fire is also used to clear away unwanted vegetation in fields. As farmers till the fields prior to planting them, they pull up plants and place them in large piles throughout the field and light them on fire to create ash that is later tilled into the earth as fertilizer. Occasionally, people burn grass and shrubs in uncultivated areas. Finally, garbage is often burned outside in large pits. This may be a modern phenomenon, but is an effective way to reduce the bulk of waste.

We have collected flotation samples from these various contexts, such as kitchen hearths, floors, and *watias*. Preliminary observations of the plant and animal remains from these modern samples are used in this paper to develop expectations for the archaeological record of such contexts, but the samples have not yet been fully analyzed.

2.1 Modern Plant Species: Their Potential Uses and Entry into the Archaeological Record

The three major categories of plant remains in the samples are wood, parenchyma lumps, and seeds (Table 3). We sorted and quantified wood from the >2 mm screen only. The potential wood species are several species of shrubs and the native wood species qenua (*Polylepis* spp.) and qiswara (*Buddleja diffusa*).

We sorted parenchyma lumps from the >2 and >1 mm screens. Some of these fragments have potentially diagnostic characteristics and are classified as “tuber.” The potential sources of parenchyma tissue are the various Andean tubers including

Table 3 Plant taxa identified in the Kala Uyuni sample (Bruno 2008; Levieil and Orlove 1992; Loza de la Cruz 1998; Pestalozzi et al. 1998)

Domesticated food	
Chenopodium quinoa[a,b]	Quinoa, *ch'iwa, ajara*
Poss. domesticated food	
Parenchyma	
Tuber	
Solanum cf. *tuberosum*[a]	Potato
Oxalis sp.[a]	Oca
Wild food	
Cactacaeae	Cactus family
Cactoideae Type 1	Cactus family
Cereus sp.	Column cactus
Opuntia Type 1	Opuntia cactus
Opuntia Type 2	Opuntia cactus
Maihuenopsis cf. *boliviana*	Opuntia cactus, *qualla, waraqu*
Poss. wild food/non-food	
Unknown Amaranthaceae[a,c]	Amaranth family
Wild non-food	
cf. Apiaceae	Umbellifers, Carrot family
Asteraceae[a,b,c]	Sunflower family
Brassicaceae Type 1[c]	Mustard family
Brassicaceae Type 2	Mustard family
Cyperaceae[a,c]	Sedge family
Fabaceae – *Trifolium amabile*[a,c]	Legume family – clover
Festuca sp.[a,c]	Fescue grasses
Iridaceae	Iris family
Malvaceae[a,c]	Mallow family
Malvaceae Type 2 cf. *Urocarpidium shepardae*[a,c]	Mallow
Nicotiana cf. *undulata*	Tobacco
Plantago spp.[a]	Plantain family
Poaceae[a,b,c]	Grass family
Polygonaceae	Buckwheat family
Portulaca sp.[a]	Purslanes
cf. Rosaceae	Rose family
Potamogeton sp.[a]	Pondweeds, included in term *llachu*
Relbunium sp.[c]	Madder family,
Lamiaceae[c]	Mint family
Sisyrinchium sp.[a,c]	Iris family, *aykaya*
Solanaceae	Nightshade family
Solanum sp. Type 2	Potato
Tetraglochin cristatum[b]	Rose family, *kayna, anawaya*
Verbena sp.[a]	Verbena
Verbena cf. *microphylla*[a]	Verbena

[a]Animal fodder; [b]Fuel; [c]Agricultural weed

potato (*Solanum tuberosum*), oca (*Oxalis tuberosa*), ullucu (*Ullucus tuberosus*), isañu (*Tropaeolum tuberosum*), and possibly the starchy rhizome of the totora reed (*Schoenoplectus tatora*).

The most abundant plant remains (by count) in these samples are seeds. As a result, they also represent the greatest diversity of plant species in the samples (see Table 3). The known food taxa include quinoa (*Chenopodium quinoa*), possibly the small Amaranthaceae which tentatively is identified as another *Chenopodium* species, possibly related to kañawa (*Chenopodium pallidicaule*), and the fruit-bearing cacti (*Maihuenopsis* sp. and *Opuntia* sp.). We also identified seeds of *Solanum* spp. and *Oxalis* spp. These could be wild relatives of the domesticated species, but could also be from the domesticated plants. Although people do not consume these seeds, their presence can suggest the presence of edible tubers.

The majority of the seed species present in the samples are from wild, weedy plants that grow throughout the landscape and have a variety of uses. Grasses and reeds could have been used for building and domestic furnishing, but they also are important as fodder and fuel. Many of the wild plant species were also likely fodder for camelids, and would have entered the archaeological record in dung used for fuel. Bruno (2008:152) found that just about every plant that grows on the peninsula is considered food for domestic animals today. The native camelids forage broadly, but some of their favorite foods are represented here, such as the grasses, clover (*Trifolium amabile*), and the lily (*Sisyrichium*). In their study of camelid dung, Hastorf and Wright (1998) also found several of these species, including *Relbunium*, Malvaceae, Fabaceae, *Chenopodium*, and grasses.

Finally, there are some species that have known medicinal or hallucinogenic properties including a local tobacco species (*Nicotiana undulata*) and verbena (*Verbena* spp.) (Bruno 2008:149–152). Many of the wild fodder species also have medicinal properties. It is important to keep in mind that most of the herbaceous and shrubby species have multiple uses. Although the chenopods are best-known for their role as food, their woody stalks are excellent fuel sources and it is nearly impossible to remove every seed from the plant. *Quinoa* seeds even occur in camelid dung. Therefore, we cannot rule out the presence of this species as a fuel as well and must recognize the multiple pathways through which burned seeds enter the archaeological record.

2.1.1 Analysis of the Degree and Type of Burning in the Modern Botanical Samples

The environmental conditions of the Lake Titicaca Basin are such that only carbonized remains preserve, thus, all the botanical material we examine has been in contact with fire. As part of the paleoethnobotanical analysis of light and heavy fractions from flotation samples (sorting and identification of species), we also conducted a general assessment of the overall condition of the carbonized plant remains. On the basis of Hubbard and al Azm's (1990) system for describing the variation in seed condition and preservation, Hastorf and Bruno developed a qualitative ranking system to describe observed variation in the degree of burning and preservation of seeds (Table 4). By doing so, we hoped to better understand the context in which these items were burned, and/or the post-burning processes that resulted in their final deposition.

After examining and sorting a sample, we ranked the entirety of the seed assemblage based on four categories: first, *condition* describes the preservation of the epidermis on the seeds and seed fragments; second, *quality* describes the degree of distortion of seeds; third, *fragmentation* describes the degree of fragmentation of seeds, an ordinal measure of the proportion of the seeds that are too fragmented to be identified; and fourth, *firing condition* describes the relative temperature of fire and quantity of oxygen reaching the fuel. While all of these categories reflect to some degree the conditions under which the items were carbonized, quality and firing conditions describe this best. Condition and fragmentation, on the other hand, reflect the degree to which the remains were disturbed after firing.

Density of plant remain categories can be recorded on a ranked scale by visually scanning the sample, but is also quantified by dividing the weight or count of remains by the total volume of soil for the sample (Miller 1988). Densities can be used to compare different kinds of plants and materials in the same deposit, and are essential in comparing plant remains from different deposits (see also Wright, this volume).

On the basis of the qualitative measures, we can hypothesize what various burning and depositional contexts might look like in the botanical assemblage. Undisturbed cooking contexts might produce two types of plant assemblages. If plant foods were cooked by toasting, we might expect to get a moderately dense assemblage of food seeds that had low distortion and low fragmentation. If plants were used for fuel, we might expect high densities of fuel plant remains with high distortion but moderate fragmentation. If the remains from these contexts were not *in situ*, but disposed of in a midden, we might find both food and fuel plants with a range of distortion, but high fragmentation. If plant materials were burned outside of a cooking setting, such as burnt midden, we might expect a moderate density of plant remains burned at fairly high temperatures. They would likely be highly distorted. If the deposit was buried immediately, the fragmentation would be low, but if it was left exposed the fragmentation would be high.

Finally, another category of burned plant remains that archaeologists recorded in the field was the presence or absence of the grayish, bubbly, slag material known as silica aggregates or opal ash. This is an altered form of the ash produced by burning fuel but cannot be further identified (Schiegl et al. 1996). In a future phase of this study, we hope to integrate information from the geoarchaeological research on these samples to increase our understanding of this evidence for burning. We do note, however, its presence here.

Table 4 Condition of charred botanical material: Kala Uyuni samples

Attribute/score	Condition	Quality	Fragmentation	Firing condition
1	Majority of seeds with intact testa (seed coat)	Majority not noticeably distorted	Majority of seeds (>75%) whole or nearly whole	Low heat, low oxygen: indirect heat
2	Half seeds with intact testa	Majority slightly distorted, still unidentifiable	Half of seeds whole or nearly whole	High heat, reduced, low oxygen: high but indirect heat
3	Majority of seeds with fragmented testa	Majority grossly distorted: unidentifiable	Majority fragmented; unidentifiable	High heat, oxidized, high direct heat with distortion
4	Most seeds only identifiable on gross morphology	Seeds fused together, melted, or vitrified		Wet conditions, low heat, reduced, low oxygen: indirect heat with cell structures damaged
5	Clinkered			Wet conditions, high heat, reduced, low oxygen: high but indirect heat (good quality and condition)
6				Wet conditions, high heat, oxidized, high oxygen: direct heat, great lesions and distortions

2.2 Modern Animal Species: Their Potential Uses and Entry into the Archaeological Record

Most of the animal remains at the site are assumed to be the remains of food, aside from commensal animals such as toads and mice. Table 5 outlines the animals raised and hunted for food at these sites. The economic importance of fish shifted over time at Kala Uyuni: for the Late Chiripa period, 34.3% by weight of all bone is fish bone, but the proportion of fish bone dropped to 23.6% during the Tiwanaku I period and to 13.2% for the Tiwanaku IV/V deposits. Even so, fish bones and scales were present in almost every deposit, providing a window into the highest burning temperatures attained. The majority of large mammals used at the site consists of domestic camelids (*Lama* spp.), though wild vicuna (*Vicugna vicugna*) were also hunted. Herds of several different breeds (based on size) were kept, and collecting fuel from the habitual dung piles of these animals would have been efficient. Birds were the most common hunted food; the density of bird bone peaked sharply in the Tiwanaku I deposits (6.4%), from less than 1% in the Early through Late Chiripa deposits. It is not clear that this is related to the shift in staple foods away from fish. Rodents such as the *cuy* (*Cavia* sp.) and birds were minor parts of the assemblage from Kala Uyuni in all periods.

Table 5 Animals identified from flotation samples at Kala Uyuni. Identifications of large mammals to genera are drawn from study of screened remains

Vertebrate class	Taxa identified from archaeological remains	Animal parts recovered	Probable prehistoric uses
Fish	*Orestias* (at least 3 species)	Bone and scales	Staple food, possible offering
	Trichomycterus	Bone	Minor food
Amphibians	(2 body sizes)	Bone	Commensal, associated with middens
Birds	*Fulica*, ducks, 5–6 other important species.	Bone eggshell	Minor food, occasional offering
Mammals	*Lama* spp., mostly domesticated; *Vicugna*	Bone	Staple food, raw materials, transport, offering
	Cervid cf. *Hippocamelus*	Antler, bone	Materials for craft production, possible food
	Cavia,Ctenomys, Phyllotis, Akodon, several other mice	Bone	*Cavia*: Offering, minor food. *Ctenomys*: commensal, possible food. Mice:commensals
	Canis, presumed domestic dog based on size	Bone	Commensal, fed freely in middens

The remains of a mid-sized canid in an ash-filled pit outside the KU structure allow us to identify one important agent of bone destruction. While the canid remains from Kala Uyuni are too fragmentary to be identifiable as dog (*Canis familiaris*), they are consistent with the size of pre-Columbian dogs. Remains of domestic dog were identified at Chiripa and other Titicaca sites. Bones, including fish scales, showing signs of having been passed through a carnivore digestive system (pitting, thinning) were found in several samples. In addition to carnivore ravaging, light gnawing from large rodents is thought to be the work of a large gopher-like rodent (*Ctenomys* sp.) whose remains are found across the site.

On the basis of evidence for fragmentation, carnivore ravaging, weathering and skeletal dispersal, large mammal bones at Kala Uyuni are assumed to have been discarded at some distance from where the associated meat was served. As noted below, bone is rarely burned in cooking, and the relatively high incidence of burned bone also indicates its secondary context. Birds and fish may have been served on the bone and their discard location may be closer to where they were consumed. Dried meats and fish may have been prepared for storage still containing bone; the hard texture of these products usually means they are prepared in water for eventual consumption, reducing the chance that bone would be exposed to direct heat and charred. For several samples, charred fish bones have reddened, burned earth still clinging to them, and we speculate that these remains had been burned directly on a hot surface. On the basis of our cooking experiments, though, this event is unlikely to have related to intentional food processing.

Taphonomic measures of weathering and erosion (Behrensmeyer 1978) were slightly modified to reflect the tiny fragment sizes in these samples. To record physical damage taking place after food preparation, bones were scored from 0 to 5 with respect to weathering and splitting of the surface; and from 0 to 3 for erosion and rounding of the surface from trampling or water action. Weathering in these tiny fragments is seen when bones either show splitting characteristic of weathering stages described by Behrensmeyer (1978) or resulted from such splitting. Erosion and rolling were judged based on smoothing of edges viewed under 10× magnification. Burning states were recorded based on color, vitrification of the bone surface, and deformation. The intensity of burning was assessed by the density (weight per volume of soil) of burned fragments of various colors. Fragmentation in this study was evaluated by comparing the relative density of fragments greater than 6.35 mm (1/4 in. mesh) and fragments greater than 1 mm (score 1 indicates the maximum fragmentation measure, less fragmented samples range downward to approach 0). A fragmentation measure used in larger scale remains is the average weight per fragment, calculated by dividing the count of a group of bones by its weight. No counts were made for the smaller, 6.35 to 1 mm fragments, in this study, so this measure is not applicable. Here, fragment weights were calculated for the >6 mm fragments so that they could be compared to other samples from that locus.

2.2.1 Analysis of the Degree and Type of Burning in the Modern Faunal Samples

The effects of heating and burning on animal bone are well studied (Alhaique 1997; David 1990; Nicholson 1993; Shipman et al. 1984; Stiner et al. 1995), though few of these studies simulated conditions similar to that of traditional cooking. In fact, most traditional cooking techniques produce no visible changes in bone. In this study, assessments of bone color, texture, and fracture pattern allow bone fragments to be separated into categories ranked by their exposure to heat: unburned, partially charred, fully charred or blackened, and calcined (Table 6). Moore and Capriles have made observations of burned bone (and the lack of it) in a variety of experimental and ethnoarchaeological settings for this study. We have observed that no charred or burned bone is produced in normal cooking in (metal) pots. In roasted meat held over the fire, thin halos of charred bone can be produced in minutes where edges protrude from the surrounding flesh, but the flesh insulates the rest of the bone from charring. In *watia* cooking, no burned bone was produced within the cooking pit, though abundant burned bone was produced by the heating of the deposits into which the pit was dug. The charring of bone in deposits under heat features was noted in experiments by Stiner et al. (1995) and was shown to extend in a zone 5 cm thick around the heated deposits.

The taphonomy of fish bone, especially for relatively small fish (10–25 cm long) is poorly established. In Formative cooking, fish appear to have been cooked and served whole, based on the similar distribution of scales, head, and body elements. Bruno has observed that, today, cooked fish are served whole and the bones are discarded from the table. We have observed cooking techniques where fish are placed on hot rocks (protected today by layers of cardboard), but we speculated that

Table 6 Condition of animal remains, Kala Uyuni sample. The left-hand column outlines heat-related changes which can take place at any time during the process of physical destruction. For example, both fresh bone and weathered, eroded bone can later be blackened by heat. The right-hand column lists agents that can alter bone, emphasizing the accumulation of traces and destruction over time. All of these conditions were observed in the Kala Uyuni sample

Alteration from heat treatment (intensity order)	Alteration from physical damage (relative order of occurrence)
No heat treatment	Cut marks and fracture in butchering (before discard)
Boiling, steaming (indistinguishable from unheated bone). Fish scales bend and fold	Carnivore ravaging: punctures, grooves, crenulated edges (possibly within minutes of discard)
Partially charred (one edge or section). "Grilling" of fresh meat or incomplete burning of dry bone	Carnivore digestion: thinning, rounding, pitting (hours later)
Burned (black to brown); defleshed bone	Trampling and erosion: striae, rounding and fracture (weeks to years)
Calcined (gray-blue to white); high heat, prolonged heating of defleshed bone	Weathering: flaking and splitting of surface, more fracture (weeks to years)

accidents of overcooking might lead to charring of the fish scales and bones of the head. In the Uros region on the eastern shores of Lake Titicaca, Portugal (2002) observed fish being added to an earth oven (*waxa*) but she emphasizes that the fish were wrapped in fresh vegetation to keep them clean and moist before they were placed in the oven.

Moore and Capriles carried out several experiments with whole killifish (*Orestias* spp.) in an attempt to produce burned fish bone similar to that seen in the archaeological record, carrying possible cooking techniques to extremes. Neither fish roasted on a stick nor fish laid directly on hot coals produced the slightest hint of burned bone because of the insulation of the scales, skin, and flesh. The fin and tail rays of the fish roasted on hot coals burned away in 3–5 minutes. Completely and partially charred scales were produced which were similar in appearance (though much more fragmented) than burned scales of killifish found in Formative features. In sum, while burned fish scales might be related to cooking, no evidence suggests that burned fish bones are a result of cooking.

We also sought to identify some plausible process that would produce the bent and puckered scales of killifish seen in flotation samples. Boiling had been suggested as one possibility but boiling sufficient for cooking produced no immediate effect. When the boiled scales were exposed to weathering for 10 days, however, they did begin to bend slightly.

Our timed burning experiments with large mammal bone in wood fires show that charred bone can be produced in as little as 10 minutes of exposure to wood flame. Calcined bone can be produced in small quantities in 20–30 minutes. Prolonged fires produced progressively greater amounts of calcined bone as moisture was driven off and insulating soft tissues and fat burned away. Nicholson (1993) noted that higher temperatures were required to calcine fish bone than mammal bone, a difference that is relevant for our study since mammal and fish bone are found in most deposits. The burning times needed to produce discernable burned bone are less than the times needed to cook most tubers and grains, especially at 3,800 m above sea level where water boils at 86°C. It seems likely that the majority of charred and calcined bone in these samples was produced by burning refuse or accidental burning of bone-bearing deposits underneath fires. The exception to this generalization would be the partially charred bones that are sometimes referred to as grilled or scorched; these partially burned bones are uncommon.

In regions where wood is scarce, reconstructions have occasionally been suggested for the use of bone scrap as fuel for heating, cooking, or ritual. Such practices have been used to explain incidence of burned bone, particularly where large proportions of bone are burned (Joly et al. 2005; Théry-Parisot 2001). In the TAP study area, though wood has always been scarce, these behaviors seem to be a poor match with the evidence for the availability of plant fuels and the relatively low incidence of charred and calcined bone.

Putting together the qualitative aspects of the effects of burning and heat treatment on plant and animal materials, we developed parallel scales of the intensity of burning (Table 7). The density of unburned bone attests to the possible presence of plant materials which were not consumed in fire but which have decomposed, and thus are

Table 7 Changes in materials with increasing cooking and firing temperatures

Temperature	Wood fire	Earth and ceramic	Food	Mammal bone	Fish bone
100°C	Water begins to be driven off from fuel, steam and smoke		Water boils, starches soften	No visible effect on bone	No visible effect on bone, fish scales pucker and fold
200°C	Volatiles driven off, begin to burn with flame and smoke		Meat browns and roasts	Bone begins to discolor and char, fat melts and burns	Bone blackened
400°C	Flames die back, heat produced from burning carbon			Bone begins to calcine	Bone blackened
700°C	Embers glow, ash remains	Dull red glow, low fired ceramics		Bone completely white	Bone begins to calcine
800°C	Embers glow, ash remains	Cherry red glow, low fired ceramics		Bone completely white	Bone completely white

completely missing. After firing, the condition of the animal remains can confirm the reconstruction of firing temperature and condition based on the appearance of the burned plant material. Lower temperatures (100–300°C, the range at which foods actually cook) are the most difficult to track using bone condition. Mid-range temperatures (300–700°C) leave charred bone. Higher temperatures are produced in the presence of abundant oxygen and can consume most fuel materials, but leave distinctive traces on bone as organic materials burn off and the bone turns white. Using dung fuel in firing experiments, Shepard (1965:78) achieved a kiln temperature of more than 900°C for 50 min. The highest temperatures (700–900°C) might be reached in preparation for *watia* cooking or kiln firing. These temperatures would continue to calcine mammal bone and would begin to calcine fish bone, allowing us to distinguish the intensity of heating that could not be reconstructed using the remains of plant fuels.

Experiments show that multiple bone fragments in the same fire quickly take on a uniform condition and appearance. Small variations between fragment color is due to covering by soft tissue or other materials; but typically no unburned bone remains if some bone has begun to char. Where estimates of burning are similar between different plant and animal remains in a deposit, it is possible to reconstruct a consistent practice of burning. Where indications of maximum temperatures differ within the deposit (e.g., a mixture of charred and unburned bone), the deposit is likely to represent repeated events of burning and discard.

3 Characteristics of the Archaeological Samples

To integrate observations of plant and animal remains, we turned to charred plant materials and animal remains from flotation samples (see Table 1). Thirty three flotation samples were examined in detail for signs of burning, fragmentation, weathering, and erosion. For the plant samples, we calculated the density (by weight) of materials most likely to be fuel (wood, stems, grass, dung, and seeds from dung) and the remains most likely to represent food (crop seed such as chenopods and amaranth, cactus fruits, tubers, and undifferentiated parenchyma). Measures of the intensity and circumstances of burning were ranked as described above. The density of bone fragments was calculated for the following categories to capture the progress of heat-related changes: unburned bone (all taxa), partially charred bone (all taxa), charred mammal bone, charred fish bone, calcined mammal bone, and calcined fish bone. Several other observations related to burning, mixing, and the speed of burial were recorded on a presence/absence basis. Below, we review some general trends regarding the presence of food, type of burning, and degree of post-depositional disturbance.

The association of different archaeobiological indicators of food in the samples is positive but weak. The association of bone density and burned bone density with plant material densities is also generally positive, indicating the general association of discard and occupational intensity. The denser deposits do show considerable variation, indicating diversity of function and site formation processes. To begin to address this variation, we divided the flotation samples into four groups based on attributes of their archaeological context (Table 8). The first attribute is whether they appeared to excavators to be the result of discrete events or gradual accretion, and second is whether they appeared to contain abundant evidence of fire. The general assumptions made in the field were born out by the relationships shown here: the features with obvious signs of burning did have larger proportions of charred plant material and significantly more samples with seeds distorted by firing (Table 9). The range of firing conditions producing those features were found evenly distributed between the four contextual categories, emphasizing that many kinds of fires were used across the site, and that clearing and dumping were on-going activities. There was a weaker association between bone density and these four types of samples. This reflects, the fact that unburned bones and plants were probably being added to all types of deposits, however, our record of unburned plants has been lost through decomposition (Table 10). Deposits with burned materials were not necessarily the location where the burning took place. In particular, calcined bone, the most intensely burned, was less dense in the high-burning discrete features than the low-burning discrete features. Calcined bone is also not correlated with plant remains showing the highest firing temperatures. This suggests that specific and repeated burning events across the site had accumulated in these contexts after burning took place and that finer grained analysis might reveal some of these details.

Table 8 Distribution of flotation samples chosen for study based on burning states and context as reported by excavators

	Accretional contexts	Discrete contexts
Low burning	11 samples: midden, fill, adobe wash	7 samples: pits, burials – includes some ceremonial
High burning	4 samples: midden with ash, midden with charcoal	11 samples: pits and lenses with ash and charcoal, hearths – includes some ceremonial

Table 9 Density of charred plant food remains and fuel remains, according to context. Charred foods are the remains of tubers and other parenchyma, crop seeds, cactus fruits. Charred fuels are the remains of wood, twigs, grass, dung, and seeds thought to have been incorporated in dung

	Accretional contexts (g/l)	Discrete contexts (g/l)
Density of charred plant food remains		
Low burning	0.01139	0.01066
High burning	0.02945	0.02381
Density of charred fuel remains		
Low burning	0.01533	0.00876
High burning	0.06591	0.05759

Table 10 Summary of burning on animal bone between contexts. Values are mean densities of fragment, gram of bone/liter of deposit

	Accretional contexts (g/l)	Discrete contexts (g/l)
Density all bone, unburned and all burned		
Low burning	2.74	4.11
High burning	6.42	1.59
Density charred bone		
Low burning	0.25	0.12
High burning	0.71	0.39
Density calcined bone		
Low burning	0.006	0.043
High burning	0.076	0.037

3.1 Detailed Analysis of Samples

The amount of variation within each contextual category was not surprising since individual contexts have complicated histories of burning. In addition, the variable behavior we were tracking had further been obscured by decomposition, bioturbation, and weathering. To delve deeper into the issues of the source and purpose of burning, the degree of mixing, and the effects of weathering and decomposition on these archaeological contexts, we turned to the model for burning developed in Table 1, and compared a range of individual samples to the expectations for the model. Because of our interest in food preparation, we chose seven samples based on their high density of charred plant foods. We then examined the range of evidence for food processing, burning, dumping, mixing, and weathering in each of those samples. The sample characteristics were compared with our models from ethnographically observed burning outlined above (Table 11). Samples with consistent indications across the data points were judged to be the result of fewer different kinds of burning or discard, perhaps even the results of a single event. In other samples, the behaviors indicated by plant and animal remains were widely divergent, suggesting multiple smaller episodes of burning, dumping, weathering, and erosion.

3.1.1 Mixed Kitchen Debris in an Accretional Midden

Kala Uyuni, Area AC, Locus 5238, Flot no. 13200. A sample with high densities of both charred tubers and chenopod seeds was identified as a high density midden in ash by the excavators (Cohen and Roddick 2007:57, 62). This deposit contained undecorated Middle Chiripa ceramics, and predated the construction of the sunken courts at AC. The sample was also dense in fuel remains including wood, dung, and grass. The firing conditions appeared to indicate a lower heat, reducing fire with the majority of seeds slightly distorted. The bone remains indicated lower amounts of

Table 11 Comparison of burning model with flotation samples. The samples chosen were the highest ranking in combined densities of crop seeds and tuber/parenchyma fragments

Cooking/burning	Plant density	Seed distortion	Seed fragmentation	Weathering	Effect on animal remains
Stews and porridges	Residues on ceramics only				Residues on ceramics; no burned boned produced
Toasting seeds	High density of food plant	Low distortion	Low fragmentation		
Pit cooking (*Watia*)	High density of fuel, some food	Low distortion	Low fragmentation	Rake out spreads fuel and burned earth beyond pit	No burned bone from cooked meat, heat in pit chars bone in underlying deposits
Plants as fuel for open cooking fires	High density of fuel plants	High distortion	Moderate fragmentation	Increasing fragmentation if open	Light charring with “grilling,” heat from cooking chars bone in underlying deposits
Site maintenance, trash burning	Variable density	High distortion	Low fragmentation	Increasing fragmentation if open	Charring, calcined bone produced with repeated burning
Field clearance	Low density, high ash		High fragmentation		Little effect
Locus 5238, Flot no. 13200, “Midden”	High density of food and fuel	Moderate distortion	High fragmentation	High weathering	Burning 7.9% Calcined 0.3%
Locus 5193, Flot no. 13169 “Pit with fish bone”	Moderate density of fuel and food	High distortion	High fragmentation	Moderate	Mammal: 17% burned; Fish: 34% burned, 3% calcined
Locus 6125, Flot no. 14248 “Hearth”	Grass/weed fuels moderate density	Low distortion	Low fragmentation	Little weathering	Burned bone: 20%; Calcined bone: 40%; Fish bone not calcined
Locus 5363, Flot no. 13339 “Hearth”	No wood fuel, grass	Moderate distortion	Moderate fragmentation	Moderate weathering	Dense unburned fragments, fish bone burned
Locus 5183, Flots no. 13143 and 13144 “Ash lens”	Wood and grass slag	Moderate distortion	Moderate fragmentation		Burned bone: 30%
Locus 5431 Flot no. 13351 “Ash lens”	Dense wood and quinoa seeds	Low distortion	Low fragmentation	No weathering	Dense burned bone, 66% burned

burning, with less than 10% of the sample showing burning and only a trace amount being calcined, and no fish calcined. A signal of the diverse history of the deposit was the high state of weathering and erosion on both the plant and animal remains. A pottery sherd with a charred encrustation was recovered from this locus and several of the bone tools were burned. The patterns of this sample indicate different types of burning and suggest that fuel, food remains, and floor debris had been deposited together. When this sample is compared to the model developed for burning in different contexts, it is a plausible match for earth oven cooking, but it cannot be readily distinguished from the remains of a combination of several different cooking events. In particular, the general level of weathering and fragmentation, and the mixture of burned and unburned bones, suggest multiple episodes of burning and dumping.

3.1.2 Two Ash Lenses in the Sunken Courts

Kala Uyuni Area AC, Locus 5183, Flot no. 13143 and Flot no. 13144 (Ash lens on floor of lower court, radiocarbon dated to 762–402 BC*), and Kala Uyuni, Area AC, Locus 5431, Flot no. 13351 (Ash lens on floor of upper court, radiocarbon dated to 373–113* BC*)*. The hilltop AC site is thought to be the local ceremonial center during the Late Chiripa period, when two trapezoidal structures were built, maintained, and then abandoned (Cohen and Roddick 2007). Two burning features were identified on the floors of these structures, and were suggested as possibly ceremonial in nature because of their location. One of these lenses (Locus 5183) contained highly burned and distorted plant materials that had become fragmented. Heavy amounts of burned earth were recovered, indicating that burning probably occurred *in situ*. Fish bones also appeared to have been burned directly on this surface. Most of the bone, however, was unburned, and the burned bone here was in tiny fragments, including several bird bone beads. The other ash lens (Locus 5431) also had very high densities of burned plant remains, but they were not very distorted or fragmented. Very high proportions of burned bone were recovered, including calcined mammal bone and traces of calcined fish bone, reinforcing the impression of direct, *in situ* burning. While both deposits appear to have been burned *in situ*, Locus 5183 appears to have been a hot, open fire whose deposits may have been left exposed. The excellent condition of the plant remains in Locus 5431 suggests that it was a lower heat fire that may have been buried immediately after or during burning.

Both lenses are similar in the types of plant remains present: high densities of wood, grass, and chenopods. In particular, both deposits contain very high densities of a small-seeded *Chenopodium*, which Bruno (2008:304–305) argues is not *quinoa*, but possibly a wild relative of *kañawa*. Given the extremely high densities of this seed, it is likely that this particular plant was selected for burning in these contexts. Bruno (2008:311) suggests that people may have intentionally burnt this plant because it possessed some special property, perhaps an odor or color. The unique character of the plant remains in these deposits do support the hypothesis that the burning may have been for ritual purposes rather than for cooking or general disposal of garbage.

3.1.3 A Pit for a Meal and Then Dumping

Kala Uyuni, Area AC, Event A 29, Locus 5193, Flot no. 13169. A discrete pit outside of the lower court was chosen because of its high density of both plant food remains and fish bones. Compared to other contexts, this deposit had a range of food species, including relatively high densities of *quinoa*, parenchyma tissue, and at least two species of edible cacti (*Maihuenopsis* and *Opuntia*). Overall, the plant remains were highly distorted from direct heat, and were quite fragmented, particularly the parenchyma. The presence of dung fragments (one of which still possessed an embedded seed) provide evidence that a fire may have been lit in the pit with fuel (Bruno 2008:340). Some of the mammal bones had been subjected to heat but the dense fish bones were highly burned and significantly calcined. Many scales were bent, showing that they had been exposed to boiling temperatures, but had not heated to the same extent as some of the bone. The mammal bone may have been a later dumping event on top of a plant and fish cooking event, or the burned remains of a meal. Like the plant remains, the condition of the burned fish and scales suggested they had been subjected to direct heat on a hot surface, but we cannot determine if this was in a cooking accident or in a clean-up episode. Interestingly, the ceramic assemblage primarily contained Late Formative undecorated serving wares (Bruno 2008:338). Perhaps some of the serving vessels still contained partial meals, or were recipients for the residue, such as fish bones that were later discarded in the pit and burned.

3.1.4 A Garbage Pit with Residue of a Grassy Fire and a Pot of Soup

Kala Uyuni Area KU, Locus 5363, Flot no. 13339. A context identified as a hearth by excavators may actually be a pit filled with the residue of several cooking procedures dumped together, some of which did not produce burned food remains. This locus was dated to the Late Formative period based on the ceramics and was likely associated with one of the oval buildings in the area. The plant remains were primarily wild plants, particularly grasses, but little wood. The wild seeds showed relatively high distortion. Taken by themselves, these remains could be the rake out of an earth oven, a reconstruction born out by bits of burned earth, small amounts of parenchyma, crop seeds, and high densities of burned fish bone. These indicators all suggest the role of direct heat. Given this, it is striking that the densities of unburned bone in this sample are particularly high. Small unburned bone fragments dominated the sample, suggesting that fatty crushed bone had been dumped from a soup or stew. Heat would have been needed to liberate this fat, yet the lack of charring shows that the heat was applied indirectly, probably to a ceramic cooking pot containing these remains.

3.1.5 Hearth or Earth Oven

Sonaji, Locus 6125, Event A 67, Flot no. 14284. A lens of burned material was suggested as a hearth by the excavators (Ulloa Vidauree and Killackey 2005). It probably dates to Tiwanaku I times based on ceramics (Steadman et al. 2005). The sample was heavy in grass and weed seeds, particularly Malvaceae and *quinoa negra*. There were also bits of silica slag (opal ash), but there was little wood. A close examination of the mixture of burning conditions in this sample showed that the seeds were highly burned but few were distorted or fragmented, suggesting a lower heat but prolonged exposure to those temperatures. The animal remains from this sample were highly burned, with many calcined bones. The amount of calcined bone is consistent with the botanical pattern of low, extended heat since calcined fragments flake off from blackened bone as burning progresses. The bones in this sample are very similar to our modern *watia* in the proportion of burned bone produced by inadvertent heating of the underlying soil. Although the presence of animal bones may suggest food preparation, there was virtually no evidence of plant foods. Instead, it seems that wild, herbaceous plants were the fuel. Given the high density of *quinoa negra*, a weed that is commonly separated from *quinoa* during crop processing, Bruno (2008):283–284) suggests this may be a fire comprised of processing residues.

4 Summary and Conclusions

Our understanding of burning and discard from the ethnoarchaeological record is paralleled by our detailed evidence for how householders and cooks controlled several different kinds of fires in domestic contexts. The remains of direct and indirect burning become mixed in archaeological deposits, even when they appeared to be discrete dumps when excavated. Evidence for earth oven cooking seems very strong, and should be combined with our allied study of cooking in ceramic vessels. The evidence for cooking tubers and fish together is suggested in several deposits. In contrast, we do not have very clear evidence for cooking camelid meat, and our evidence for preparation of meat from bone fragmentation and butchering traces does not seem directly related to these observations. Partial burning of long bone ends is the least common category of visible heat treatment on bone. Traditional cultures in the Andes today cook most meat in a moist setting where no changed appearance would be likely, and we assume that most meat was consumed in a cooked state. The dense crumbs of bone in Flot. no. 13339 do indicate that the fragmentation of bone to extract fat was an important technique, less familiar today because of the availability of cooking oils. Dried meat and fish may have differed from fresh meat and fish in the way that they entered various dishes. A closer examination of fragmentation and body part utility indices may help clarify this issue.

The deposits in ceremonial contexts in this study strike us because of their homogeneity of evidence for a particular kind of high burning. Clearly, behavior represented by these contexts has a different pattern of burning and discard from that in the middens and other accretional deposits. The contexts also appear to differ from discrete contexts such as trash pits and hearths that have received several episodes of dumping. At this time, we cannot link this behavior with the kinds of communal food consumption suggested for these public locations, but we are closer to understanding the scale and nature of the cooking that did take place. In integrating our evidence for fuel, temperature, and the food remains themselves, we get closer to the conditions that created the archaeobiological record and the behaviors behind it.

For our questions about the creation of the archaeobiological database at Kala Uyuni and other sites, we arrived at several important insights that help us reconstruct both everyday and special purpose burning. Mixtures of highly fired and lower-fired materials are typical of accretional deposits, and in fact, the addition of unburned materials into dumps of burned materials shows the intensity of site maintenance on a small scale. This practice limits the degree to which individual deposits, though depositionally discrete, can be attributed to a single event or kind of prehistoric activity. We have developed a clearer picture than was available at the time of excavation for the remains of *in situ* burning and feel that we are able to separate food processing from other burning events. We have identified diverse fuel sources for prehistoric heating, cooking, and other fires, and we have begun to outline the limitations of analogies with modern cooking using cattle dung and introduced wood (and gas).

Attention paid to formation processes in the creation of archaeobiological datasets is an essential step in the interpretation of animal and plant remains. The constituents of such datasets, while they may have arrived in a particular deposit in separate events, share a subsequent depositional history. One dataset may shed light on attributes of the other, as in the case of fish remains attesting to high firing, and plant remains attesting to firing conditions for cooking. Our integration of these sources of information will be key in further stages of research in which we anticipate integrating geoarchaeological and isotope geochemical data for these same events, and bring these combined approaches to our questions about ceremonial and non-ceremonial burning.

5 Notes

1. For the analysis of animal remains in this study, approximately 91,000 bones were recovered from the heavy fractions of flotation samples. Fewer than 350 of these fragments would have been recovered in routine screening with 6.35 mm mesh. Flotation lab personnel in the field separated bone and other animal remains from sherds, lithics, burned earth, pebbles and other particles in the bulk heavy fraction. Precise sorting, identification, weighing and description of each component was conducted by Moore with reference to collections at the Philadelphia Academy of Natural Science and the University of Michigan Museum of Zoology. Capriles Flores (2006) further separated and analyzed the fish bones from 17 of these samples with reference to the collections at the Colección Boliviana de Fauna, Museo Nacional de Historia Natural, La Paz. Bruno (2008) analyzed the plant remains from the flotation samples as part of her doctoral dissertation, using collections and equipment at Washington University St. Louis and the University of California Berkeley.

Acknowledgments The authors would like to gratefully acknowledge the support of the National Science Foundation, the Wenner-Gren Foundation, the IIE Fulbright Program, and the University of California. The authors are grateful for assistance, advice, and cooperation from the entire Taraco Archaeological Project team, especially Lee Steadman, Melissa Goodman-Elgar, William Whitehead, Nicole Anthony, and Alejandra Dominic. At the University of Pennsylvania Museum, the authors received invaluable help from Naomi Miller and Teagan Schweitzer. This chapter is based on a paper presented at the 71st Annual Meeting of the Society for American Archaeology, San Juan Puerto Rico, April 29, 2006; presented as part of the Symposium "Quantitative Integration of Zooarchaeological and Archaeobotanical Data: A Consideration of Methods and Case Studies," organized by Tanya Peres and Amber VanDerwarker.

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A Tale of Two Shell Middens: The Natural versus the Cultural in "Obanian" Deposits at Carding Mill Bay, Oban, Western Scotland

László Bartosiewicz, Lydia Zapata, and Clive Bonsall

Composed largely of mollusc shells resulting from food procurement activities, coastal shell middens have been regarded as valuable sources of information about past human exploitation of coastal and marine resources. It is less widely appreciated that these sites, which lie at the interface between the sea and the land, have significant potential to inform us about the terrestrial environment and its resources. In this chapter, an attempt has been made to integrate results of paleoethnobotanical and zooarchaeological studies with existing archaeological knowledge concerning Mesolithic and Neolithic environments and subsistence at a shell midden site on the west coast of Scotland. We compare and contrast the information derived from macrobotanical and vertebrate faunal remains from two locations at the site of Carding Mill Bay. Although the midden deposits were also studied from the malacological point of view, the shellfish remains are not considered here as they characterize only the marine environment. Moreover, the terrestrial component of a midden may tell us more about post-depositional taphonomic processes than the marine component.

Carding Mill Bay I and II are the westernmost known sites in a cluster of Mesolithic/Neolithic shell middens around Oban Bay (Fig. 1). Following the discoveries made in caves in the area during the late 19th century (Anderson 1895, 1898; Bonsall and Sutherland 1992; Lacaille 1954), these sites were originally believed to represent a discrete Mesolithic culture confined to the coastal areas of central-west Scotland, which came to be known as the "Obanian culture" (Movius 1942). Subsequent research has cast doubt on this interpretation, and the "Obanian" shell middens are now seen as simply one aspect of the Mesolithic maritime adaptation in western Scotland (Bonsall 1996). Moreover, they do not belong exclusively to the Mesolithic period (9500–3900 cal. BC); the deposition of shell middens

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_9, © Springer Science+Business Media, LLC 2010

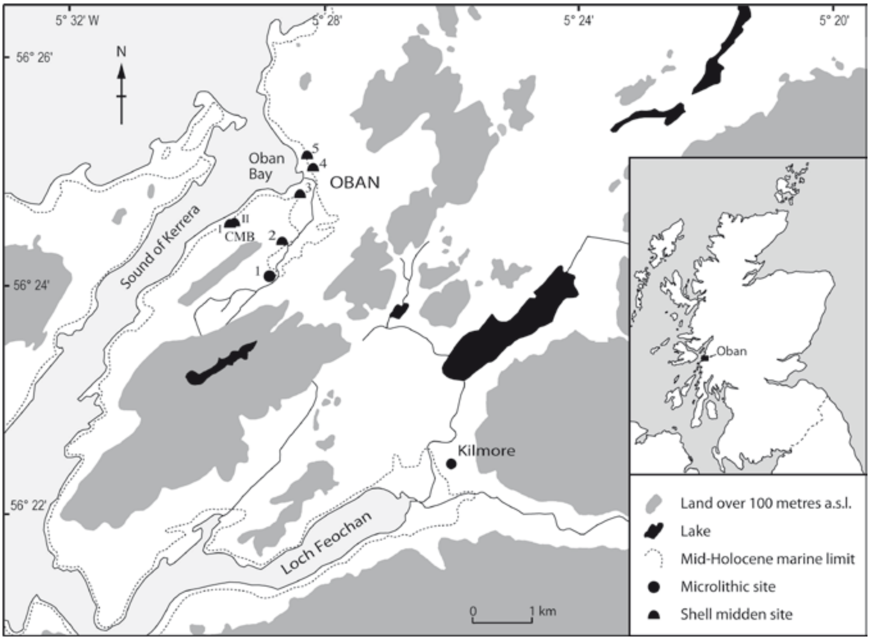

Fig. 1 Mesolithic/Neolithic sites in the Oban region. *CMB* Carding Mill Bay, 1 = Lón Mór, 2 = Raschoille Cave, 3 = Druimvargie Rockshelter, 4 = Distillery Cave, 5 = MacArthur's Cave

containing characteristic "Obanian" bone tools continued in western Scotland into the Neolithic period (3900–2500 cal. BC) and, possibly, as late as the Bronze Age (2500–600 cal. BC) (Griffitts and Bonsall 2001). Faunal studies of several "Obanian" sites have been undertaken, including the analysis of material from Carding Mill Bay I (CMB I), which is located some 15 m south of CMB II. The excavation of CMB I was undertaken in 1989, and the excavation report (Connock et al. 1993) included a study of the vertebrate remains by Hamilton-Dyer and McCormick (1993) as well as a report on the paleoethnobotanical remains by Boardman (1993). Their detailed accounts permit comparisons with the animal and plant remains recovered more recently at CMB II.

1 Materials and Methods

Carding Mill Bay II (CMB II) is located approximately 1.5 km southwest of Oban, at latitude 56° 24′ 26″ N and longitude 5° 29′ 26″ W. Prior to its discovery, the site was buried beneath the talus deposits that accumulated at the base of a raised marine cliff. The cliff and the rock platform in front of it constitute a former marine shoreline (known as the "Main Rock Platform") that is particularly well developed in the Oban area. The site was discovered in 1988 when the talus deposits were disturbed during construction work. Excavations, funded by Historic Scotland and directed by Clive Bonsall, were undertaken between 1991 and 1993.

The site faces northwest and consists of a shallow natural recess in a near-vertical rock face. The recess was infilled with sediments containing a variety of archaeological remains. These could be divided into a series of lithologically distinct layers (Fig. 2). Excavation was based on a 50-cm grid, and the deposits were removed in horizontal unit levels ("spits") of 5 cm thickness between layer boundaries. All excavated materials were passed through a nest of sieves, with mesh sizes between 1 and 4 mm, while the material from one 50×50 cm grid square (Q5D) was treated as a column sample and subjected to flotation and wet sieving using mesh sizes down to 0.25 mm – the majority of the nonwood botanical samples were recovered from this column.

Radiocarbon dates for the shell midden at CMB I range from ca 4010 to 3550 cal. BC, suggesting an Early Neolithic age, possibly extending back to the time of the Mesolithic–Neolithic transition in western Scotland (Bonsall and Smith 1992; Connock et al. 1993). The dating of the midden layers at CMB II is less well-documented. Currently, no radiocarbon radiocarbon dates are available, and the artifact inventories differ significantly from CMB I – for example, there are no bevel-ended

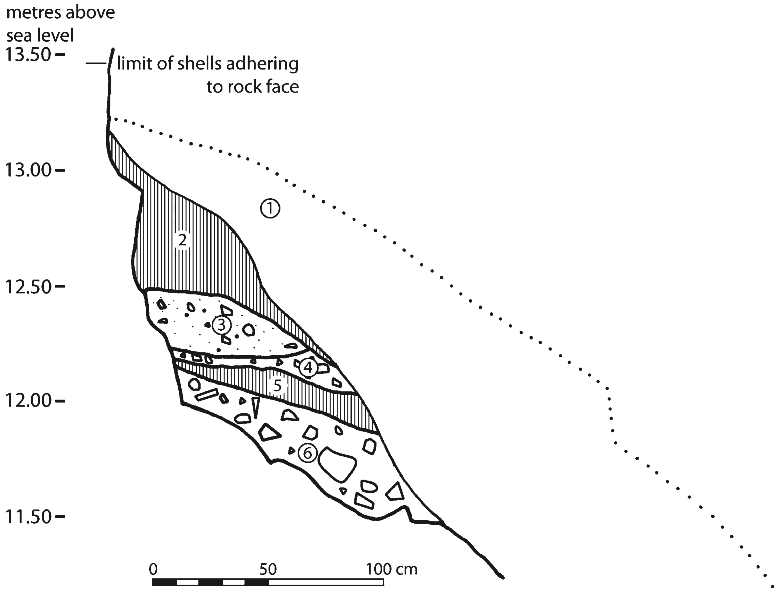

Fig. 2 Stratigraphic (SE–NW) profile through the deposits at CMB II. Layers: 1 = disturbed/redeposited material, 2 = upper midden, 3 = talus with shells, 4 = talus, 5 = lower midden, 6 = talus. Layer 1, being unstable, was removed in its entirety at the start of the excavations and prior to recording the profile; the *upper* boundary of this layer (*dotted line*) has been reconstructed from height measurements taken prior to excavation

tools of bone or antler (see also Griffitts and Bonsall 2001) from either the lower or upper midden of CMB II, though these were common in the CMB I midden. The presence of pottery and bones of domestic livestock, especially caprines, in the upper midden of CMB II indicates a post-Mesolithic date. The lower midden, however, produced no pottery, and only a single bone from a domesticate was observed. On the basis of the pottery typology, the upper midden is provisionally assigned to the Late Neolithic; the lower midden could date earlier in the Neolithic or, if the single sheep/goat (*Ovis/Capra* spp.) bone was not *in situ*, to the Mesolithic. However, differences in the artifact and faunal inventories of the midden deposits at CMB I and II (see below) may indicate that the respective middens belong to different periods in the human use of the Carding Mill Bay locality.

An initial set of samples was retrieved by wet sieving. The Q5D "column" was processed separately at a later date, primarily for the recovery of macrobotanical remains and land snails. This yielded a vertical series of 58 individual samples, each comprising material from a single 5 cm-thick "spit." The paleoethnobotanical material was recovered by flotation in the laboratory using a 0.25 mm sieve. The residues (heavy fraction or "retent") from the flotation process were hand sorted in order to retrieve other archaeological components (molluscs, small bones, lithic debitage, etc.). The plant material that was found during this sorting was included in the paleoethnobotanical sample. Some of the residues were double-checked by Zapata in order to assess the effectiveness of the initial sorting, which was found to be adequate.

The processed flotation samples (light fraction or "flot") were sorted under a low-power reflected-light microscope. Wood charcoal was identified using epi-illuminated light microscopy. Schweingruber (1990) was used for identification and nomenclature. Identification was facilitated by using a reference collection of modern carbonized wood. All fragments of wood charcoal >2 mm were examined, which is usually considered to be the minimum size when using anatomical features as criteria for identification. Most fragments were close to this size, so the process was quite time-consuming and may have increased the number of problematic identifications.

Virtually all the identifiable animal bones were found in the 1–4 mm sieve fractions, and these fractions were critical for the recovery of the remains from microvertebrates. The <1 mm sieve fractions provided very few animal remains. Even the recognized pieces (e.g., incisor splinters from rodents, fragmented fin rays, branchyostegalia, and ribs from small fish) likely originate from identifiable specimens encountered in the less finely recovered fractions. This falls in line with experimental evidence that bone splinters shorter than approximately 20 mm have a 95% chance of being missed when only hand collection is practiced (Bartosiewicz 1988; see also Peres, this volume chapter 9, for further discussion). The significance of sieving is clearly illustrated by the example of fish bones at the site, of which only a few large fragments ended up in the hand-collected sample of bones. Evidently, fine sieving led to an increase in the number of nonidentifiable, small fragments, but also resulted in a more complex faunal picture, especially in the case of fish and rodents. As a convention, "cf." is used here to signify that the identification is not certain, but there is a very high probability of belonging to a particular taxon (see also Peres, this volume chapter 9).

2 Study Results

2.1 Macrobotanical Remains

The types of remains recovered in the samples include: (a) wood charcoal, the most abundant type; (b) a few seeds, badly preserved; (c) fragments of hazelnut (*Corylus avellana*) pericarp; (d) a few small fragments of possible vegetative parenchyma (soft storage tissue) which forms the major part of organs such as roots and tubers (Hather 1993); and (e) miscellaneous plant material that could not be identified further.

The results of the charcoal analysis are presented in Table 1. A summary of the results can be seen in Table 2 and Fig. 3. In order to simplify presentation, identifications have been grouped by the most probable taxa (that is, cf. oak/durmast oak [*Quercus robur/petraea*] was classified as oak/durmast oak [*Quercus robur/petraea*]). The fragment described as alder/birch (*Alnus* sp./*Betula* sp.) was not considered.

The data show that in the lower midden hazel is the most important taxon (73.4% of the fragments identified), followed by oak (12.4%), alder (*Alnus glutinosa*, 6%), elm (*Ulmus* sp., 4%), and willow/aspen (*Salix/Populus*, 3%). Only one fragment of birch (*Betula* sp.) and another belonging to the rose family (Rosaceae) have been identified. Remains from the upper midden show that hazel continues to be the most important taxon, but its proportion is reduced to approximately half of the fragments identified (52.6%). In contrast, oak increases in relative importance (30.7%) in the sample. Alder (9.6%), willow/aspen (5.2%), and birch (one fragment) are the other taxa identified; in these cases the proportions are low, similar to their frequency in the lower midden. No fragments of the rose family were identified here (but only one had been recognized in the lower midden) and most importantly, elm wood is no longer present. Layer 4 and the Layer 5/6 transition did not yield statistically significant results since the number of fragments identified was very low (18 and 25, respectively). The presence/absence of species is similar to that in the midden deposits, however, in both cases the percentages are closer to the lower midden, with proportions of hazel wood exceeding 70%.

Other carbonized plant remains besides wood charcoal are extremely scarce and poorly preserved. There are only a few seeds (grass [*Poaceae*] and stitchwort [*Stellaria* sp.]) and a few fragments of unidentified, possible parenchyma tissues. The stitchwort seed was also identified at CMB I, along with the sporadic charred seeds of sedge/knotgrass (*Cyperaceae/Polygonaceae*), bedstraw (*Galium* sp.), cinquefoil (*Potentilla* sp.), and bramble/raspberry (*Rubus fruticosus seu ideaus*). Except for the latter, these weeds – indicative of a humid environment – are difficult to interpret in archaeological terms (Boardman 1993).

A few uncharred seeds were also present in some of the samples but these are interpreted to be modern in origin. The small number of carbonized seeds and (possible) parenchyma does not allow any paleoecological or paleoethnobotanical interpretation. Fragments of hazelnut pericarp occurred commonly in the midden samples. Much has been written about the role of hazelnuts as a past food resource,

Table 1 Results of charcoal analysis from the Carding Mill Bay sites, expressed as counts

Layer		2	2	2	2	2	4	5	5	5/6	5/6
Grid square		O5A	Q6B	O6B	R5C	Q5D	Q5D	Q5D	O6C	O6A	O6B
Flotation sample No.						1	34	44–46			
Common name	Taxonomic name										
Alder	*Alnus glutinosa*	4		3	1	3	1	5	4	4	
cf. Alder	cf. *Alnus glutinosa*						1		1		
Birch	*Betula* sp.					1			1		
cf. Birch	cf. *Betula* sp.					1	1			1	
Alder/birch	*Alnus* sp./*Betula* sp.			1							
Hazel	*Corylus avellana*	7	2	5	20	24	14	81	41	17	
cf. Hazel	cf. *Corylus avellana*					2		2			
Oak/durmast oak	*Quercus robur/ petraea*	6		7	6	16	1	13	4	1	
cf. Oak/ durmast oak	cf. *Quercus robur/ petraea*							2	2		
Rose family	Rosaceae Pomoideae tp. Sorbus								1		
Willow	*Salix* sp.			3				2			
cf. Willow	cf. *Salix* sp.							1	1		
Willow/aspen	*Salix* sp./*Populus* sp.					2		1			
cf. Willow/ aspen	cf. *Salix* sp /*Populus* sp.					1					
Elm	*Ulmus* sp.							7			
Total		17	2	19	27	50	18	114	55	23	2
Indeterminate		1			1	12	2	19	7		

Table 2 Summary of charcoal analysis from the Carding Mill Bay sites

Layer		2	4	5	5/6
Grid square		O5A, Q6B, R5C, Q5D	Q5D	Q6C, Q5D	Q6A, Q6B
Provisional chronology		Late Neolithic		Neolithic (Mesolithic?)	
Common name	Taxonomic name	Count (%)	Count (%)	Count (%)	Count (%)
Alder	*Alnus glutinosa*	11 (9.6)	2 (11.1)	10 (6.0)	4 (16)
Birch	*Betula* sp.	1 (1.75)	1 (5.5)	1 (0.6)	1 (4)
Hazel	*Corylus avellana*	60 (52.6)	14 (77.7)	124 (73.4)	19 (76.0)
Oak/durmast oak	*Quercus robur/ petraea*	35 (30.7)	1 (5.5)	21 (12.4)	1 (4)
Rose family	Rosaceae Pomoideae tp. Sorbus			1 (0.6)	
Willow/aspen	*Salix* sp./ *Populus* sp.	6 (5.2)		5 (3.0)	
Elm	*Ulmus* sp.			7 (4.0)	
Total		114	18	169	25

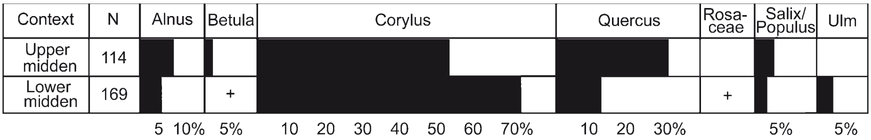

Fig. 3 Graphical summary of the charcoal analysis. Differences between the lower and upper midden are shown as the percent of fragment numbers (N)

especially in the context of the European Mesolithic (Mason 1996), although hazelnuts seem to have remained very popular until at least the Bronze Age at many sites in Britain (Moffett et al. 1990).

Several explanations have been provided for the abundance of carbonized hazelnut shells at the Mesolithic sites. It is often considered that they were roasted to benefit storage or shelling, or to kill insects. Heating also releases oil and changes oil structure, thereby improving flavor and making grinding easier. Hazelnuts may also have been used as fuel. Boardman (1993) further notes that hazelnuts are one of the few edible wild plants likely to be very productive under both fully wooded and more open habitats. Most experts agree that these general explanations should be supported by further ethnographic, taphonomic, and experimental research.

2.2 *Animal Remains*

To inform our discussion of the zooarchaeological remains from CMB II, we compared our results for the major taxonomic groups with the number of identifiable animal specimens (NISP) in water-sieved samples from CMB I, identified by Sheila Hamilton-Dyer (1993) and Finbar McCormick (1993).

2.2.1 Bony Fish

This group comprised mainly the remains from both marine and anadromous/catadromous fish (Table 3). The main characteristics of the identified taxa will be reviewed in terms of their occurrences at CMB and the habitat types they represent. Common eel (*Anguilla anguilla*) may attain a maximum length of 140 cm (Campbell 1989:274). In contrast to CMB I, bones of this species occurred sporadically at CMB II. The colorless elvers of eel move into brackish water areas and start moving upstream to live in fresh water for several years. Some of them, however, remain in river estuaries. The older individuals move downstream during their spawning migration by the end of summer (Angel 1977: Figure 40). Present day otter (*Castor fiber*) feces from Mull (Argyll) contained up to 7.4% eel remains (Watt 1991:24, Table 7).

Remains from salmon (*Salmo* cf. *salar*) and trout (*Salmo trutta*; Salmonidae) were found in significant numbers. Most of the remains originate from fairly large, adult individuals. Smolts of salmon (Angel 1977: Figure 36) move down river to the sea in May and June. They spend some time in estuaries where they acclimatize to the salinity of sea. Most of these fishes migrate to the sea at a length of 10–19 cm (Muus and Dahlstrøm 1977:76). The maximum adult length of these fishes is 1.5 m, although none of the bones recovered at CMB II belonged to such large individuals. Trout (maximum adult length 1 m), a species with a similar life history, is distinguished from salmon by its plumper body. Young trout migrate to the sea when 15–25 cm long but they stay in the vicinity of the coast for 0.5–5 years (Muus and Dahlstrøm 1977:78). Consequently, fragments not identifiable at the species level may originate from either salmon or trout.

With the exception of cod (*Gadus morrhua*), species in the cod family (Gadidae) prefer waters of high salinity. Their remains dominated the CMB II fish bone assemblage, both in terms of NISP and weight. The young, especially, may be caught along the shore. Species identification was limited to the few most diagnostic skeletal elements. Of the known Mesolithic zooarchaeological assemblages from Scotland, cod formed the majority of the identified fish remains at the east coast site of Morton as well (McCormick and Buckland 1997:90). In later periods, fishing in Scottish waters has increasingly concentrated on several species in the cod family (Barrett et al. 1999:354).

At CMB II, poor cod (*Trisopterus minutus*), saithe (*Pollachius virens*), and pollack (*Pollachius pollachius*) contributed the most identifiable bones to the

Table 3 Fish and amphibian remains from the Carding Mill Bay sites

Common name	Taxonomic name	CMB I	CMB II	
		NISP	NISP	Weight (g)
Common eel	*Anguilla Anguilla*	20	51	0.039
Salmon	*Salmo* cf. *salar*		74	0.660
Trout	*Salmo trutta*		63	0.545
Cod family	Gadidae	24	130	1.802
Cod	*Gadus morrhua*	2	5	0.053
Poor cod	*Trisopterus minutus*	8	25	0.058
Whiting	*Merlangius merlangus*	151	7	0.084
Pollack	*Pollachius pollachius*	14	23	0.058
Saithe	*Pollachius virens*		51	1.143
Rockling	*Gaidropsarus* sp.	2		
Cuckoo wrasse	*Labrus mixtus*		54	0.471
Eelpout	*Zoarces viviparous*		9	0.029
Gray gurnard	*Eutrigla gurnardus*		2	0.002
Sculpins	Cottidae	15	115	0.571
Sea scorpion	*Taurulus bubalis*		65	0.258
Pogge	*Agonus cataphractus*		16	0.041
Black/sand goby	*Gobius niger seu minutus*		25	0.094
Right-eyed flatfish	*Pleuronectes* sp.		58	0.281
Dab	*Limanda limanda*		3	0.002
UID fish		84	1121	15.691
Frog/toad	Anura.		37	0.704

gadid remains. Both small and large individuals were recognized among the latter. While 19–23 cm long, poor cods are considered economically unimportant by modern standards (Muus and Dahlstrøm 1977:106); saithe and pollack may reach a maximum length of 130 cm, while they are 60–70 cm long in the fifth year. Remains of small individuals from CMB II seem to correspond to the first year age group in the bimodal size distributions obtained for this species by Mellars and Wilkinson (1980:21). Whiting (*Merlangius merlangus*) can attain maximum lengths of 40–50 cm (Muus and Dahlstrøm 1977:106). This species was far better represented at CMB I.

Cuckoo wrasse (*Labrus mixtus*) is a fish whose length varies between 30 and 35 cm. It lives in the algal zone on rocky coasts (Muus and Dahlstrøm 1977:128), usually in waters below 10 m (Campbell 1989: 288). Among the non-gadid species, the contribution of labrids to prehistoric faunal assemblages seems to decrease through time (Barrett et al. 1999: Figure 4). Gray gurnard (*Eutrigla gurnardus*) is a bottom-dwelling species found in waters 10–150 m deep. It may reach a length of 45 cm (Muus and Dahlstrøm 1977:162).

Bullheads or sea scorpions (Cottidae) are predatory, bottom-living fish with no swim bladder. They do not move far from the area in which they have grown up (Muus and Dahlstrøm 1977:12). While these usually small fish are of no known commercial value today, their remains made up 11.3–12.4% of the fish bone recovered from otter feces in Mull (Watt 1991:24, Table 7). The remains of similar small individuals were found in the CMB II material, a possible indication of animal predation rather than human activity.

The family of right-eyed flatfish (Pleuronectidae) was represented by numerous bones from dab (*Limanda limanda*), commonly occurring in coastal waters. The length of this flatfish species rarely exceeds 40 cm (Muus and Dahlstrøm 1977:182). While most adult flatfish occur at depths of 10–15 m, the young usually frequent shallower coastal waters (Muus and Dahlstrøm 1977:184) and may even be caught by hand. This is consistent with the observation that bones of this fish at CMB II originate from small individuals.

High concentrations of small fish bones, especially when flattened and distorted, showing signs of digestion (such as some salmon remains at CMB II), would alternatively be characteristic of offal and feces from otter holts (Cerón-Carrasco 1992:3), daily hideouts of these animals.

2.2.2 Amphibians

Only sporadically occurring long bones of frogs/toads (Anura) were recognized in the material. Remains from these small terrestrial animals, often considered commensal at ancient settlements, most typically represent “taphonomic gain” resulting from active intrusion or water transport (precipitation). In contrast to warmer climates, where these animals grow large enough to be exploited for meat (Cooke et al. 1996), it seems unlikely that bones of small frogs at CMB would have been introduced by human consumption into the stratigraphy.

2.2.3 Birds

The exploitation of birds was of great importance in coastal adaptations throughout the Mesolithic of northwestern Europe (Grigson 1989:60). In comparison with mammals, usually numerous avian species are represented by relatively few bones, a trend characteristic of bird remains owing to both their natural taxonomic diversity and the greater degree of fusion between elements in the bird skeleton (Bartosiewicz and Gál 2007). The bird taxa identified are compared to the results from CMB I in Table 4. Bones of willow tit (*Parus montanus*), robin (*Erithacus rubecula*), finch (Fringillidae), and other small perching birds may be considered natural deposits at CMB II. These small birds indicate that the midden was located in the woodland/littoral ecotone. Like amphibians, small birds identified at this site are indicative of the natural habitat, rather than human activity.

Given the long tradition of seabird exploitation in the coastal areas of Scotland (Serjeantson 1988), it is somewhat disappointing that larger birds are represented only by one bone of a red-throated diver (*Gavia stellata*) and a cormorant (*Phalacrocorax carbo*) each. The seven bones of puffin (*Fratercula arctica*) may have even originated from burrowing individuals. At CMB I, remains of common or

Table 4 Avian remains from the Carding Mill Bay sites

Common name	Taxonomic name	CMB I	CMB II	
		NISP	NISP	Weight (g)
Red-throated diver	*Gavia stellata*		1	1
Cormorant	*Phalacrocorax carbo*		1	0.260
White-tailed eagle	*Haliaetus albicilla*	1		
Gull	*Larus argentatus seu marinus*	3		
Guillemot	*Uria aalge*	8		
Puffin	*Fratercula arctica*		7	1.257
Passerine	Passeriformes	31	75	1.166
Swallow	Hirundinidae	18		
cf. Crow	cf. Corvidae	1		
Willow tit	*Parus montanus*		13	0.071
Robin	*Erithacus rubecula*		3	0.003
Finch	*Fringillidae*		2	0.001
UID bird		77	89	3.103

herring gull (*Larus argentatus seu marinus*), razorbill (*Alca torda*), and guillemot (*Uria aalge*) form a group of findings that originate from birds most commonly encountered in marine environments. White-tailed [sea] eagle (*Haliaetus albicilla*) is more typical of coastal habitats than the golden eagle (*Aquila chrysaetos*), and its eyries were usually on sea cliffs and pinnacles (Barnes 1975:83). The bird bone assemblages from the two CMB sites may be seen as complementary to one another.

2.2.4 Mammals

Mammalian remains identified at CMB I by McCormick (1993) are compared to the recent results in Tables 5 and 6. The greatest difference between the two faunal assemblages is the overwhelming dominance of small rodents, especially bank vole (*Clethrionomys glareolus*) and field vole (*Microtus agrestis*) remains, at CMB II. Bones from these species must have been fewer at CMB I, although they were quantified only using the loose term “dozens” in that report (see Table 5). Rodent remains occur rather uniformly across all contexts.

Pigmy shrew (*Sorex minutus*) contributed the smallest bones to the CMB II assemblage. Although common shrew (*Sorex araneus*) is known from CMB I (Hamilton-Dyer and McCormick 1993), it was not recorded at Morton or sites on

Table 5 Micromammalian remains from the Carding Mill Bay sites

Common name	Taxonomic name	CMB I	CMB II	
		NISP	NISP	Weight (g)
Pigmy shrew	*Sorex minutus*		130	0.871
Common shrew	*Sorex araneus*	1		
Bank vole	*Clethrionomys glareolus*	Many	147	6.394
Field vole	*Microtus agrestis*	Dozens	22	0.254
Small vole	Muridae		4816	99.410
Water vole	*Arvicola amphibius*		7	0.114
Water vole?	*Arvicola* cf. *amphibius*		29	1.182
Red squirrel	*Sciurus* cf. *vulgaris*	4		

the island of Oronsay (Inner Hebrides). Although it is impossible to recover articulated skeletons from sieve residues, given the excellent preservation of their bones at CMB II, it is possible that these tiny animals found their way into the cracks and cavities of the midden by entering into archaeological deposits in search of their prey. The possibility of water transport must also be considered.

Of the numerous rodent remains deposited in all contexts, bank vole, field vole, and water vole (*Arvicola amphibius*) could be identified to species on the basis of tooth enamel patterns. Some specimens were assigned to the latter, largest species on the basis of size. From an environmental point of view, it is significant that bank voles inhabit mixed woodland habitats. This species is the only vole that climbs bushes (Mitchell and Delap 1974:56). Field vole was also considered one of the faunal indicators of a forested environment at the site of CMB I (Hamilton-Dyer and McCormick 1993).

Woodland is best indicated by the presence of shrew and bank vole. Field and water voles are typical of humid, bushy areas; this does not contradict the previous conclusion. All these species may burrow near the soil surface, but are unlikely to go deeper than 10 cm (Zsófia Kovács, personal communication 2008). Whether the animals died at the site or their remains were washed in from above, their presence is yet another indication that the immediate environment of the shell midden was forested. Some bones of red squirrel (*Sciurus* cf. *vulgaris*) and pine marten (*Martes martes*) at CMB I support the reconstruction of a woodland environment. The bones of larger mammals, especially those of domesticates found in the upper midden at CMB II, are the most likely to have been introduced by human activity (Table 6).

In contrast to rodent remains, two bones of common hare (*Lepus timidus*) in the lower midden may originate from prey items of either animals or humans, and in fact may have been imported by humans to the site. This is even more of a possibility in the case of large mammals. Hand-collected mammalian remains from the upper and lower midden deposits are summarized in Table 7.

Table 6 Mammalian remains from the Carding Mill Bay sites

Common name	Taxonomic name	CMB I	CMB II	
		NISP	NISP	Weight (g)
Common hare	*Lepus timidus*		6	0.755
Pine marten	*Martes martes*	>5		
Otter	*Lutra lutra*	2		
Cattle	*Bos taurus*		7	63.789
Sheep	*Ovis aries*		2	15.530
Sheep/goat	Caprinae		33	27.312
Pig	*Sus* sp.	3	24	53.924
Roe deer	*Capreolus capreolus*	1	3	3.210
Red deer	*Cervus elaphus*	2	11	62.373
Small ruminant	Ruminantia		24	12.947
Large ungulate	Ungulata		80	28.439
Small ungulate	Ungulata		2527	180.563

Table 7 Hand-collected large mammalian remains from the upper (Layer 2) and lower (Layer 5) midden deposits

	Caprine	Suid	Roe deer	Red deer	Large	Small
Upper Midden						
NISP	28	12		4	49	890
Weight (g)	13.490	34.927		39.290	7.808	4.652
Lower Midden						
NISP	1	2	1	3 + 1	9	237
Weight (g)	0.390	4.135	2.720	11.363	6.221	28.430

Remains of sheep (*Ovis aries*) or, less likely, goat (*Capra hircus*), usually referred to here by the subfamily name, Caprinae, were found in relatively large numbers in the upper midden but only one such bone was found in the lower deposit. While the latter, single occurrence may be considered accidental, the presence of domesticates in the upper midden corresponds with the later chronological position of that deposit. No cattle (*Bos taurus*) remains were found in either of these two layers at CMB II.

Wild boar (*Sus* cf. *scrofa*) is a mammal whose domestic form (*Sus domesticus*) is often difficult to recognize from its skeletal remains. No suid bones were large enough at this site to be unambiguously identified as those of wild pig, a game animal known from Mesolithic deposits both at the site of Morton and even on the small island of Oronsay (McCormick and Buckland 1997: Table 6.1). Although pig domestication is not thought to have taken place before the Neolithic, several biological traits of this species could have facilitated the development of a special relationship between wild pigs and humans that preceded domestication in a classic sense (Bolomey 1973:48).

Like dogs (*Canis familiaris*), these social animals were more likely to have scavenged on human refuse than the ancestors of other, herbivorous domesticates.

In comparison with other ungulates, roe deer (*Capreolus capreolus*) is underrepresented in the CMB II faunal assemblage. In addition to the identifiable remains of this species, many of the 1,000+ small ungulate bone splinters probably belong to roe deer. While some of these bones could not be distinguished from the remains of sheep (hence, the term "small ruminant"), sheep could be present only if the lower midden were post-Mesolithic in date. Roe deer remains occurred both on the island of Oronsay and at Morton (McCormick and Buckland 1997: Table 6.1). Together with wild pig, roe deer is considered to be an animal of deciduous woodland with dense undergrowth or parkland habitats, although recently increasing adaptation to open grassland has been recorded in Hungary (Bencze 1978:56). No antler fragments could be identified as those of roe deer.

Red deer (*Cervus elaphus*) remains, including some antler fragments, occur sporadically both in the upper and lower middens. Although red deer remains were found in relatively small numbers, non-identifiable large ruminant bones probably also originate from this animal. In comparison with small and adaptable roe deer (15–27 kg; van den Brink 1968:157), large bodied red deer (95–160 kg in Scotland; van den Brink 1968:154) are more dependent on the cover provided by forested habitats.

When the number of taxa are plotted against the number of identifiable specimens by vertebrate classes (fish, bird, and mammal), the subassemblages of various sizes from the two CMB middens show the same trend (Fig. 4), in that they are com-

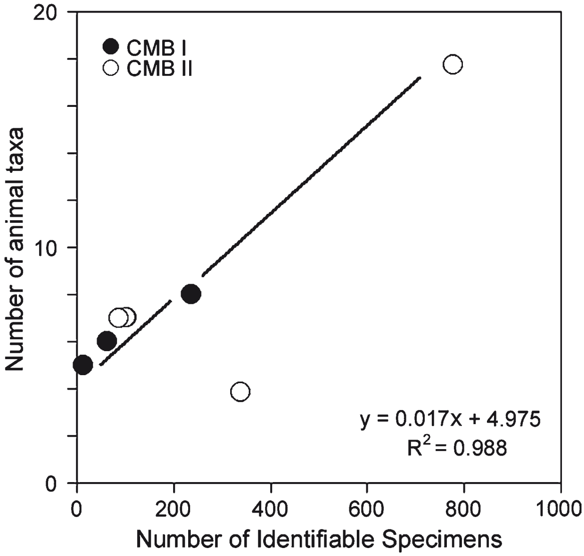

Fig. 4 Plot showing the relationship between assemblage size (x) and taxonomic richness (y) among vertebrate classes. Micromammals, counted only at CMB II, falling outside the main trend were not included in the calculation

parable regardless of the differences in sample size. CMB II was particularly rich in fish remains. The only outlier from this main trend (not taken into consideration when calculating the regression line, Fig. 4), is the group of microvertebrate remains. As mentioned before, the large number of these bones was counted in terms of NISP only at CMB II, but the subassemblage was not very diverse, containing only four identifiable taxa.

3 Discussion

Plant and animal remains differ radically in terms of their taphonomic histories, including exploitation by humans as a cultural factor of biostratinomy. Prehistoric plant remains recovered from CMB II have been preserved through charring. Wood charcoal is the most frequent type of paleoethnobotanical material. Apart from the possibility of natural forest fires, this special form of preservation also offers evidence of human activity: the use of fire at the locus investigated, which includes the selection and transport of firewood to the place of use.

Zooarchaeological remains may represent different forms of deposition. In order of increasing complexity, faunal materials may originate from (Gautier 1987):

1. Intrusive animals (bones of actively burrowing rodents, shrews, puffins, etc.)
2. Carcasses originating from *in situ* death, water transport, or deposited by predators (otter feces, owl pellets, gut contents of larger fish preyed upon by otters or humans)
3. Human food refuse (bones showing butchering marks, burning, or marrow extraction)
4. Debitage from craft activities (waste from *in situ* manufacturing, bones with skinning marks)

Given the horizontal, coastal location of shell middens and their vertical positions relative to prehistoric sea levels, the direct role of tidal activity in accumulating fish remains should be considered. Many sites in central-west Scotland located below 15 m above present sea level were probably destroyed by wave erosion, or at least affected by storm waves, during the Mid-Holocene marine transgression, which culminated in the Oban area between 5500 and 5900 cal. BC (Bonsall and Sutherland 1992). As opposed to marine tidal activity, some bones representing terrestrial microfauna (amphibians, insectivores, and rodents) may indeed have been washed into the midden deposit by rainwater from above, a phenomenon frequently observed in rockshelters and caves (e.g., Andrews 1990). This type of accumulation is a characteristic source of microvertebrate remains.

Just as burning by humans contributed to the preservation of charred plant parts, the vertebrate remains recovered from the middens also owe their survival, at least partially, to human activity. In the highly acidic soils of the area, the preservation of bone and antler simply would not have been possible without the accumulation of shell middens. The calcareous organic matrix of predominantly limpet shell deposits

(Russell in Connock et al. 1993:34; Bonsall et al. 1994) creates an alkaline environment, buffering soil acidity and thereby promoting the preservation of bone.

3.1 Vegetation

Two of the main characteristics that explain the presence and relative importance of any type of wood at an archaeological site are its relative abundance in the vicinity and its quality as a fuel wood. The most abundant species and those that are considered good fuel tend to be well represented. A relevant ethnobotanical study was carried out among farmers in the Atlantic Basque Country, in areas where mixed oak woodland is the main arboreal community. In Table 8, arboreal species identified at CMB II were ranked according to the mean fuel quality value established during that study (Zapata and Peña-Chocarro 2003).

The presence and relative abundance of the different fuel woods in the CMB II deposits seem to indicate that hazel and oak wood were abundant around the site. In all the samples, these two taxa account for more than 80% of the identified fragments. Taphonomic problems aside, this would mean that there was a mixed-oak woodland close to this site. According to Table 8, both hazel and oak are highly valued fuel woods (oak scores 4 and hazel 3.8 on the 5-point scale of fuel quality in domestic fires). Thus, hazel must have been a very important component of the woodland around the site (in all samples, it constitutes over 50% of the fragments identified). This is also supported by evidence from CMB I, where hazel nutshells dominated the charred plant remains. Even if they were highly fragmented, significantly overrepresenting the number of nuts involved, their presence is important in itself (Boardman 1993).

The presence of elm charcoal in the lower midden and its absence from the upper midden is interesting in light of the general decline in elm pollen values recorded in pollen diagrams across NW Europe around the time of the Mesolithic–Neolithic transition, 4150–3400 cal. BC (Parker et al. 2002). Could this indicate that the lower midden at CMB II (layer 5) pre-dates the elm decline, which in the Oban

Table 8 Average scores of fuel quality for various species established in domestic fires (from 1 = very bad fuel to 5 = excellent fuel) according to modern farmers' opinions (Zapata and Peña-Chocarro 2003)

Species	Fuel quality
Oak	4
Hazel	3.8
Willow	3
Birch	2.5
Elm	2.25
Alder	2
Aspen	1.4

area occurs ca. 3900 cal. BC (Davies 1997)? Since cultural selection of wood must always be considered in charcoal analysis, this ecological conclusion needs to be confirmed by direct radiocarbon dating of terrestrial organic matter (plant macro remains or animal bone) from layer 5.

3.2 Fauna

Animal remains from the excavations at CMB II further complement the environmental picture outlined by the charcoal analysis and also corroborate the previous zooarchaeological study of CMB I by Hamilton-Dyer and McCormick (1993). Their opinion that "much of the bone in the shell midden contexts can be accounted for by natural factors" can be substantiated. The rodent and bird species identified at this site reflect the proximity of wooded/bushy environments in the site's immediate proximity.

Some differences in diversity between the two faunal samples from CMB are evidently related to assemblage size as has already been shown in Fig. 4 by the very close (almost 99% determination) linear relationship between sample size and sample richness. Poorly represented species are more likely to occur when more specimens are available for study (Grayson 1984:137; see also Peres, this volume). This is clearly the case with fish remains, where the number of identifiable bones from CMB II is twice as great as from CMB I. Consequently, a slightly richer inventory of species was recognized. Large numbers of salmon and cottid remains at CMB II are especially conspicuous. The number of non-identifiable fish remains is also greater at CMB II.

Almost the reverse of this situation, however, was observed in the case of birds. Only remains of various (mostly non-identifiable) perching birds were found in the samples from CMB II, while a fairly rich range of predominantly marine birds came from the CMB I excavation. The different representation of fish and birds in the two assemblages may indicate that there is more than a size-related difference between the two assemblages. The greater numbers of non-identifiable fish and vole bones from CMB II may result from finer recovery techniques applied at this latter site; many of the bones were found by sieving through mesh sizes of 1 and 2 mm, respectively.

4 Summary and Conclusions

Both palaeoethnobotanical and zooarchaeological evidence available from the two sites at CMB are primarily indicative of the environment. While charcoal was present as a result of probably human-induced fire, it must have originated from locally gathered wood. Many of the small terrestrial vertebrates (perching birds, rodents) also seem to be indicators of a wooded natural environment. On the other hand, remains of hazelnut and hand-collected animal bones are indicative of human subsistence activities related to the two shell middens.

It is too simplistic to assume that the proportions of tree taxa represented in archaeological assemblages reflect their relative abundance in the local vegetation. However, it is usually accepted that archaeological wood charcoal is an indicator of at least some of the plant communities formerly growing in the site area and thus a valuable source of data for reconstructing prehistoric vegetation and environments (Smart and Hoffman 1988). Consideration should be given to: (1) taphonomic questions; (2) cultural selection of wood; and (3) context-related variation within the site.

Like plant remains, cultural deposits of animal remains tend to reflect culturally idiosyncratic preferences, rather than the fauna of the local environment. However, as far as the archaeological interpretation of the animal remains under discussion here is concerned, rodent remains, rare bones from amphibians, and even some small fish are unlikely to have been deposited by humans at CMB II. Sporadic long bone fragments from frogs /toads (Anura) tend to appear only in the largest sieved assemblages, thus being indicative of the effect of sample size on taxonomic richness.

Although otter was identified only at CMB I, it is an important carnivore at midden sites along the west coast of Scotland. The number of otter bones was second only to those of seals at the “Obanian” site of Cnoc Coig, Oronsay, where these animals were considered to have been hunted (Grigson and Mellars 1987:274). In contrast to the other mammals previously discussed, otters could easily colonize island habitats. Although this species thrives in fresh water, populations adapted to marine environments have been regularly observed (Mitchell and Delap 1974:64). Today, however, otters are rare around all the islands of the Inner Hebrides. These avid predators of fish were treated as “vermin” in the recent past (Mercer 1974:46). Otters feed on fish, such as wrasse, cod and other gadids, and flatfish, as well as on various crustaceans (Matthews 1989:246).

The few pig and deer bones, on the other hand, directly reconfirm observations by Hamilton-Dyer and McCormick (1993:34), concerning human exploitation of the wild fauna. Although deer bones were most probably deposited by humans, they are also characteristic of the wooded environment than the narrow littoral zone. The CMB II assemblage contained only a few identifiable bones from marine birds, a group which may have been targeted by Mesolithic hunters.

Complex relationships between the factors that determined the contents of the two shell middens are summarized in Fig. 5. Special emphasis has been placed on the importance of human activity in the preservation of zooarchaeological and paleoethnobotanical remains in the middens, located in the ecotone between the forested inland habitat and the littoral zone. Although humans inadvertently contributed to the survival of the floral and faunal remains under discussion here, many of the findings represent natural deposits, especially in the case of vertebrate fauna. Studies of animal and plant remains from coastal shell middens have rarely been given equal emphasis in archaeological research in western Scotland, and even more rarely have attempts been made to integrate the two lines of evidence to aid

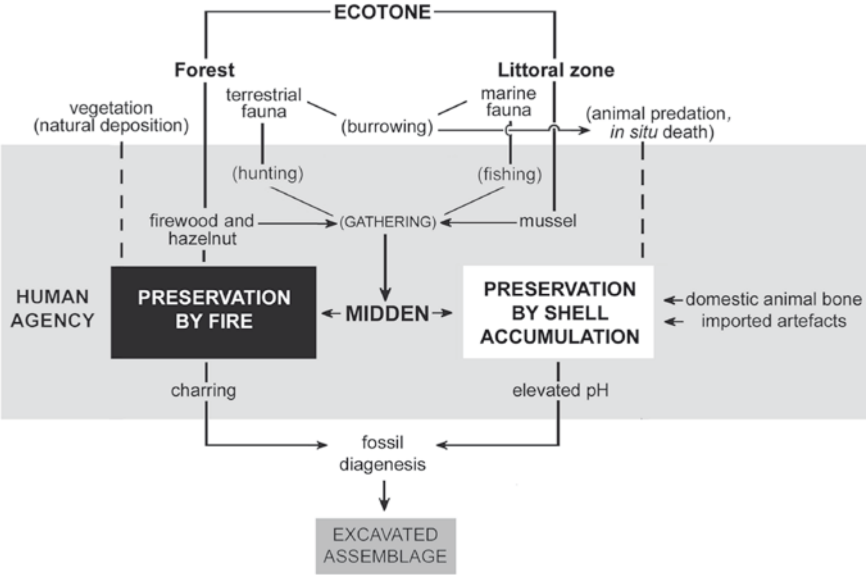

Fig. 5 Factors contributing to the archaeobiological assemblage from a shell midden. Actions and events shaping the deposit are parenthesized. Gathering played a central role, not only as a prehistoric form of subsistence but also in preserving the plant and animal remains at the midden

in site interpretation. The results of zooarchaeological and paleoethnobotanical research at Carding Mill Bay serve to emphasize that shell midden sites are the result of activities that took place at the interface between land and sea, and while they are an important repository of information on human exploitation of coastal and marine resources, they also have the potential to inform us about the local terrestrial environment and its use by humans.

Acknowledgments The excavations at CMB II were sponsored by Historic Scotland. Clive Bonsall thanks the landowner, Mr Danny Keenan, for his forbearance throughout the excavations, and members of the Lorn Archaeological & Historical Society (especially Margaret Kay and Charles Hunter) for their assistance in the field.

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Documenting Subsistence Change During the Pleistocene/Holocene Transition: Investigations of Paleoethnobotanical and Zooarchaeological Data from Dust Cave, Alabama

Kandace D. Hollenbach and Renee B. Walker

1 Introduction

The subsistence practices of early hunter-gatherers are predominantly presented with a familiar gloss: hunters primarily targeted larger game, while gatherers collected available wild plant foods. This treatment obscures the wide variation of foraging practices in which early hunter-gatherers engaged, both in terms of tactics employed and in terms of the resources used. Much of this gloss can be attributed to the paucity of subsistence data available for early foraging groups, particularly in the southeastern United States. Poor preservation conditions yield few instances in which both plant and animal remains are recovered from intact Paleoindian or Early Archaic contexts. This is further exacerbated by the fact that plant and animal data are often not considered in concert, but tend to appear as separate discussions in published materials.

The site of Dust Cave, located in northwest Alabama, provides a rare opportunity to utilize paleoethnobotanical and zooarchaeological data collected from the same contexts to answer questions about early foragers' subsistence strategies, habitat use, and responses to environmental change. Investigation of these questions is made more substantive by combining both datasets. Specifically, this research examines the changes in animal and plant use that occurred between 11,500 and 5800 cal. BC. This period overlaps the very end of the Pleistocene and the beginning of the Holocene (Fig. 1). Our research documents changes in subsistence occurring over this time and examines the extent to which these changes may be due to environmental change.

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_10, © Springer Science+Business Media, LLC 2010

<table>
<tr><th>Calibrated Years BC</th><th>Cultural Periods in Northwest Alabama*</th><th>Dust Cave Zones*</th><th>Global Climate Shifts</th><th>Plant Communities in the MidSouth // Deep South</th></tr>
<tr><td rowspan="2">3,000</td><td></td><td></td><td rowspan="6">Hypsithermal: Warmer and drier conditions</td><td rowspan="10">Oak-hickory-southern pine forest // southern pine forest</td></tr>
<tr><td rowspan="2">Benton (4,800-3,700 cal. BC)</td><td rowspan="2">Zone D (4,500-3,600 cal. BC)</td></tr>
<tr><td rowspan="2">4,000</td></tr>
<tr><td rowspan="2">Sykes/White Springs (5,400-4,300 cal. BC)</td><td rowspan="4">Zones E, J, K, N (6,400-4,000 cal. BC)</td></tr>
<tr><td rowspan="2">5,000</td></tr>
<tr><td rowspan="2">Eva/Morrow Mountain (6,300-5,400 cal. BC)</td></tr>
<tr><td rowspan="4">6,000</td><td rowspan="2">8.2ka Event (6,200-5,900 cal. BC)</td></tr>
<tr><td rowspan="2">Kirk Stemmed (6,900-6,300 cal. BC)</td><td rowspan="4">Zone P (8,200-5,800 cal. BC)</td></tr>
<tr><td rowspan="9">Continuing warming and increase in moisture as glaciers retreated</td></tr>
<tr><td rowspan="3">LeCroy/Kanawha Bifurcates (7,800-6,600 cal. BC)</td></tr>
<tr><td rowspan="4">7,000</td><td rowspan="4">Deciduous hardwoods // warm temperature broadleaf-evergreen forest</td></tr>
<tr><td rowspan="2">Zone Q? (7,600-7,470 cal. BC)</td></tr>
<tr><td rowspan="3">Kirk Corner-Notched (8,500-7,800 cal. BC)</td></tr>
<tr><td rowspan="6">Zone R (9.500-6,900 cal. BC)</td></tr>
<tr><td rowspan="2">8,000</td><td rowspan="7">Mixed hardwoods // oak-hickory-southern pine forest</td></tr>
<tr><td rowspan="3">Early Side-Notched (9,200- 8,500 cal. BC)</td></tr>
<tr><td rowspan="5">9,000</td></tr>
<tr><td rowspan="3">Preboreal Oscillation (9,400-9,200 cal. BC)</td></tr>
<tr><td rowspan="3">Dalton (10,000-9,200 cal. BC)</td></tr>
<tr><td rowspan="4">Zones T, U (11,500-9,500 cal. BC)</td></tr>
<tr><td rowspan="2">Younger Dryas (10,900-9,600 cal. BC)</td></tr>
<tr><td>10,000</td><td>Quad/Beaver Lake (10,900-10,000 cal. BC)</td><td rowspan="4">Non-analog mixed conifers and northern hardwoods // mixed hardwoods</td></tr>
<tr><td rowspan="2">11,000</td><td rowspan="3"></td><td rowspan="3">Continuing retreat of glacial sheets</td></tr>
<tr><td rowspan="2"></td></tr>
<tr><td>12,000</td></tr>
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*From Sherwood et al. 2004.

Fig. 1 Correlations of Dust Cave components, cultural periods, and environmental shifts in northwest Alabama

2 Environmental Background

As climatic patterns shifted with the northward retreat of glacial sheets at the close of the Pleistocene, the colder and drier conditions associated with the last glacial maximum ameliorated. In the southeastern United States, January temperatures were probably between 4 and 8°C cooler than present, and July temperatures probably between 0 and 2°C cooler by 12,500 cal. BC (Delcourt and Delcourt 1987; Kutzbach et al. 1993). Annual precipitation appears to have been roughly 200 mm less than present (Kutzbach et al. 1993; Webb et al. 1993). In the Midsouth, Late Pleistocene forest communities lack modern analogs, both in terms of plant and animal species. Tree species included northern hardwood species and boreal conifers (Delcourt and Delcourt 1981; Overpeck et al. 1992), while animals included now-extinct megafauna and various rodents that are today found much further north (FAUNMAP Working Group 1996; Grayson and Meltzer 2003; Walker 1998).

Although global temperatures dropped markedly during two periods of oscillation – the Younger Dryas and Preboreal Oscillation – the general trend toward warmer and moister conditions continued. By 8000 cal. BC, winter temperatures were 1 to 4°C cooler than present, while summer temperatures may have been as much as 2°C warmer than present. Annual precipitation appears to have been roughly similar to current values (Kutzbach et al. 1993; Webb et al. 1993). Forests of the Midsouth were characterized by mixed hardwood species (Delcourt and Delcourt 1981; Overpeck et al. 1992).

Shortly after a final cooling period, the "8.2 ka Event," associated with the collapse of the last ice sheet, temperatures in the southeastern United States were comparable to present values, although winters may have remained slightly cooler. Annual precipitation continued to increase to roughly 200 mm greater than present, particularly in the Coastal Plain (Shuman et al. 2002; Webb et al. 1993). This wetter period was followed by the Middle Holocene Hypsithermal, which brought drier and even warmer conditions to the region (Webb et al. 1993). Modern forest communities, characterized by oaks (*Quercus* spp.), hickories (*Carya* spp.), and southern pines (*Pinus* spp.), were established in the Midsouth at this time (Delcourt and Delcourt 1987) and supported familiar animal communities that included white-tailed deer (*Odocoileus virginianus*), eastern gray squirrel (*Sciurus carolinensis*), common opossum (*Didelphis marsupialis*), and eastern woodrat (*Neotoma floridana*) (FAUNMAP Working Group 1996).

3 Site Background

The site of Dust Cave was the location of intensive excavation for over 11 field seasons (Fig. 2). First excavated in 1989 by a research team from the University of Alabama in Tuscaloosa directed by Boyce Driskell (now at the University of Tennessee, Knoxville), the cave went through several testing phases, including the excavation of 2×2 m test units and a large test trench in the center of the entrance chamber (Driskell 1994). These tests were subsequently expanded with 1×1 m units to the east and west of the entrance trench. After over a decade of intensely focused research, we now know that people periodically occupied Dust Cave between 11,500 and 3600 cal. BC. The limestone cave environment protected and preserved abundant organic materials, including bone, shell, and macroscopic plant

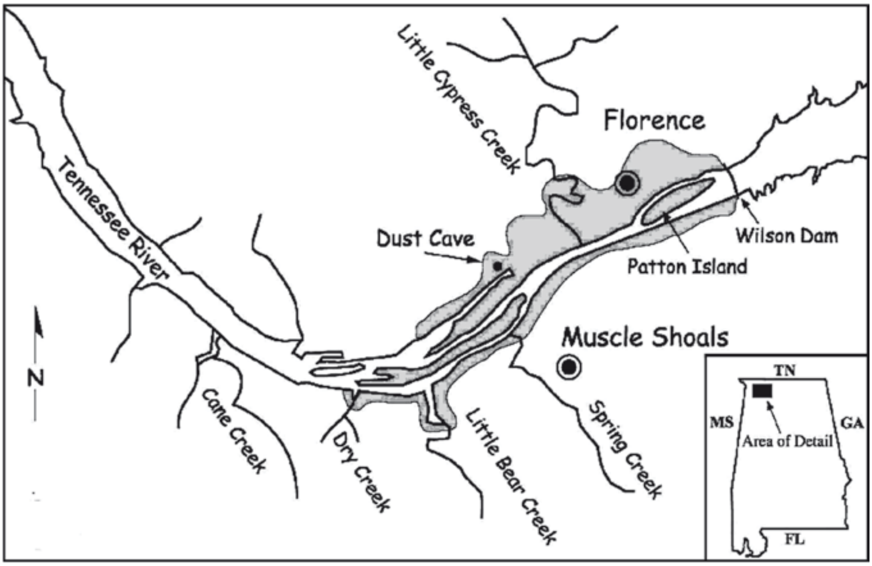

Fig. 2 Location of Dust Cave, Alabama

remains, as well as microstratigraphy rarely recovered in open-air sites (Hollenbach 2005; Homsey 2004; Sherwood 2001; Walker 1998; Walker et al. 2001). Large quantities of stone tools and debitage were also recovered, which provided materials for research on lithic resources, tool manufacturing techniques, and tool use (Meeks 1994, 2000; Randall 2002).

3.1 Stratigraphy at Dust Cave

The stratigraphy at the cave has been the focus of intensive analyses, including research on the microstratigraphy of the cave (Sherwood 2001), prepared clay surfaces (Sherwood and Chapman 2005), and cultural features (Homsey 2004). In addition, the calibration of radiocarbon dates and their correlation with the stratigraphic zones of the cave have been instrumental in refining the chronology at the site (Sherwood et al. 2004). A total of 44 radiocarbon dates have been recalibrated from 29 zones and have been used in tangent with projectile point typologies to define five occupational components (see Fig. 1).

3.1.1 Late Paleoindian: Quad/Beaver Lake/Dalton

The Quad/Beaver Lake/Dalton component dates from 11,500 to 9500 cal. BC and is largely contained in zones U and T. The projectile points from this component include “Quad, Beaver Lake, a reworked Cumberland, Dalton and Hardaway side-notched" (Sherwood et al. 2004:544). Features at this time include prepared surfaces, small pits, and burned surfaces (Homsey 2004; Sherwood et al. 2004). Use of the cave may have been relatively limited at this time, given the fewer numbers of features and lower quantities of plant, animal, and stone tool debris. Alternatively, cultural evidence may have been reworked by fluvial activities in the cave during this period (Hollenbach 2005; Homsey 2004; Sherwood 2001; Sherwood et al. 2004).

Late Paleoindian foraging groups are presumed to have ranged more widely in their subsistence rounds than did subsequent groups, evidenced in part by use of non-local cherts for making stone tools (Anderson and Sassaman 1996). The availability of high-quality chert in the immediate vicinity of Dust Cave, however, largely precluded the use of non-local materials at the site (Meeks 1994; Sherwood et al. 2004).

3.1.2 Early Archaic: Early Side-Notched

The Early Side-Notched component dates from 9500 to 6900 cal. BC, and correlates with Zone R at the site. This component is similar to the Quad/Beaver Lake/Dalton component in that features include prepared surfaces and small pits, but differs in that it marks the first appearance of rock-lined hearths (Homsey 2004; Sherwood et al. 2004:546). Cultural debris recovered from the deposits increases over the preceding period (Hollenbach 2005). Notably, the density of stone tool debitage is greatest in this component, suggesting that tool manufacture from local high-quality chert was a significant activity of the Early Side-Notched occupants (Hollenbach 2005; Randall 2002).

3.1.3 Middle Archaic: Kirk Stemmed, Eva/Morrow Mountain, and Benton Components

The Middle Archaic period of the cave's occupation includes three components. The Kirk-Stemmed component includes Kirk Stemmed points, as well as two Kanawha bifurcated-base points and ranges in age from 8200 to 5800 cal. BC. Human use of the cave intensifies at this time, as evidenced by the presence of multiple prepared clay surfaces built and rebuilt in the same areas, small pit features, and increased burned food debris (Hollenbach 2005; Homsey 2004; Sherwood et al. 2004). This component correlates with Zone P.

The Eva/Morrow Mountain component dates from 6400 to 4000 cal. BC. The major change associated with this component is the additional use of the cave as a burial site, although human activity during this time may have been the most intensive of the cave's occupation (Homsey 2004). In addition to human burials, there are also dog burials, prepared clay surfaces, small pits, and rock-lined hearths (Homsey 2004; Sherwood et al. 2004; Walker et al. 2005). Zones E, J, K, and N are assigned to this component.

Finally, the Benton component represents the last occupation of the site, ending between 4500 and 3600 cal. BC. The projectile points from this component are composed of Benton, Sykes/White Springs, and Crawford. This component, like the Eva/Morrow Mountain component before it, also includes human and dog burials, but with activity shifting to the front and east sections of the cave as headroom decreased (Homsey 2004; Sherwood et al. 2004). Occupants of the site likely participated in the Benton Interaction Sphere, obtaining high-quality local chert to trade with other populations in the Midsouth, in both raw and finished form (Meeks 2000). The Benton component is associated with Zone D.

The research presented here will focus on the Quad/Beaver Lake/Dalton, Early Side-Notched, and Kirk Stemmed components and not the later components for two main reasons. First, these earlier components span a time of significant environmental change in North America, including both the end of the Pleistocene and the onset of the Hypsithermal period. Second, these components represent the greatest overlap between the analyses of the paleoethnobotanical and zooarchaeological data from the site (Table 1). For comparative purposes, the data are grouped by zones. Zones U and T are associated with the Quad/Beaver Lake/Dalton occupation, and Zone R with the Early Side-Notched. Zone Q, the upper boundary of which is marked by an erosional disconformity, appears to represent a mix of the Early Side-Notched and overlying Kirk Stemmed occupations, which is more clearly defined in Zone P (Sherwood et al. 2004).

4 Study Results

4.1 Paleoethnobotanical Remains

The carbonized macro-botanical remains from Dust Cave provide important information on the use of nuts, wild fruits, and seeds by early foragers, and suggest some interesting changes through time. Hickories (*Carya* spp.) and acorns (*Quercus* spp.) were the most important nuts recovered from the samples. When comparing the recovery of hickory nuts relative to other plant remains, hickory shows a significant increase in use during the Kirk Stemmed period (Zone P) over all zones except the earliest period (Zone U) (Fig. 3). The relatively high value of hickory for

Table 1 Sample sizes of plant and animal remains from Dust Cave

Zone	Plant samples (N of flotation samples)	Plant specimens (count)	Animal specimens (count)
P	8	3306	1141
Q	10	832	604
R	12	925	2783
T	15	1666	2479
U	21	848	773

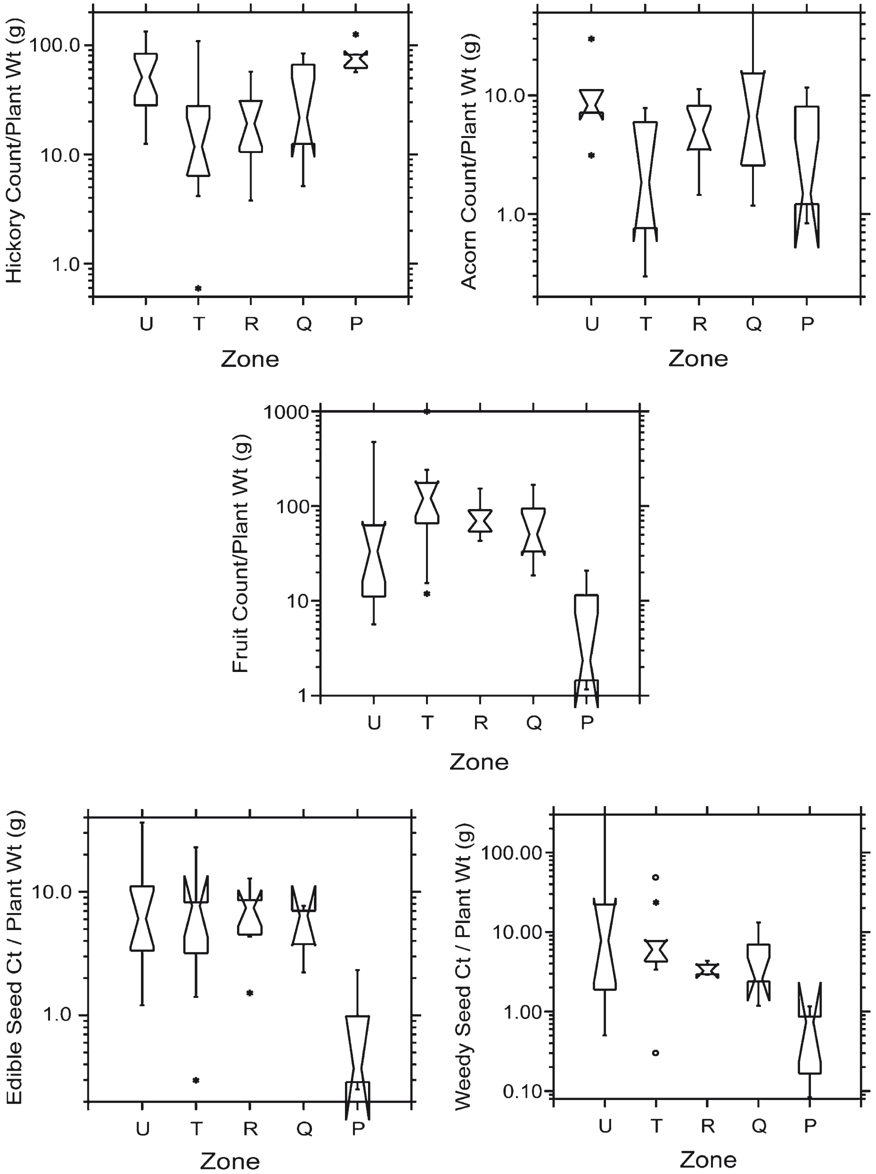

Fig. 3 Relative density of hickory, acorns, fruits, edible seeds, and weedy seeds (*y*-axis is log transformed)

Zone U is largely due to the low recovery of plant remains from these samples. Acorn use, however, appears to have remained relatively steady through time.

The recovery of wild fruits, such as hackberry (*Celtis* sp.), grape (*Vitis* spp.), persimmon (*Diospyros virginiana*), and sumac (*Rhus* sp.), show a decrease in use in the Kirk Stemmed period, likely reflecting the dominance of hickory nuts in these samples. Similar trends are seen for edible seeds, like chenopod (*Chenopodium* sp.) and wild legumes (Fabaceae), and for weedy seeds, like purslane (*Portulaca* sp.), poke (*Phytolacca americana*), and stargrass (*Hypoxis hirsuta*). The boxplots (see Fig. 3) suggest that gatherers began to focus more of their efforts on use of hickory nuts by the end of the Middle Archaic period.

4.1.1 Diversity in Plant Samples

Measures of richness, diversity, and equitability are a valuable tool for recognizing the regional diversity of plant and animal populations and the means of human exploitation of these populations (Peres, this volume; Wright, this volume; Reitz and Wing 2008:110–113). Richness is the number of taxa in an assemblage. Generally, species richness is related to climate and habitat complexity, with greater richness equal to greater habitat complexity, and lower richness equal to less complex habitats (Reitz and Wing 2008:110–113). Diversity is the measure of heterogeneity of an assemblage and is calculated with the Shannon-Weaver index, the formula for which is given by Peres (this volume). In this formula, diversity is a function of the representation of various taxa within an assemblage, summing the number of specimens of each taxon divided by the total number of all specimens recovered. Equitability is a measurement that estimates the distribution of the sample between taxa. This formula is also provided by Peres (this volume), and is calculated as the Shannon-Weaver index divided by the natural log of the richness measure (number of taxa present). For example, one assemblage may be very rich, but have only a few taxa well represented. This would be a less equitable assemblage (Reitz and Wing 2008:110–113).

Unfortunately, use of diversity measures such as the Shannon-Weaver index may be questionable with the paleoethnobotanical samples included here, as many of the taxa are present in low numbers. In addition, the number of samples analyzed varies for each zone, although the zone with the fewest samples analyzed (P) produced the greatest number of plant remains, and the zone with the most samples analyzed (U) produced among the fewest (see Table 1). That being said, the overall trend in richness, diversity, and equitability is a decrease in all three categories through Zone P, or the Kirk Stemmed occupation (Fig. 4). Similar to the boxplots, the diversity measures suggest that Kirk Stemmed groups focused on a narrower set of plant foods, particularly hickory nuts.

4.1.2 Correspondence Analysis

Comparisons among the zone assemblages can be further illustrated by correspondence analysis. This technique essentially reduces the variation of a data matrix (rows and columns) into two (or more) dimensions, and then displays the data along these dimensions, or *x*- and *y*-axes, in a graph (Baxter 1994; see also VanDerwarker,

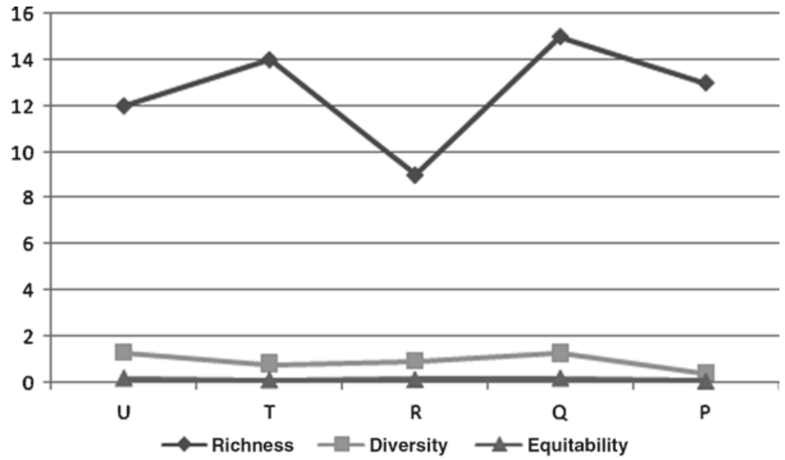

Fig. 4 Richness, diversity and equitability measures of plants

this volume). The origin of the graph is the expected value, and the axes are drawn in the direction of the greatest spread of points (Baxter 1994:114; Bush 2004:106). Variables are thus plotted with respect to how they differ from the expected value. Those that differ most will be plotted farthest from the origin, and those that differ in similar ways will be plotted near each other.

Correspondence analysis is useful to this study for several reasons. First, it reduces the various taxa, recovered at the sites in varying quantities, to two factors and then plots these, facilitating the identification of similarities and differences among the samples. Second, it handles samples of different sizes, facilitating comparisons among the different zones. Although the smaller samples may or may not adequately represent the use of plants in these zones, their use within correspondence analysis is mathematically justified (Bush 2004:107).

A correspondence analysis of the plant remains by zone describes 89% of the variability in the data along two axes (Fig. 5).[1] The *x*-axis primarily separates black walnut (*Juglans nigra*), stargrass, and hazelnut (*Corylus* sp.), from other taxa. The *y*-axis separates hickory nuts, persimmon, sumac, and wild legumes from hackberry, chenopod, and several other seeds. Plotting the zones along these axes, zones U and P are distinctly separate from the others. Zone U is best described by the recovery of black walnut, hazel, and stargrass. Zone P, on the other hand, is heavily influenced by the recovery of hickory nuts, as well as persimmon, sumac, and wild legumes. Zones T and R are roughly similar, plotting closest to chenopod and hackberry. Zone Q plots near the center of the graph, reflecting the fact that no item in particular dominates the samples.

In general, it appears that the Zone U occupants of the cave relied on a wider range of nuts, including black walnuts and hazelnuts, than subsequent groups. Use of chenopod seeds and hackberries becomes more important in Zone T, and the cave's occupants continue to use a similar range of plants in Zone R. Zone Q marks

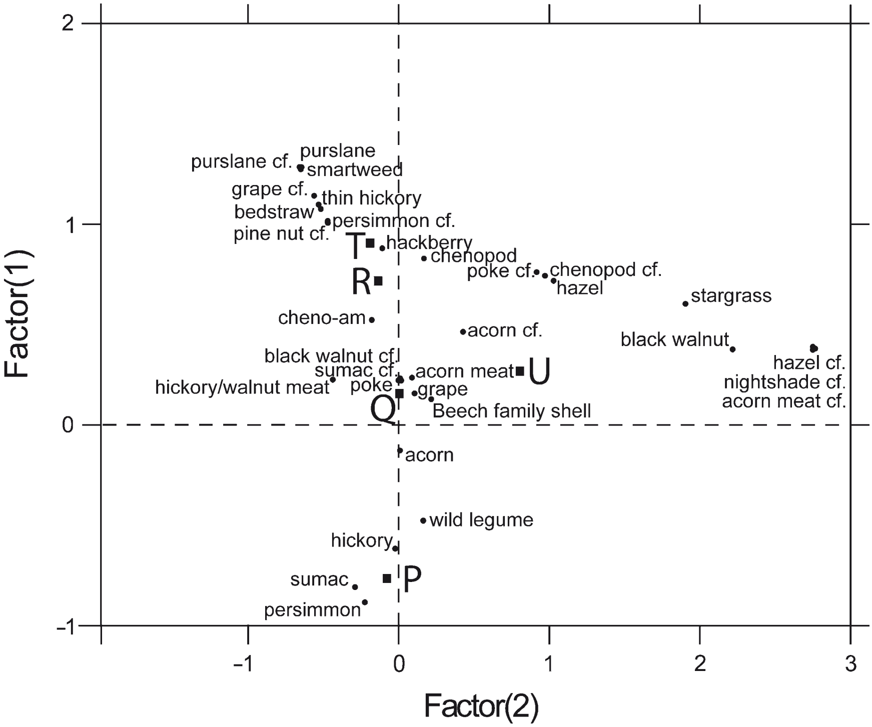

Fig. 5 Correspondence analysis of plants by taxa and zone

a trend toward greater use of hickory nuts, which is quite pronounced in Zone P. Kirk Stemmed occupants of the cave seem to have used a more limited range of plants, focusing on hickory nuts, but also using fruits such as persimmon, sumac, and wild legumes to a greater degree than previous groups.

4.2 Zooarchaeological Remains

An examination of the zooarchaeological remains from Dust Cave focuses on differences in animal classes, use of aquatic and terrestrial resources, and diversity over time. A comparison of animal classes between the components revealed some interesting trends from earlier to later components. First, between the Quad/Beaver Lake component and the Early Side-Notched component there is a significant decrease in the percentage of birds in the assemblages, from 67% to 42% (Fig. 6). This decrease continues into the Early Side-Notched and Kirk Stemmed components with percentages of 30 and 31, respectively.

The number of birds in the Quad/Beaver Lake component is particularly high due in large part to the quantities of waterfowl present in Zone T. An important find

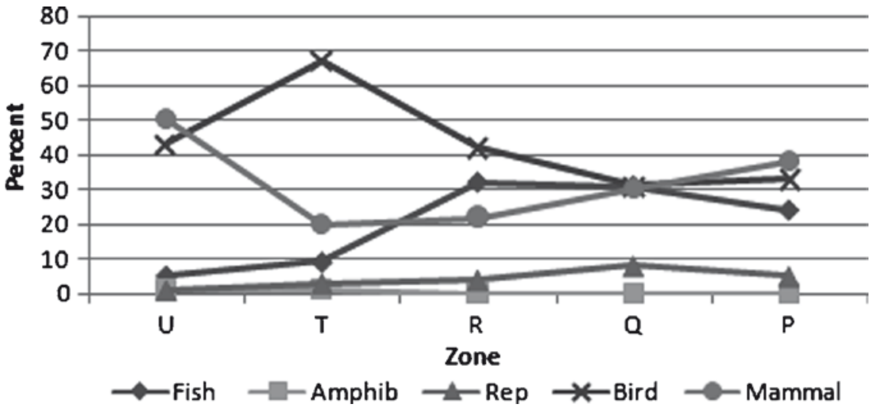

Fig. 6 Animals class percentages by zone

from this zone includes a cache of 23 Canada goose (*Branta canadensis*) humeri that was recovered during the 1999 season. There were 11 right and 12 left humeri, for an MNI of 12. Nineteen of the bones had cut and/or scrape marks, which suggest disarticulating and cleaning of the bones in preparation for use. However, it is not clear what the bones were intended for, but tool making or ceremonial activities are intriguing possibilities (Walker and Parmalee 2004).

4.2.1 Aquatic and Terrestrial Species

In general, analysis of the aquatic species represented at the cave shows a decrease over time in the number of aquatic resources exploited (Fig. 7). However, in this comparison of the earlier components of the cave, there is a slight increase from the Quad/Beaver Lake/Dalton component (Zones T and U) to the Early Side-Notched component (Zone R), but then the numbers of aquatic species decrease, particularly the number of aquatic birds and mammals in the Kirk Stemmed Component. The decrease in the number of aquatic birds is particularly striking, with a total NISP of 48 from the Quad/Beaver Lake/Dalton component to 6 in the Kirk Stemmed component. Although the number of aquatic birds (mostly ducks and geese) and aquatic mammals (e.g., beaver [*Castor canadensis*]) decrease, the number of fish increases. This suggests that upland ponds and backwater areas favored by aquatic birds and mammals may have been drying up as the Hypsithermal commenced around 6000 BC, but that permanent streams and rivers were still being utilized for fishing.

4.2.2 Diversity in Faunal Samples

The richness of the assemblages shows an increase between Zones U and T, which are the Late Paleoindian components, then a sharp decline during the Early Side-Notched Component (or Zone R), followed by a slight increase during the Kirk

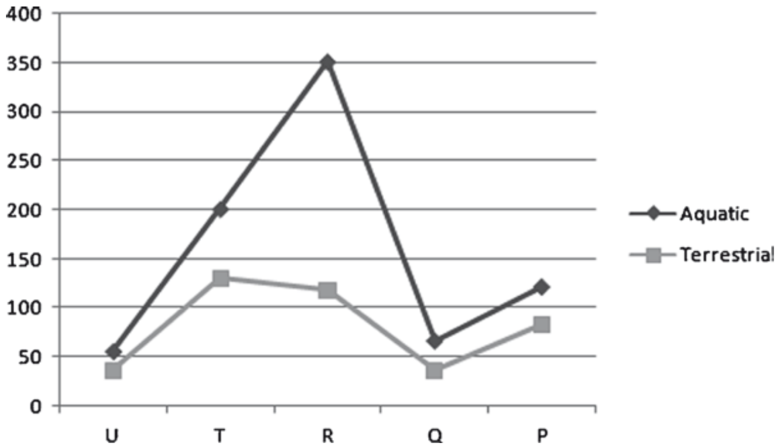

Fig. 7 Aquatic and Terrestrial class percentages by zone

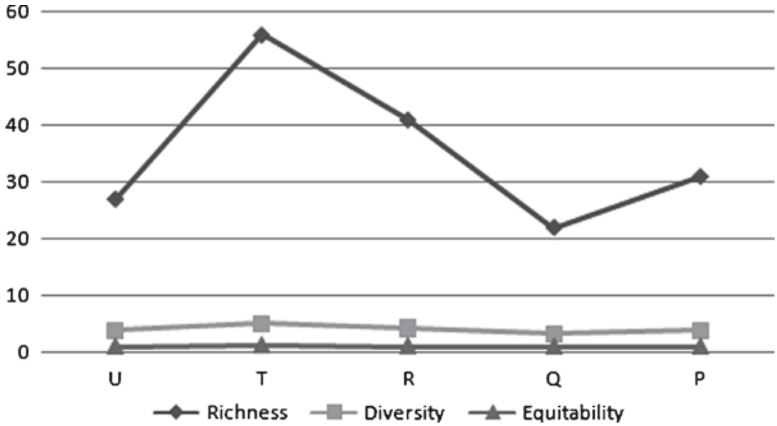

Fig. 8 Richness, diversity and equitability measures of animals

Stemmed Component (or Zone P) (Fig. 8). This is somewhat related to differences in sample size, but not entirely. For example, Zone U has almost twice the number of specimens in its assemblage as Zone P, yet the richness of Zone P is slightly higher than Zone U.

The changes in diversity of the assemblages show a similar trend to the richness of the assemblages. The highest diversity is in Zone T, which corresponds to the Quad/Beaver Lake component, and the lowest is in Zone Q, which is transitional between the Early Side-Notched and the Kirk Stemmed components. However, it should be noted that all the diversity estimates for these components are relatively high when compared to other sites of the same time period (Walker 1998).

Equitability estimates again repeat this pattern, with a slightly more even distribution of specimens in Zone T, and slightly less equitability in Zones Q and P. Again, it should be noted that all of the assemblages have equitability estimates of over 1.0, which means they are all fairly evenly distributed among the taxa represented.

4.2.3 Correspondence Analysis

The faunal assemblages in each zone can also be compared using correspondence analysis, which explains 83% of the variation in the faunal remains from the five zones along two dimensions (Fig. 9). Looking at the taxa with the highest contribution to each dimension, the *x*-axis separates "indeterminate mammals" and to some degree rodents and turkey/grouse (Phasianidae) from most other taxa. The *y*-axis primarily separates "indeterminate birds" from several different groups of fish, but a variety of other taxa exhibit a relatively significant contribution to this axis. For example, gray squirrels and musk turtles (*Sternotherus odoratus*) contribute to the upper portion of the *y*-axis, while canids, voles (*Microtus* spp.), and frogs (*Rana* spp.) contribute to the lower portion.

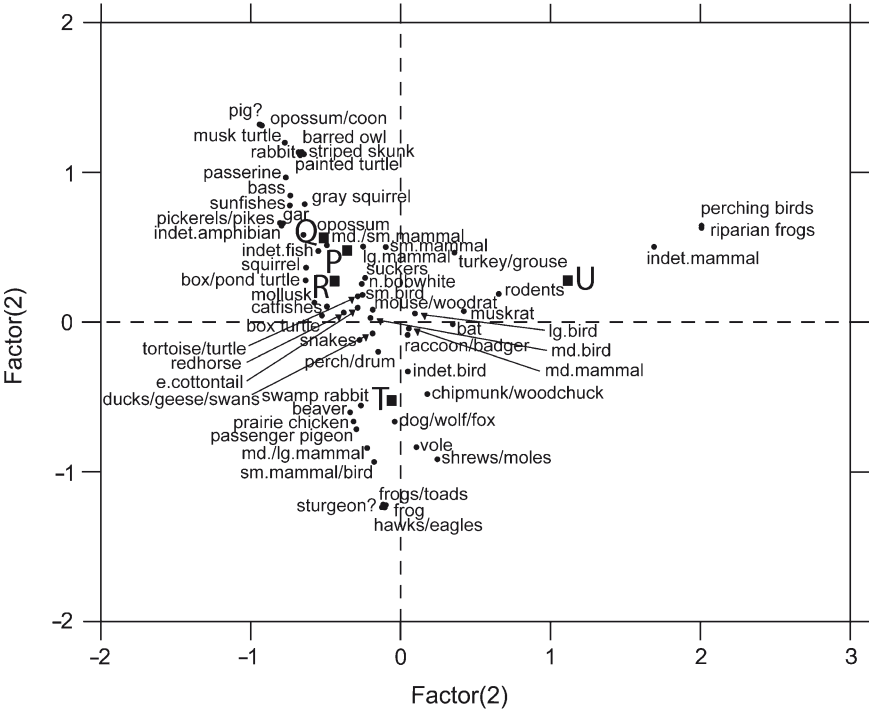

Fig. 9 Correspondence analysis of animals by taxa and zone

By plotting the zones onto these same axes, we can see which taxa most heavily influence the various zone assemblages. Zone U plots on the right end of the *x*-axis, demonstrating the importance of the category of indeterminate mammal, as well as wild turkey and grouse (Tetraoninae), to this assemblage. Zone T also plots by itself, on the lower end of the *y*-axis. This places it near the indeterminate bird category, as well as canids, voles, frogs, and medium/large mammals. In contrast, Zones R, Q, and P plot relatively close to each other in the upper portion of the *y*-axis, corresponding most closely with various fish taxa, gray squirrel, and musk turtle.

The overall picture, then, is similar to that shown in the graph comparing zones by animal class (see Fig. 7). Zones U and T are significantly different both from each other and the remaining zones. It appears, then, that occupants of the cave shifted from predominantly using birds and mammals in Zone U, to an increased importance of birds in Zone T, and finally a decrease in birds and increase in fish in Zones R, Q, and P.

5 Trends in the Dust Cave Paleoethnobotanical and Zooarchaeological Assemblages

Having discussed the animal and plant data from Dust Cave separately, it is useful to compare the two datasets to obtain a more complete picture of subsistence activities at the site. Here we use the results of the correspondence analyses as a visual summary of the differences among the zones.

In both datasets, Zone U stands out as markedly different (see Figs. 5 and 9). The faunal assemblage is characterized by birds, especially waterfowl, as well as mammals. A wide range of plant foods, particularly nuts like black walnut and hazelnut, in addition to weedy seeds, are associated with the Late Paleoindian component (Zone U). The fact that the Zone U plant and animal assemblages are so different from the succeeding occupations does not appear to be related solely to preservation and recovery. Although relatively few plant and animal remains were recovered from these samples, the assemblages are quite diverse. The site's occupants may have practiced a more diverse foraging strategy at this time. It is also possible that the structure or distribution of local resources was markedly different during this early occupation of the site, associated with the Terminal Pleistocene environment. Although environmental reconstructions indicate that these transitional forest communities lack modern analogs, comprising a mix of plant and animal species found farther north today, local habitats probably differed from their succeeding Holocene counterparts more in degree than in kind, at least in terms of edible resources. Similar plant and animal foods were used by later peoples occupying the cave, although in different quantities. For example, highly valued hickory and acorn nuts appear to have been less abundant in these mixed boreal forests, and subsequently supported smaller populations of the animal species that rely on them. Foragers would have had to turn to other food resources to meet dietary needs.

Both datasets suggest a shift in subsistence at the very end of the Late Paleoindian component (Zone T). Use of birds, including waterfowl, became even more important, while mammals appear to have played less of a role. Black walnuts and hazelnuts decreased in importance, while chenopod seeds and hackberries characterize use of seeds and fruits during the terminal Late Paleoindian occupation. Subsistence practices may have shifted as Early Holocene conditions affected the local landscape, perhaps bringing wetter conditions that increased habitats favorable to waterfowl, and increasing the availability of hickory and acorn nuts so that black walnuts and hazelnuts, which are more difficult to process, declined in use.

There is notable continuity in use of plants between the terminal Late Paleoindian component (Zones T) and the Early Side-Notched component (Zone R), but the faunal data indicate a significant shift. The use of birds decreases significantly, while fish increase in importance. As mentioned earlier, this may reflect the drying up of backwaters and upland ponds favored by waterfowl and a reorientation toward use of larger streams and floodplains.

Use of animal resources remains relatively consistent from the Early Side-Notched Component (Zones R through Q) and the Kirk Stemmed Component (Zone P). However, plant use changes significantly during the Kirk Stemmed (Zone P) occupation. Use of plant foods appears to narrow, focusing on hickory nuts in particular, but also persimmon, sumac, and wild legumes. The onset of Hypsithermal conditions may have further favored the productivity of hickory stands in local forests. Gatherers' use of the cave may have become more specialized during the Kirk Stemmed (Zone P) occupation, associated with the processing of hickory nuts, while hunting, trapping, and fishing activities remained similar.

The different timing of shifts in plant and animal use by gatherers and hunters using Dust Cave is of interest, as they may reflect differences in the responses of plant and animal communities to climatic fluctuations. For example, while waterfowl may have been more difficult to capture in the main channel if backwaters and upland ponds significantly contracted by the Early Side-Notched occupation, weedy plants and fruits that favor these settings still would have been readily available along larger creek bottoms and the valley floodplain. By the Kirk Stemmed occupation, the warmer Hypsithermal conditions may have favored mast production, making collection of hickory nuts particularly profitable and encouraging the continued use of terrestrial species such as squirrels, along with fish.

These discordant shifts in plant and animal use may also reflect differences in the goals and strategies of the foraging groups that used the cave, likely for a span of several days up to several weeks. Although we tend to think of hunting-and-gathering groups in a rather homogeneous fashion, it is quite likely that the composition of groups who visited Dust Cave varied significantly, both within and between cultural components.

We might think of these foraging groups in terms of gatherers (who were primarily women, children, and the elderly) who targeted reliable plant and animal resources that could be readily and predictably collected; and hunters (who were largely men) who pursued primarily larger game requiring a specialized set of tools and skills (Bird 1999; Hawkes 1996; Kelly 1995; Panter-Brick 2002). The goals of gatherers, which include the procurement of a reliable food base for themselves and their children, differ markedly from those of hunters, which are to provide a protein source that is as socially valuable as it is nutritionally (Bird 1999; Hawkes 1993, 1996). Thus, it is not surprising that their subsistence strategies should change in different ways and at different times, regardless of climate changes.

The differences in plant and animal use at Dust Cave may then reflect differences in the importance of the site to gatherers and hunters over time. During the Late Paleoindian occupations, it may have served as a convenient campsite for hunters targeting waterfowl in the upland sinks above the site and the backwaters at the base of the bluff line, as well as for gatherers collecting a variety of nuts, fruits, and seeds. In the succeeding occupations, fishers and trappers appear to have taken advantage of the cave to a greater degree than hunters, and by the Kirk Stemmed occupation, gatherers used the site for significant collection and processing of hickory nuts. It is interesting to consider whether fishers and trappers also would have been primarily women, children, and the elderly. Fish and small mammals, similar to plant foods, constitute stable and predictable food sources that can be procured with relatively little skill. This is not to say that hunters did not use Dust Cave at all during these later occupations; the recovery of hafted bifaces in varying stages of production and use, as well as quantities of debitage throughout the site's deposits indicates that hunters did visit the site, at least to refurbish their toolkits (Randall 2002). But the variety of plant foods and animal resources, in addition to the suite of features such as prepared clay surfaces and various processing pits found in the many cultural zones at the site (Homsey 2004; Sherwood 2001; Sherwood and Chapman 2005; Sherwood et al. 2004), demonstrate that Dust Cave served as much more than an overnight stop for hunting and gathering parties.

6 Conclusion

Viewed in concert, the paleoethnobotanical and zooarchaeological data suggest significant changes in the ways early foragers used resources on the landscape, including the cave, as the landscape shifted during the close of the Pleistocene and onset of Holocene climatic conditions. Although each dataset hints at changing subsistence strategies in its own right, together they suggest more nuanced patterns of resource use, affected by changes in group composition as much as changes in local landscapes. The inclusion of additional datasets, particularly local pollen cores that could provide a more detailed reconstruction of surrounding habitats, would further enhance our understanding of the interplay of these environmental changes and foragers' subsistence strategies. While plant and animal data, much less pollen, are seldom recovered from early sites in the southeastern United States, such studies are key to developing a more robust picture of early foragers' lifeways.

7 Notes

1. Note that Factors 1 and 2 are reversed on this graph, especially with respect to the one constructed for the faunal remains (Fig. 9). This was done to group the zones as similarly as possible on the two sets of graphs, in order to facilitate comparison. As the relative position of the variables is the salient feature of correspondence analysis, and not which factor describes which variables, the transposition of the axes does not affect the underlying analysis.

Acknowledgments We would like to thank Amber VanDerwarker and Tanya Peres for inviting us to participate in the SAA symposium and edited volume, and for their patient and careful editing. We also thank Boyce Driskell for giving us the opportunity to work at Dust Cave and his continuing support of our research on the site. Hollenbach thanks Margaret Scarry for her help with identification of unruly specimens and Vin Steponaitis for his insight on multivariate statistics. Hollenbach also acknowledges the support of the National Science Foundation for a portion of this research in the form of a Dissertation Improvement Grant (No. 0332275).

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In the Light of the Crescent Moon: Reconstructing Environment and Diet from an Ottoman-Period Deposit in Sixteenth to Seventeenth Century Hungary

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1 Introduction

In the Old World, the contribution of paleoethnobotanical and zooarchaeological studies tends to be better appreciated in prehistoric rather than historic archaeology. In the absence of written information, using plant and animal remains in the reconstruction of the natural environment and its culturally idiosyncratic forms of exploitation is of evident significance. Given the different taphonomic processes acting on these two major classes of organic remains, as well as respective methods of recovery, quantification and analysis, the results of macrobotanical and faunal analyses are not always directly compatible (see "Simple Measures for Integrating Plant and Animal Remains" and "Correspondence Analysis and Principal Components Analysis as Methods for Integrating Archaeological Plant and Animal Remains"). While this discrepancy has long been recognized, it is rarely discussed against the backdrop of the selective survival of additional sources of data, such as "true" archaeological artifacts as well as textual documents and iconographic sources whose contents are often taken at face value in the study of historical periods.

In the introductory chapter (VanDerwarker and Peres, this volume), an important distinction is made between *quantitative integrative* and *qualitative integrative* approaches to reconstructing subsistence. Quantitative integration would require the quantitative combination of plant and animal data to create a coherent result. A relatively early example for this effort includes the conversion of food resources identified into caloric values as a common denominator, as was modeled at prehistoric lakeshore settlements in Switzerland (Gross et al. 1990: Figs. 6–10). Estimated absolute values, however, are often prone to cumulative bias and can be applied only under exceptionally good conditions of both preservation and recovery.

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases,*
DOI 10.1007/978-1-4419-0935-0_11,

Qualitative integrative measures, on the other hand, involve separate evaluations of the paleoethnobotanical and zooarchaeological lines of evidence with quantitative analysis relevant to each dataset and a subsequent, qualitative integration of the two, usually within the archaeological context. This approach has been most common in the Central European tradition (Schibler et al. 1997; Becker and Kroll 2008) as well as worldwide, as reviewed in the introduction to the volume (VanDerwarker and Peres). Even comparative analyses, however, rarely focus on later, historical periods, whose researchers tend to rely on written sources and have only recently begun to show some interest in enlisting the help of bioarchaeologists in the parallel assessment of material evidence. A pioneering effort was made by Reitz et al. (1985) who dealt with sixteenth-century deposits in Florida. A comparative analysis of the two types of data sets was also carried out in Hungary using medieval and Ottoman-period urban deposits from the city of Vác (Bartosiewicz 1995; Gyulai 1995).

It must be recognized, however, that in the case of Hungarian historic sites one is rarely faced with a subsistence crisis. Even in the years of meager production, one is dealing with evidence left behind by surplus economies, whose basic features tend to be overlain by a market re-distribution system. In contrast to prehistoric contexts, the cognitive, often religious background of material culture is also known.

During the analysis presented here, we had no opportunity to quantitatively integrate data on plant and animal remains to create a single, coherent body of results. This case study, therefore, employs a multidisciplinary method of qualitative integration embedded within the broader culture historical issue of Islamic influence in post-medieval Hungary. Comparative measures did not only involve separate quantifications for each data set, but relevant aspects of archaeological artifacts and the historical record were also compared in qualitative terms. The resulting picture may be impressionistic, but is considered an appropriate means of testing previously unchallenged hypotheses concerning urban microenvironments and ethnic/religious aspects of diet during the Ottoman period in Hungary.

2 Ottoman-Period Research in Hungary

Turkish occupation of Hungary began with the decisive battle of Mohács in the south in 1526, and lasted until the Karlóca Peace Treaty concluded in 1699. The medieval kingdom of Hungary was divided into three parts, as the Ottoman Empire wedged into its soft underbelly from the south along the open Danube Valley, occupying most of the plains and hillier Transdanubia that largely correspond to modern-day Hungary. A relatively narrow band in the west and north fell under Habsburg influence, while Transylvania to the east became a Turkish protectorate as it eventually sought independence from the Holy Roman Emperor and protection for the Protestant religion that flourished there (Fig. 1).

The former royal capital of Buda, central to this paper, was first occupied in 1529, regained and lost by Christian forces several times, and finally liberated in 1686. These tumultuous 170 years of Hungarian history were not only violent; they

Fig. 1 The subdivision of historical Hungary during the sixteenth to seveteenth century Ottoman Turkish Period

brought about amply documented population movements resulting in ethnic and religious interactions that, over several generations, created a complex and variegated material culture.

Interest in the archaeology of the sixteenth to seventeenth century Ottoman period has recently increased in Hungary. In addition to individual articles, a collection of studies in English (Gerelyes and Kovács 2003) was published, and Volume 38 of the journal *Budapest Régiségei* was also devoted to the subject in 2004.

While the Gerelyes and Kovács (2003) volume included reviews on hand-collected zooarchaeological remains from this period (Bartosiewicz and Gál 2003; Vörös 2003), analyses of plant materials and microfauna were missing. This may be partly explained by the bias towards scientific recovery methodologies (e.g., flotation and water-sieving) being used almost exclusively in prehistoric archaeology in Hungary. In later periods, especially the Early Modern Age, there is an overwhelming reliance on written sources in reconstructing the economy and culture, rather than studying biological materials brought to light during excavations.

It must be recognized, however, that all sources (including written documents) are prone to selective taphonomic processes specific to their media; therefore, they preserve different aspects of ancient lifeways. It is not only that they would not substitute for each other; in reality, it is actually difficult to make various types of data compatible with each other. This brief case study is aimed at integrating multiple lines of evidence, including paleoethnobotanical, zooarchaeological, archaeological, and historical documents, to produce a coherent body of information and more robust cultural interpretations.

3 Materials and Methods

The Ganz Street site was uncovered during systematic salvage excavations in the second district of Budapest (12-14 Ganz Street) directed by András Végh and Katalin H. Kérdő on behalf of the Budapest History Museum in 2003. During the Middle Ages, this area, named after St. Peter the Martyr, belonged to the northern section of the *Viziváros* (*Wasserstadt*) suburb located between the Danube River and Castle Hill in the royal capital of Buda.

The feature singled out for detailed analysis was recovered from Squares C2 and C3 of the site (Fig. 2). It was first noted at a height of 102.31 m above the Adriatic sea level, encircling a smaller pit, that was superimposed over it. A loose, oval fill, surrounded by traces of noncharred wood, was visible in the middle of the pit during the removal of the top layer. As if they had been buried in a barrel, eleven beakers were recovered from an elevation of 101.35 masl. Aside from this phenomenon, the loose fill of the Ottoman-period pit was a homogeneous dark-gray silt, rich in charcoal fragments. The assemblage of pottery found in the pit consisted mostly of cooking vessels and tableware used in serving food and beverages. The feature also contained organic materials, visible to the naked eye, including paleoethnobotanical macroremains and zooarchaeological finds in the form of large bones. Fifteen soil samples were gathered for water sieving. While it is impossible to tell whether the pit had a different primary function, it certainly ended up being used as a refuse pit. The total depth of the deposit was 2.14 m, which given the 1.5 m diameter of the pit and its conical shape, would correspond to a volume of around 3 m^3. The 15 soil

Fig. 2 Excavating the feature in Square C/3 at 12-14 Ganz Street. The measuring rod shows 20 cm units

Table 1 Plant associations used in the ecological classification of paleoethnobotanical remains (also used in Tables 2 and 5)

Code	Type of environment
1	Aquatic
1.1	Submerged aquatic
1.2	Floating reed grass
1.3	Diverse decorative plants
2	Floodplain
2.1	Reed bed
2.2	Elevated floodplain
2.3	River bank pioneers
3	Diverse river bank
3.1	Bog meadow
3.2	Humid perennial
4	Floodplain forest
4.1	Humid fragmentary forest
4.2	Gallery forest
5	Open mixed forest
6	Shady forest
7	Open forest
7.1	Forest clearing
7.2	Average forest edge
7.3	Dry forest edge
8	Meadow
8.1	Humid meadow/pasture
8.2	Average meadow/pasture
8.3	Dry meadow/pasture and rock grasses
9	Agricultural
9.1	Cultigens
9.2	Spring cereal or garden weed
9.3	Fall cereal weed
10	Human
10.1	Humid ruderalia
10.2	Average ruderalia
10.3	Dry ruderalia
Diverse	Miscellaneous plants

samples, each containing ca. 5 liters of fill, were taken from the part of the pit located in Square C3. They correspond to approximately 2.5–3% of the pit's entire volume. Hand-collected animal bones were analyzed from the entire pit (Squares C2 and C3). The soil samples were water-sieved using screens of 4.0, 2.0, 1.0, and 0.5-mm mesh sizes [coded as 1 (largest) to 4 (finest) in Tables 1, 4, and 7]. The residue was sorted and identified under low-powered (10–30×) magnification.

Depending on the state of preservation, seeds and other macrobotanical remains could be identified to differing taxonomic levels using a reference collection and identification manuals (Németh 1966; Schermann 1966). The 15 soil samples

Table 2 Wild plant remains from the Ganz Street site

Common name	Taxonomic name	Ecological code	Part	Count	Sample id./mesh size code					
Livid amaranth	*Amaranthus lividus*	9.2	Seed	3	181/4	183/4	198/4			
Hairy sedge	*Carex hirta*	8.1/10.2	Seed	3	183/4	197/4				
Pale sedge	*Carex pallescens*	8.2	Seed	5	183/4	198/4				
Forest sedge	*Carex silvatica*	6	Seed	1	183/4					
Fat-hen, seed	*Chenopodium album*	10.2	Seed	6	130/4	181/4	197/4	198/4	306/4	307/4
Nettle-leaved goosefoot	*Chenopodium* cf. *murale*	10.2	Seed	1	197/4					
Maple-leaved goosefoot	*Chenopodium hybridum*	9.2/9.3	Seed	4	307/4					
Pulse/bean family	Fabaceae	diverse	Bean	1	181/4					
Strawberry	*Fragaria vesca*	7.1	Seed	12	181/4	183/4	196/4	198/4	312/4	
Common fumitory	*Fumaria officinalis*	10.2	Seed	1	307/4					
Goosegrass	*Galium aparine*	9.3/10/7.2	Seed	1	130/4					
Common horned poppy	*Glaucium cornicolatum*	9.3	Seed	3	181/4	197/4				
Common heliotrope	*Heliotropium europaeum*	8.3/10.3	Seed	1	181/4					
Black henbane	*Hyoscyamus niger*	10.3	Seed	2	181/4	183/4				
Common mallow	*Malva silvestris*	9.3/10.2/9.2	Seed	2	305/4	312/4				
White sweet clover	*Melilotus album*	10.2	Seed	1	197/4					

Wild mignonette	*Reseda lutea*	10.2	Seed	1	307/4			
Dewberry	*Rubus caesius*	7.1	Seed	1	183/4			
Bramble	*Rubus fruticosus*	7.1	Seed	4	183/4	198/4	312/4	
Raspberry	*Rubus idaeus*	7.1	Seed	1	183/4	198/4		
Dwarf elderberry	*Sambucus ebulus*	10.2/7.1	Stone	2	130/4	308/4		
Black elderberry	*Sambucus nigra*	4.1/6/10.2	Stone	5	130/4	183/4	197/4	309/4
Lakeshore bulrush	*Schoenoplectus lacusrtis*	2.1	Seed	9	183/4	198/4		
Yellow foxtail grass	*Setaria lutescens*	9.2/9.3	Bare grain	1	183/4			
Bitter nightshade	*Solanum dulcamara*	4.1	Seed	2	197/4	198/4		
Black nightshade	*Solanum nigrum*	9.2/7.1	Seed	2	305/4	307/4		
Annual hedgenettle	*Stachys annua*	9.3/9.2/8.1	Seed	2	130/4	183/4		
Stone clover	*Trifolium arvense*	8.2	Seed	1	183/4			

Table 3 Relative percentages (in descending order) of wild flora identified in the Ganz Street site pit based on 85 habitat preferences

Habitat preference	Percent
Forest clearing	22
Average ruderalia	14
Spring cereal or garden weed	12
Reed bed	11
Miscelleneous	9
Fall cereal weed	9
Humid fragmentary forest	8
Average meadow/pasture	7
Humid meadow/pasture	4
Dry ruderalia	2
Dry meadow/pasture and rock grasses	1
Shady forest	1

Table 4 Animal remains from water-sieved samples from the Ganz Street site

Common name	Taxonomic name	NISP
Catfish	*Silurus glanis*	2
Common carp	*Cyprinus carpio*	3
Carp family, small	*Cyprinidae*	21
Fish	*Pisces* indet.	251
Toad	*Bufo* sp.	2
Frogs and toads	Anura indet.	41
Reptiles	Reptilia indet.	4
Domestic hen	*Gallus domesticus*	5
Domestic (?) duck	*Anas* sp.	4
Bird	Aves indet.	14
Red squirrel	*Sciurus vulgaris*	1
Cattle	*Bos taurus*	2
Sheep	*Ovis aries*	1
Caprines	Caprinae	18
Large ungulate		2
Small ungulate		136
Unidentified macro-mammals	Mammalia indet.	1,033
Unidentified micro-mammals	Micromammalia indet.	6
Unidentified micro-vertebrata	Microvertebrata indet.	11
Total		1,557

Table 5 Domestic plant remains from the Ganz Street site

Common name	Taxonomic name	Ecological code	Part	Count	Sample id./mesh size code						
Cereals											
Common wheat	*Triticum aestivum* ssp. vulgare	9.1	Calcined grain	1	312/3						
Millet	*Panicum miliaceum*	9.1	Bare grain, chaff	4	198/3	198/4					
Oil plants											
Poppy	*Papaver somniferum*	9.1	Seed	2	198/4						
Flax	*Linum usitatissimum*	9.1	Seed	1	312/4						
Fruits											
Water melon	*Citrullus lanatus*	9.1	Seed	1	196/3						
Cantaloupe	*Cucumis melo*	9.1	Seed	2	196/3	196/4					
Fig	*Ficus carica*	9.1	Seed	58	181/4	183/4	191/4	196/4	197/4	198/3	198/4
Apple	*Malus* sp.	Diverse	Seed	3	181/4	196/4	197/4				
Black mulberry	*Morus nigra*	9.1	Seed	26	181/4	183/4	191/4	197/4	305/3	305/4	312/4
Pomeganate	*Punica granatum*	9.1	Seed	1	198/4						
Grape	*Vitis vinifera* ssp. vinifera	9.1	Seed	70	130/3	130/4	191/3	191/4	196/4	198/3	305/4
Vegetables											
Dill	*Anethum graveolens*	9.1	Seed	1	198/4						
Cabbage	*Brassica* cf. *oleracea*	9.1	Seed	1	198/4						
Cabbage species	*Brassica* sp.	Diverse	Seed	3	306/4						
	Vicia sp.	Diverse	Seed	1	130/4						

Table 6 The taxonomic and anatomical distribution of hand-collected mammalian remains from the Ganz Street site

	Cattle			Sheep/goat			Pig			Dog			Horse		
Skeletal part	*Bos taurus*			Caprinae			*Sus domesticus*			*Canis familiaris*			*Equus caballus*		
	C2	C3	Sum	C2	C3	Sum	C2	C3	Sum	C2	C3	Sum	C2	C3	Sum
Atlas		2	2	1	2	3									
Axis				1	2	3									
Vert. cervicalis					2	2									
Vert. thoracalis	2	5	7	1	4	5									
Vert. lumbalis	2	1	3	3	5	8									
Os sacrum					1	1									
Vert. caudalis															
Vert. indet.	3	3	6		2	2									
Sternum															
Scapula	2	3	5	4	11	15									
Humerus	2	6	8	8	8	16									
Pelvis	2	3	5	3	4	7	1	1	2						
Femur	1	2	3	1	4	5									
Category A total	14	25	39	22	45	67	1	1	2						
Cranium	3	3	6		3	3									
Mandibula	1	1	2	3	9	12									
Linguale															
Costa	19	18	37	19	23	42								1	1
Radius	1		1	5	5	10								1	1
Ulna		1	1	1		1									
Radius + ulna					2	2									
Patella															
Tibia	2	2	4	7	4	11									
Fibula															
Category B total	26	25	51	35	46	81								2	2
Horn core		1	1		1	1									

Viscerocranium															
Maxilla		1	1		1	1									
Dentes															
Carpalia															
Metacarpalia	2		2	3	2	5				1		1			
Ph. proximalis	1	2	3	1		1							1		1
Ph. media	2	2	4												
Ph. distalis		2	2												
Sesamoideum															
Calcaneus	1	1	2												
Astragalus		1	1	1		1									
Centrotarsale	1	1	2												
Metatarsalia	2	1	3	3	3	6									
Category C total	9	12	21	8	7	15				1		1	1		1
Total NISP (A+B+C)	61	73	134	88	106	194	1	1	2	1		1	1	2	3
Long bone fragment	3	7	10	17	8	25									
Flat bone fragment	9	4	13	6		6									
Non-identifiable	12	11	23	23	8	31									

Table 7 Bone measurements (mm) from the Ganz Street site (after von den Driesch 1976)

Species	Skeletal part	GL	Bp	Dp	SD	Sd	Bd	Dd
Feature C/2								
Sheep	Humerus						34.3	
Sheep	Humerus						33.5	28.7
Sheep	Radius		34.8	18.5				
Sheep	Femur		47	36.1				
Sheep	Metatarsus		22.6	23.6				
Sheep	Metatarsus	139.9	25.2	19.1	14.7	10.9	26.5	17.9
Sheep	Tibia						30.2	23.4
Sheep	Tibia						34.7	22.4
Sheep	Tibia						29.2	22.1
Sheep	Tibia						30.2	24.3
Cattle	Metatarsus		45.1	43.6				
Cattle	Metatarsus		53.9	30.5				
Feature C/3								
Sheep	Humerus		44.1	47				
Sheep	Humerus						33.2	27.9
Sheep	Radius		39.5	19.7				
Sheep	Metacarpus						26.8	17.2
Sheep	Femur		44.9	21.4				
Sheep	Tibia				13.8	11.9	26.1	21.7
Sheep	Tibia						27.9	22.6
Sheep	Metatarsus		24.7	25				
Cattle	Calcaneus	122.7						
No feature								
Sheep	Humerus		43.1	51.4				
Sheep	Metatarsus		24.3	24.7				
Sheep	Metatarsus		25.9	25.5				
Horse	Radius						78.7	51.9

yielded 49 plant taxa. Paleoethnobotanical analysts often have only carbonized plant remains at their disposal which results in a bias against plant foods that are eaten raw and have fragile macro structures (see also Wright, this volume). Although some carbonized fruit remains were found at this site, the majority of paleoethnobotanical finds were preserved because of at least partially water-logged deposits resulting from the characteristically high water table in the proximity of the Danube River.

Since the majority of identified plant taxa are not cultigens, their remains recovered from this pit can be used to tentatively reconstruct the site's environment. A revised list of plant associations used in the ecological classification of paleoethnobotanical remains (Gyulai 2001:63) is summarized in Table 1. Codes shown here were also used in Tables 2 and 5. Plant species with multiple codes in the latter tables indicate those with overlapping habitat preferences.

As for animal bones, the identification of hand-collected, large bones from well-known domestic animals posed little difficulty. Measurements on these remains were taken following the osteometric protocol compiled by von den Driesch (1976). The nutritive value of various body parts represented by the bones of domestic animals are discussed in terms of the classification set up by Uerpmann (1973:316): A = meat-rich regions of the vertebral column and proximal limb segments; B = head, ribs, central extremity segments; C = facial bones, tail, "dry limb bones" of the feet.

There are very few micro mammalian bone fragments recovered from the water-sieved samples. The identification of microvertebrate bones was based on published data (Niethammer and Krapp 1978; Ujhelyi 1994; Vigne 1995). The condition of bone fragments was recorded by the subjective assessment of three parameters: preservation, fragment angularity, and color (O'Connor 1991).

4 Results and Discussion

The results of our investigations fall into two distinct categories. Environmental information represents the first category. Remains of weeds and many other wild plants represent natural deposition and may be considered diagnostic of the site's immediate environment. Skeletal elements of the microvertebrates (small fish, rodents, etc.) represent the same category. Environmental information is introduced with a brief review of nonbiological data, in order to contextualize our finds within the urban landscape.

The second category is composed of dietary information, represented by domesticated plants and animals, but also by pottery. Domesticates have been brought into being and perpetually transformed by conscious and unconscious human selection. Their remains therefore have a strong artifactual quality as they result from cumulative cultural activity. The composition of the pottery assemblage, largely consisting of tableware, is congruous with this argument. In addition to its culinary function, the ceramic assemblage aids in the chronological placement of food refuse within the Ottoman period of Buda.

4.1 Historical Topography and Urban Habitat

The Ganz Street site is located in the largest suburb that developed northeast of the Buda Castle between the Danube River and Castle Hill. The so-called *Viziváros* suburb could not extend onto the steep eastern slopes of the latter. A lake, located in the floodplain of the Danube River north of the city wall, served as a natural fortification, making preparations for a siege impossible in that area (Fekete and Nagy 1973:336).

The suburb was divided into sections (*bölme* in Turkish) by walls. Civilian inhabitants (especially non-Moslems) were settled toward the north. At the beginning of the Ottoman occupation, Hungarians still inhabited the area around the church of St. Peter the Martyr. Downstream along the Danube, the banks were probably inhabited by Gypsies and Jews, as this area is called *civitas ziganorum et judeorum* in written sources (Zolnay 1982). Subsequently, new settlers from the Balkans who arrived along with the Turkish military forces also made their home here (Fekete and Nagy 1973:337–339).

The same way as much of the contemporaneous written sources discuss the military, rather than everyday history of the time, precise iconographic documentation of the area was carried out by military engineers in the service of the Christian alliance against Ottoman Turks who planned the last sieges of Buda. Drawings of a Bavarian officer were etched into copper by Michael Wening (1686), of the court artist of the Elector of Bavaria in 1684–1686. Similar pictures and maps were produced, for example, by the engineers Joseph de Haüy and Luigi Fernando Marsigli in 1686–1687. A 1686 copper etching (Fig. 3) shows not only the Buda Castle, but also the surrounding landscape with understandable military precision. Even the

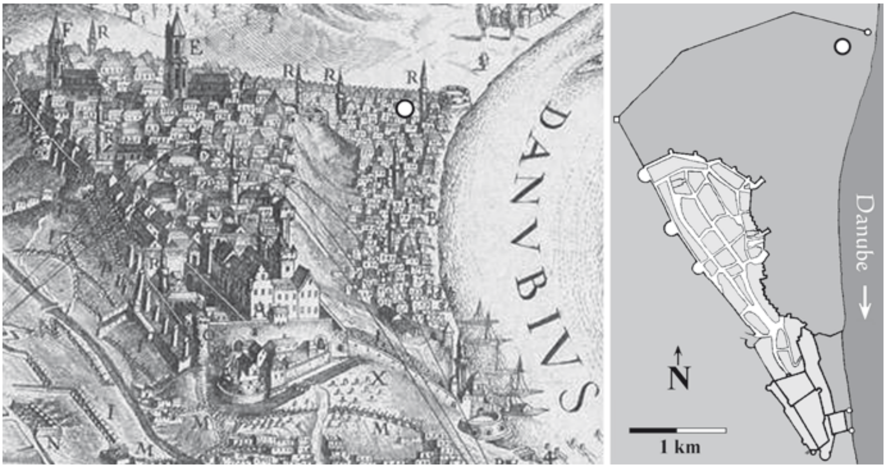

Fig. 3 The approximate location of the site (shown as the *white circle*) between the Buda Castle and the Danube, as seen from the south, in a 1686 copper etching

excavation area can be tentatively identified in this picture. As shown in Fig. 3, huts in this area defined a crowded network of narrow streets and alleys, whose complex layout has determined the settlement structure in the suburb for centuries. Written sources, however, preserved only a very few toponyms. The names of four Mosques (*Toygun pasha*, *Sokollu mustafa*, *Hadji Sefer*, and *Osman bey*) are known from the suburb, but at least a dozen smaller or larger Moslem prayer houses also existed. Similar to the rest of the infrastructure, these places of worship were not newly founded, but were built on already existing architectural features. Toward the end of Ottoman rule, western eyewitness accounts, such as the diary of Don Francisco Fabro Bremundán (1687) from Spain, barely acknowledged the elegance of minarets erected in the vicinity of former churches desecrated by the pagan cult (*profandos por el impio culto*). Turkish baths were similarly established on the medieval foundations of royal baths, hospitals and chapels that surround the abundant thermal springs in this foothill area.

Buda was not simply occupied. It also became a provincial town as a result of its great distance from the *Sublime Porte* in Istanbul. This former royal capital, built in renaissance style, became a combination of an overstaffed army camp and a neglected, Balkan-style market town. Bocatius, a traveller from Košice, visited Buda after three generations of Turkish occupation in 1605. In his short diary, he repeatedly mentions decaying corpses that had been abandoned in the streets. Periodic outbursts of warfare, natural disasters, and wide-spread fires all contributed to the decline of the city (Fekete and Nagy 1973:345).

A decade after the liberation of Buda from Ottoman rule, an index of real estate (commonly referred to as *Zaiger* by its German title) was prepared by Matthias Greischer for the purposes of property taxing. The relevant chapter discussing the *Víziváros* district ("*Zaiger über die Wasserstadt*") was finished in 1696, and described 284 lots in this suburb that, owing to the conservative nature of urban planning, may still be considered relevant to conditions under the Ottoman period. Notably, an almost continuous row of stone buildings was recorded along the western side of the main street running north to south at the end of the seventeenth century, while no remains of such houses were found on the eastern side. This seems to reflect the fact that the latter area was more prone to frequent river floodings, and thus it would have made little sense to erect valuable buildings there. The pit under discussion here was also found east of the main street. Macrobotanical remains, therefore, were preserved under waterlogged conditions in a sufficiently good state that makes species identification possible.

Unfortunately, no house associated with the discussed pit could be found during the course of excavations, as the area had been heavily disturbed by the post-Ottoman period construction of cellars. However, the excavation area could be identified as covering Lots 215, 216, and 217 in the *Zaiger* inventory. The pit under discussion here falls within the area of Lot 215, where a poorly built house with clay walls ("…*etwas wenigs von Kothmauern, ist schlecht gebaut*…") was inventoried (Nagy 1964:230).

Studies of plant ecology are of direct use in grouping paleoethnobotanical remains by habitat type using ecological criteria. Table 2 shows the weeds and other elements of the natural vegetation of the site represented in the 15 water-sieved soil samples. One of the most important questions is, to what extent can the settlement's immediate environment be reconstructed from the identified plant remains? The answer lies in understanding the habitat requirements of and associations between various plant taxa. The chief problem is that it is unlikely that the entire vegetation would be represented in the paleoethnobotanical assemblage, given human selection, taphonomic loss, and sampling bias (see Wright, this volume).

Vegetation within the immediate proximity of the excavated pit seems to have been variable (see Table 3). The flora of reedbeds are indicated by the presence of lakeshore bulrush (*Schoenoplectus lacusrtis*). Hairy sedge (*Carex hirta*) prefers shady forest habitats. Fragmented, humid forest environments were represented by bitter nightshade (*Solanum dulcamara*) and some gathered fruits such as raspberry (*Rubus idaeus*), bramble (*Rubus fruticosus*) and dewberry (*Rubus caesius*). Seeds from black and dwarf elderberry (*Sambucus nigra* and *Sambucus ebulus*), as well as from wild strawberry (*Fragaria vesca*), are usually indicative of forest clearance, thereby fitting the image of open vegetation in this urban environment. Strawberry, as well as bramble, dewberry, and raspberry may not have necessarily grown at the site, but may have been alternatively carried in as food.

Hairy sedge and pale sedge (*Carex pallescens*) are meadow plants. Most typical, however, are ruderalia, plant species that commonly take over human habitats such as roadsides, ditches, fallow fields, and the immediate vicinities of buildings. Resulting from the decay of organic refuse, these areas are usually characterized by nitrogen-rich soils. Typical members of ruderal plant associations found in this feature include fat-hen (*Chenopodium album*), nettle-leaved goosefoot (*Chenopodium* cf. *murale*), common fumitory (*Fumaria officinalis*), black henbane (*Hyoscyamus niger*), and wild mignonette (*Reseda lutea*). These are all indicative of a strong anthropogenic influence over a large area, not surprising given the historical topography of this suburb. These weeds are typical of a humid and neglected urban landscape under heavy anthropogenic influence resulting in soils rich in organic content.

Some of the weeds are associated with cereal cultivation. These include livid amaranth (*Amaranthus lividus*), maple-leaved goosefoot (*Chenopodium hybridum*), yellow foxtail grass (*Setaria lutescens*), and black nightshade (*Solanum nigrum*). Others, especially goosegrass (*Galium aparine*), common horned-poppy (*Glaucium cornicolatum*), common mallow (*Malva silvestris*) and annual hedgenettle (*Stachys annua*) tend to be associated with autumn cereals. During his 1660–1664 trips, the Turkish traveler Evliya Çelebi (1985) mentioned the richness of wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*) fields in the Pest Plain across the Danube. This observation, however, is more relevant to a typical rural setting than the more urban settlement of the Ganz Street site. The densely inhabited environment in which the pit is located, evidently represents the place of consumption rather than production, and indirectly, the proximity of cereal cultivation in the broader region geared at supplying food to the inhabitants of Buda.

In the sieved samples (see Table 4), only seven of the 1,557 bone fragments recovered belonged to small mammals (rodents, insectivores, etc.). This is in sharp contrast with the 277 fish bones, most of which originated from very small, indeterminate animals, whose bodies, given the proximity of the Danube, may have been washed into the deposit by flooding. Only five bones were large enough to have originated from what are considered to be edible-sized carp and catfish by modern standards.

Other constituents of the faunal sample include: reptiles (Reptilia, $n=4$), frogs and toads (Anura, $n=43$) and indeterminate small vertebrates (Vertebrata, $n=11$). The condition of these fragments was very similar, showing that they were exposed to comparable taphonomic conditions. There were few burned fragments ($n=4$), all from indeterminate large mammals. Of the amphibians, two fragments were identified as toads *(Bufo* sp.). These animals usually burrow for winter hibernation, which may be how they became incorporated into the pit fill.

In light of the microenvironment reconstructed from the abundant weed remains, the lack of rodents in the samples is somewhat surprising. Only one specimen could be identified: a skull fragment of a red squirrel (*Sciurus vulgaris*). This species prefers coniferous and mixed woodland, though squirrels also adapt easily to disturbed environments. Therefore, the presence of this bone may be attributed to human activity, possibly ranging from fur exploitation to keeping as a pet. Ethnographic references to eating squirrels are also known, although no relevant information is available in Moslem diets. The remaining tiny fragments of large mammal remains ($n > 1{,}000$) likely represent food remains originating from commonly kept domestic animals.

4.2 Culture Historical Interpretation of Diet

In light of the complexity of the social scenario during the 157 years of Ottoman rule in Buda, it would be especially erroneous to directly equate material culture (including the diet) with ethnicity, but studies of pottery styles by the first author have helped to fine-tune the typochronological position of the feature under discussion here. These studies have also revealed important functional characteristics that link these artifacts to traditional Turkish cuisine. In order to properly contextualize both paleoethnobotanical and zooarchaeological information within the known culture historical framework, we first provide a brief review of the most characteristic vessel types. There is little doubt that “the basic character of Turkish period ceramics was defined by Turkish-style pottery manufacturing in the Balkans that, during the sixteenth to seventeenth century arrived to Hungary under Turkish influence through the mediation of Balkanic population elements” (Kovács 1984:14). The pit, whose biological remains are discussed in this paper, was a sealed Ottoman-period feature that, in addition to the aforementioned 11 beakers, yielded a number of intact or almost complete vessels that represent only a few types and are indicative of a relatively narrow chronological range. The end points of this short time interval may be defined in both time and space. Such types have not been found in pre-Ottoman period, medieval deposits, or at sixteenth to seventeenth century sites outside the territory occupied by the Turkish military (Gerelyes 1991:21–75). *Sgraffito* decorated ceramics (with two layers of contrasting slip applied to an unfired ceramic surface, then scratched to produce a line pattern) have diagnostic significance here. This ceramic type spread in the Balkans under Byzantine influence and survived under Ottoman rule even during the fourteenth to fifteenth centuries. Along with Ottoman expansion, such ceramics arrived in Hungary by the mid-sixteenth century (Kovács 1984:21). Our pit yielded two nearly intact *sgraffito*-decorated, pedestalled bowls with translucent lead glazing, equally absent from Medieval pottery and the eighteenth to nineteenth century ethnographic material in Hungary (Fig. 4).

Two fragments of glazed, spouted jugs with a funnel-like neck, fired reddish-brown, represent a type well known from areas under Ottoman occupation. This type seems to have appeared in Hungary only during the early seventeenth century (Gerelyes 1991:45). Apparently, once this type had spread under Turkish influence, local potters in Hungary also adopted its form. Two jug fragments with spindle-shaped spouts and smooth, gray surfaces (second half of the sixteenth century) and white with yellow glaze (early seventeenth century), also indicate this time period (Lázár 1986:40, 51; Tomka 2003:308). However, the decoration of another jug fragment points to the late seventeenth century. There were two glazed pitchers, one of them white, the other painted green in the upper third of the body, with spouts compressed into a beaked shape. The first form was fashionable in the sixteenth century, while the latter is first known from the seventeenth century onwards (Lajkó 2003:314).

Fig. 4 *Sgraffito*-decorated, pedestalled bowl with translucent lead glazing. Scale bar = 50 mm

The majority of well-preserved ceramics in this pit was comprised of 11 unglazed beakers. They show only minor variability in terms of size and rim cross-section. All were fired red and represent high-quality tableware. They are similar to fifteenth-century beakers in shape; however, their shoulders are less narrow in comparison with their bases (Fig. 5). A round, flat type of baking vessel was introduced to Hungary during the Ottoman period. Even its name, *tepsi*, became a Turkish loanword in modern Hungarian (Kakuk 1996:293). One such fragment was also found in the pit.

Most of the Ottoman-period faience objects (glazed earthenware) imported to Hungary were made in Iznik. Seven fragments were recovered from the pit, three originating from the same bowl. On the basis of its decorative motifs, this vessel represents the so-called Rhodos style, which flourished between 1555 and 1700. The white interior is decorated with a bouquet of blue and manganese-purple flowers framed with black, while the rim is decorated with spiral motifs, similarly framed in black. A parallel to our specimen is kept in the Victoria and Albert Museum, dated to 1555–1560 (Lane 1957:56–57, Figure 40/B).

A pale blue-glazed ink bottle, an artifact characteristic of the sixteenth century, was decorated with an arabesque design but is not related to culinary activity (Fig. 6). Two similar pieces were found in the area of the Buda Royal Palace, and both date to the sixteenth century (Holl 2005:50). Another unpublished specimen is inventoried as No. 1951.1682 in the Budapest History Museum.

Although remains of food and beverages could not be directly associated with these vessels, the evidence of cultivated plants and animals can be used to complement the overall picture, reconstructed from this overwhelmingly Turkish-style

Fig. 5 Beakers from the pit. Scale bar = 50 mm

Fig. 6 Glazed ink bottle from the pit. Scale bar = 50 mm

tableware. As is shown by the biological finds, the inhabitants of this site consumed a varied diet. In addition to the identifiable plant and animal remains, the sieved samples contained miscellaneous fruit and meal remains, as well as eggshell fragments. Animal bones recovered by hand represent a category of their own.

4.2.1 Cultivated Plants

Macrobotanical remains of direct culinary relevance are listed in Table 5. It is evident that plant remains are best represented by fruits, both wild and domesticated. It is impossible to tell whether the wild fruits were gathered locally or purchased at market. A century earlier, the fifteenth-century law book of Buda (Blazovich 2001) regulated the location of stands in the Medieval market place. It also lists produce, including strawberries, bramble and elderberry (all recovered at the site), cornel (*Cornus mas*) and blackthorn (*Prunus spinosa*), all wild fruits that could have been collected individually, but were also marketable items in town. In Hungary, strawberries were not intensively cultivated until the eighteenth century. Until then, yields of wild strawberries were actually higher than those of the early domestic variety (Surányi 1985:119).

The aforementioned fifteenth-century Buda law book offers a rich list of well over a dozen fruits and vegetables sold at the market (Blazovich 2001). Of these, however, it is only apple (*Malus* sp.), strawberry, watermelon (*Citrullus lanatus*), grape (*Vitis vinifera* ssp.*vinifera*), poppy seed (*Papaver somniferum*) and cabbage (*Brassica* cf. *oleracea*) that were identified in the pit. It is unlikely that the medieval choice of diverse fruits and vegetables would have declined so quickly within a century, even if this household did consume a select set of fruits and vegetables. If the pit was filled within a relatively short time, seasonality may have limited the choice of plants available. Sampling bias must also be considered as only a relatively small portion of the pit's fill was chosen for study.

Of the domestic fruits, both watermelon and cantaloupe (*Cucumis melo*) were cultivated in Hungary during the Middle Ages. However, they were also highly appreciated in Turkish horticulture, and Turkish occupation made these fruits increasingly popular among Hungarians. In addition to Medieval watermelons with yellow meat, the red variety became more widespread after the Ottoman period (Gyulai 2001:184–185).

Figs (*Ficus carica*) were popular among the Turkish population in Hungary as well; it is possible that they even planted their own fig trees. According to Gyulai (2001), however, the fig seeds recovered from pre-Turkish, medieval sites in Buda seem to be of local origin. Figs from the Mediterranean had been introduced to Hungary prior to Ottoman Turkish occupation. They became popular across Europe during the fifteenth century. It is probably the intensification of trade relations with Italy during Renaissance times in Hungary that resulted in the importation of the first fig trees. Some researchers think that these plants, which sometimes survived for centuries on the sunny slopes of Gellért hill in Budapest, are the descendants of those early imports (Gyulai 2001:189). Although fig survives in warmer locales in Hungary, its fruits usually do not ripen well. This must have been especially true at the end of the sixteenth century, when the Hypsithermal led to global cooling and increased precipitation (Rácz 1993). Regardless of botanical evidence, Turkish tax records bear witness to the importation of figs from areas south of Hungary, in what constituted Yugoslavia during most of the twentieth century (Fekete and Nagy 1973:373).

While pomegranate (*Punica granatum*) has been recovered from Medieval house deposits in Buda, it is not a regular component of archaeological assemblages until after the Ottoman occupation. Mulberry trees (*Morus nigra*) were autochtonous in Hungary, and have also been consciously cultivated since the fifteenth century. The small seeds of this widely consumed fruit frequently occur in many Late Medieval paleoethnobotanical assemblages (Gyulai 1995:159).

The assemblage of macrobotanical remains from this pit was dominated by the seeds and remains of grape. The size and morphology of some grape seeds is characteristic of a large, edible form cultivated for direct consumption. The majority of remains, however, must have been marc, a by-product of preparing beverages, most probably unfermented grape juice or wine.

Medieval viniculture was of outstanding importance in Buda. This tradition was carried on even under Ottoman rule, although far less intensively, since the Hungarian population had fled and Moslem occupants probably had a limited interest in wine production (Gyulai 2002). Shortly after the Turkish occupation, Dernschwam (1984) noted during his 1553–1555 trip that vineyards were on the decline, taken over by weeds. A century later, Evliya Çelebi (1985) praised the fruits, especially grape, and even provided a precise number of vineyards (7,000) in the early 1660s. It is impossible to tell whether the increase represents a recovery in grape production or rather different attitudes by the two travelers. Some growth in wine consumption may be hypothesized as Turkish occupation was strengthened by non-Moslem settlers from the Balkans during the sixteenth century, who brought a tradition of viniculture with them. Grape production may have increased during the relatively peaceful early seventeenth century; it gave a profitable occupation to the inhabitants of suburbs and generated tax revenue for the *Sublime Porte* (Fekete and Nagy 1973:370). This historical trend is supported by numerous sites in Buda and adjacent settlements that have yielded large quantities of grape remains (Hartyányi et al. 1967–1968; Hartyányi and Nováki 1973–1974; Torma 1996:317–342).

In addition to vineyards, orchards were also abundant in the outskirts of Buda as mentioned several times in the correspondence by *pashas*, the Turkish governors seated in Buda during the sixteenth century. Later sources also refer to maize (*Zea mays*) and melon cultivation, as well as the keeping of honey bees (*Apis mellifera*) (Fekete and Nagy 1973:365). In comparison with the broad range of fruits represented in this pit, the underrepresentation of cereals is noteworthy in our assemblage. Chiefly wheat (*Triticum* spp.), but even quantities of rice (*Oryza* spp.) were shipped to Buda according to the historical record, the latter arriving from the territories of modern-day Serbia and Bulgaria under Ottoman Rule. It is therefore rather strange that cereals should be almost completely absent from the samples analyzed here. One possibility, as is shown by the sporadic presence of wheat and millet (*Panicum miliaceum*) in the samples, is that these cereals were consumed in a processed form. The same may apply for oil plants, poppy and flax (*Linum* spp.). The latter may have been mostly used in manufacturing linen, a craft activity not identifiable within the close proximity of the pit, which is seen more as a locus of consumption than production. The low representation of garden vegetables (limited to cabbage) is somewhat more difficult to explain.

Another interpretive aspect of the plant remains is seasonality. Looking at the seasonal availability of the seeds under discussion here (ranging from strawberries to grape), an early summer-early fall deposition is most likely. This broad temporal range brings into question the possibility of a single filling episode, originally hypothesized on the basis of closely related tableware among the ceramics. Some fruits ripen with a difference of several months, although imported or preserved fruit products may span longer time intervals, blurring the limits of seasonal availability (Fig. 7). Since the material originates from a large, single pit, one must address the issue of sampling bias when the representative value of the assemblage is appraised. Partial recovery, however, would not explain the relatively broad seasonal spectrum of plant species.

Another phenomenon may have more to do with sampling. It may be considered strange that usually widely represented stones from several drupes in the Rosaceae family [i.e., plums (*Prunus domestica*), cherries (*Prunus* spp.), peaches (*Prunus persica*), and apricots (*Prunus armeniaca*)] as well as hazelnut (*Corylus* spp.) or

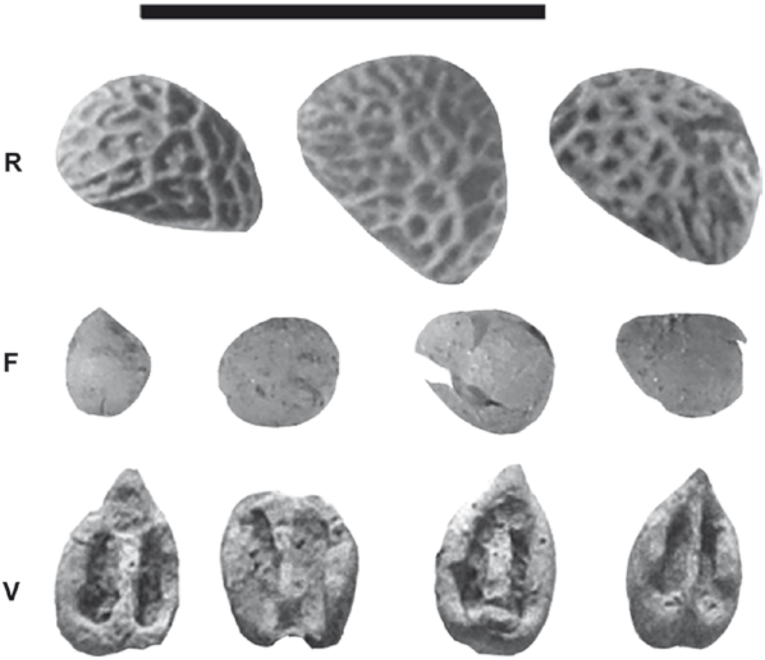

Fig. 7 Seeds of dewberries (R), figs (F) and grapes (V) from the pit, representing different seasons of harvest, as well as gathering, possible import and cultivation. Scale bar = 10 mm

walnut (*Juglans* spp.) are completely missing from this assemblage. These clearly visible, durable remains tend to be the first to be retrieved, even in hand-collected samples. Nuts could also be stored and consumed throughout the year. Aside from the possibility that they were simply not eaten at the site, the possibility must be considered that these stones occur in numbers far smaller than the abundant seeds of grape, berries, or melon. Therefore, the statistical probability of encountering them in a relatively small, 3% sample is somewhat smaller, since – as has been shown for different classes of animals – rare species are more likely to be manifested as sample size increases (Bartosiewicz and Gál 2007:39; see also Peres, this volume).

4.2.2 Hand-Collected Remains of Domestic Animals

By the sixteenth–seventeenth centuries, quantitative and qualitative parameters of animal keeping and trade were amply documented in Hungary. These sources, however, largely concern agriculture and place less emphasis on animal exploitation or the size and morphology of domestic animals. These latter topics may be better addressed through the consideration of zooarchaeological remains available from household contexts.

The exact geographic origins of animals identified in urban consumption refuse are usually unknown; cities such as Buda may have been provisioned with meat from a broader hinterland. However, as the original inhabitants, the medieval burghers, fled Buda after its 1541 Ottoman Turkish occupation, the city became increasingly rural (Bartosiewicz 2001:36). New settlers from the Balkans were also known to have kept livestock in the suburbs along the Danube. One may only hypothesize that the contribution of bones to food refuse reflects the species composition of local animal husbandry (Vörös 2003:339).

The pit under discussion here yielded 343 hand-collected bones, in addition to the remains of smaller animals recovered from the water-sieved samples. The number of identifiable specimens (NISP) was 289, all originating from domesticates (283 mammals, 6 poultry) while 54 indeterminate fragments probably also belong to the commonly occurring caprines and cattle (*Bos taurus*) (see Table 6). With a few notable exceptions to be discussed below, all bones appear to represent food refuse.

Sheep (*Ovis aries*) contributed the majority of bones to this assemblage (NISP = 187, 57%). Although some, in principle, may originate from osteologically similar goat (*Capra hircus*), all identifiable fragments represented sheep. Only 57 of the 187 bones come from adult animals; 31 originated from lambs of various ages (juvenile or subadult). The remainder could not be precisely aged. As an apparent consequence of intensive butchery, the material was highly fragmented. Using the coefficient developed by Teichert (1975:54), the single complete metatarsus from a sheep yielded a withers height estimate of 630.9 mm, which may be considered small in this period. Measurements taken on the rest of the fragmented sheep bones were compared to those of Ottoman-period sheep bones from the Pasha's Palace in Buda (Bökönyi 1974) and a small set from the site of Buda–Teleki Palace, both within the castle area (see Table 7).

Recently, osteometric data from large Early Neolithic assemblages from Ecsegfalva 23 and Endrőd 119 in Hungary (Bartosiewicz 2007:294, Fig. 14.8) have been successfully compared to a group of 26 adult Shetland ewe skeletons representing a single contemporary flock (Davis 1996:596, Table 2). Mean values and standard deviations calculated for all the measurements from this unimproved present-day breed from Britain served as a technical standard by which measurements of various fragmentary archeological sheep bones could be pooled within the same diagram regardless of their differing anatomical positions. The advantage of this method is that measurements taken on an array of fragmented skeletal elements from these three sites (Ganz Street, Teleki Palace, and Buda Pasha's Palace) can be shown relative to the respective mean value and standard deviation of the same bone as calculated from the reference collection of modern Shetland sheep.

Using the measurable bones, these three Ottoman-period sheep bone assemblages show that, in spite of the modest representation of data, the measurements of the Buda sheep tend to vastly exceed the mean size of recent Shetland ewes (Fig. 8). With the pivotal role of mutton in Moslem meat diet, an upgraded, large form of sheep was bred in Hungary, a tendency similar to what was observed on sheep bones recovered from eleventh to twelfth century Moslem deposits in

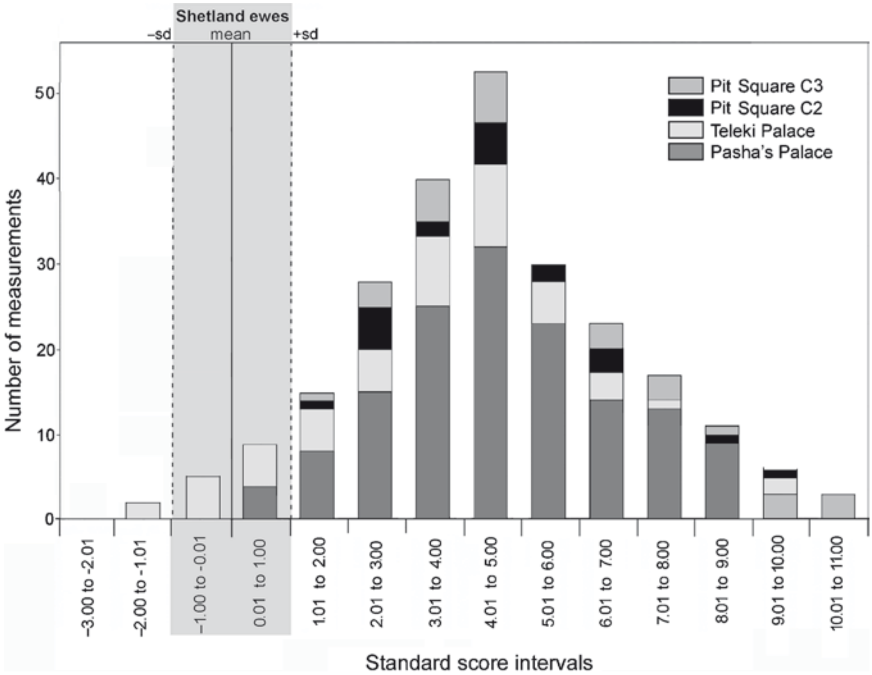

Fig. 8 Histogram showing the size distribution of Ottoman-period sheep from Buda. Bone measurements from Teleki Palace, Ganz Street (Squares C2–C3) and the Pasha's Palace (Bökönyi 1974) are expressed as standard score intervals of modern Shetland ewes.

Portugal (Davis 2008). Assuming that size increase in that case reflected upgraded stocks, Davis (2008:1001) explained this phenomenon with the importance of mutton in Moslem diets. He correctly points out the possible effect of sexual dimorphism as well. In addition to genetic differences, Shetland sheep, used as a standard in this calculation, live on meager pastures in a harsh climate which at least partly accounts for their smaller size. Ottoman-period sheep from Buda were not only significantly larger and more variable than the modern-day Shetland ewes used for reference, but their bones also show a unimodal, near-Gaussian size distribution, not indicative of any form of secondary sexual dimorphism in size (see Fig. 8). This raises the possibility that measurable bones from the food refuse originate from large-bodied wethers. Fattened castrates must have been as popular for highly appreciated suet as were lambs for their tender meat, something Arab physicians regarded close to perfection (Rosenberger 1999).

While beef tends to be prominent in the diet reconstructed at medieval urban settlements in Hungary (Bartosiewicz 1999), cattle remains ranked second at this site (NISP = 127, 40%). The contribution of cattle bones was even smaller relative to those of sheep (NISP = 162 vs. 729) at the Ottoman-period site of Teleki Palace in the Buda Castle area (Daróczi-Szabó 2004:161). An even higher ratio of sheep remains was observed in the Pasha's Palace: 151 vs. 1,245 (Bökönyi 1974:350).

In terms of age, 32 bones from the cattle assemblage originated from adult animals, and 12 belonged to subadult individuals. No age could be assigned to the remaining bones. The only worked specimen recovered at this site, a large spatulate tool, was made from a cattle tibia diaphysis splinter. A very similar implement was observed in use by modern-day shoemakers in Bulgaria (Alice M. Choyke, personal communication).

Domesticated pig (*Sus domesticus*) bones were identified only in two cases (0.6%), indicating the negligible dietary importance of this animal. Two pelvic fragments were recovered, one from an adult and one from a subadult individual. A similar lack of pig bones (NISP= 3, 0.15%) was observed in the far larger Ottoman-period faunal assemblage from the site of Teleki Palace within the Buda Castle area (Daróczi-Szabó 2004:161).

Horse (*Equus caballus*) and dog (*Canis familiaris*), neither likely food sources, were also infrequent in the assemblage (see Table 6). Similar to pig, dog has been considered unclean in Islam, so that its meat could not be consumed. Attitudes to horse flesh, on the other hand, varied. Some theological schools of Islam shunned eating horses in Medieval Turkey, while others took a more relaxed stance (Mazahéri 1989:106). From a practical point of view, aside from emergencies such as famines, given the high utilitarian and status value of live horses, slaughtering these animals for food would have been wasteful. The few horse bones found in the food refuse indirectly illustrate the negligible contribution to the diet of similarly under-represented meat-purpose pork.

The hypothesis that most animal remains in the pit represent food remains after secondary butchering is supported by the fact that in the case of sheep and cattle bones, Uerpmann's A and B category skeletal elements of greatest meat value dominate (see Table 6), especially in the case of sheep (54%). While even the feet (C category) of these may have been cooked for food, massive dry limb bones of cattle were rather unlikely to have formed part of the diet (Table 8).

Poultry (NISP=6, 2%) was represented by a sternum and three synsacrum fragments from domestic hen (*Gallus domesticus*), a goose (*Anser domesticus*) carpometacarpus and

Table 8 The distribution of 268 sheep and 388 cattle bones by meat value categories. Cattle bones of low meat yield are removed from the food remains (A=meat-rich regions of the vertebral column and proximal limb segments; B=head, ribs, central extremity segments; C=facial bones, tail, "dry limb bones" of the feet)

	Percentage
Sheep	
Category A	24
Category B	30
Category C	5
Cattle	
Category A	14
Category B	19
Category C	8

Table 9 The taxonomic and anatomical distribution of bird remains recovered by water-sieving at the Ganz Street site

Common name	Taxonomic name	Skeletal part	Count	Sample id./ mesh size code
Domestic hen	*Gallus domesticus*	Carpometacarpus	1	130/3
Domestic hen	*Gallus domesticus*	Cervical vertebra	1	191/2
Domestic hen	*Gallus domesticus*	Cervical vertebra	1	305/3
Domestic hen	*Gallus domesticus*	Phalanx 2, anterior	1	307/3
Domestic hen	*Gallus domesticus*	Carpometacarpus	1	307/3
Duck/mallard	*Anas* sp.	Phalanx posterior	2	305/3
Duck/mallard	*Anas* sp.	Phalanx posterior	1	308/3
Duck/mallard	*Anas* sp.	Phalanx posterior	1	312/3
Juvenile bird	Aves indet.	Ulna	1	104/3
Bird	Aves indet.	Fragment indet.	1	181/2
Bird	Aves indet.	Cervical vertebra	1	181/2
Bird	Aves indet.	Cervical vertebra	2	183/2
Bird	Aves indet.	Fragment indet.	1	191/2
Bird	Aves indet.	Vertebra	2	197/2
Bird	Aves indet.	Vertebra	3	197/3
Juvenile bird	Aves indet.	Scapula	1	197/3
Bird	Aves indet.	Fragment indet.	3	297/3

a long bone fragment likely from goose. With one exception, these remains represent adult birds. The bird remains recovered from water-sieved samples (Table 9) contributed additional small bones of domestic hen to this list, and, more interestingly, a few remains of possible domestic duck (*Anas* cf. *domestica*). Unfortunately, distinction between anatid species is extremely difficult even on the basis of large and characteristic skeletal elements. A twelfth to thirteenth century find was identified at Muhi and several domestic ducks seem to date to the fourteenth to fifteenth century in Hungary (Bartosiewicz and Gál 2003:372), including the sites of Szent György tér and Teleki Palace in Buda (Gál, n.d.). But the precise distinction of these bones from the remains of especially mallard (*Anas platyrhynchos*), the wild form, is nearly impossible even when measurable bones are available. On the basis of a relatively broad upper bill from the Ottoman Turkish period site of Segesd, it was suggested that it belonged to the more developed, domestic form (Bartosiewicz 1996:185, 191, Pl. IV). Other sixteenth to eighteenth century duck remains were recovered at Pilisszentkereszt and Székelykeresztúr in Transylvania (sixteenth century) (Gál 2008).

As was mentioned in relation to the animal remains recovered by sieving, only a few bones belonged to fish that may be considered of edible size by modern standards. Catfish (*Silurus glanis*) was represented by a fragment of an articular and dentary. Ten fragments of pharyngeal teeth could be relatively easily identified as originating from a medium-sized common carp (*Cyprinus carpio*). Two caudal vertebrae, as well as fragments of a preoperculum and a cleithrum from a large carp were also found in the pit. Indeterminate small cyprinid fish were represented by fragments of a dentary, a dorsal fin ray, and four precaudal vertebrae.

4.2.3 Dietary Interpretations

In addition to Turkish administration and military, a major population element of Slavic extraction from the Balkans also arrived to Buda during the Ottoman period. As much as we know from written sources, daily diet was rather simple. On weekdays, the main course was soup (*çorba*), cooked with rice, often colored with saffron and sometimes sweetened. Boiling soured milk produced the drink *yourt*, known as yogurt in modern diets. Today, sheep's and goat's milk are preferred in Turkey and southeastern Europe for preparing this drink.

Cereal grain was imported in great quantities. In 1571, one quarter of the Buda customs revenue originated from dues paid for wheat and barley; an estimated 1,000 metric tons was shipped up the Danube from the south on board 437 boats. Bread was usually eaten fresh. Other starch foods included *tarhana* (Kakuk 1996:292), a dry granulated pasta made from wheat and eggs that could be stored and transported easily, and *bulgur* which is most commonly the parboiled and sun-dried grain of de-branned durum wheat. *Bulgur* differs from cracked wheat, made from crushed cereal grain which has not been parboiled. Like rice and millet, these meals were prepared with an admixture of small cuts of spicy meat.

The complementary roles of written documents and archaeological data become evident considering that only negligible evidence of the core elements of the diet tend to survive in the excavated deposits, or even those that may be preserved (especially cereal grain) were underrepresented in the pit discussed here. On the other hand, the broad scale of fruits identified in the assemblage is far better known from medieval than contemporaneous Ottoman-period documents in Buda, showing the significance of paleoethnobotanical inquiry. Written sources would also be of little help in assessing the seasonal character of an archaeological deposit.

Among the fruits, grape is of special importance as a possible source of wine. Although the Moslem prohibition of consuming alcohol is well known, several Turks living in Hungary acquired the embellishing *epithet*, "the drunkard," indicating that this aspect of religion was not followed strictly (Gyulai 2001). In Medieval Turkey, observing alcohol prohibition also varied from time to time. Some rulers insisted on respecting the word of the Qur'an in this regard, while others had a more relaxed attitude toward drinking (Mazahéri 1989:104).

In addition to wine, non-alcoholic *pekmez*, also known as "must-honey," a Turkish syrup-like substance, was likely prepared. This liquid is made by condensing juices of grape (or figs or mulberries) by boiling the fruit juice with natural coagulants. Most of the grape products in modern Turkey are in the form of *pekmez* or dried as raisins. Among others, *pekmez* is mentioned by Kelemen Mikes, a Hungarian exile in Tekirdağ (Western Turkey), as poured on snow, producing a *sherbet*-like chilled fruit juice (Mikes 1862:55). Thus, the grape remains may be related to at least three different products. Members of an observing Moslem household would have been more likely to have consumed *pekmez* than wine (Andrásfalvy 1961:87–95).

The overwhelming dominance of bones from sheep and, to a lesser extent, cattle falls in line with the massive presence of Islam during the Ottoman period, since mutton was usually preferred to beef (Rosenberger 1999). Common Moslem households may have consumed meat relatively rarely, eating it mostly on Fridays and other festive occasions.

Cut marks indicative of secondary butchering (i.e., food preparation), were observed on 23 (12% of sheep NISP) sheep bones, while burning was detected only in a single case. Marks of cutting and splitting were observed on 27 (21% of cattle NISP) cattle remains, while only one of these bones was burnt. Although effects of heat observed on bones may not be exclusively attributed to cooking and/or roasting (e.g., bones may be incinerated as a form of garbage disposal), the high proportion of cut marks to the rare incidence of burning may result from defleshing the bones prior to cooking.

In the large contemporaneous assemblage from the Teleki Palace site, a similar proportion of sheep bones showed marks of butchering (13% of sheep NISP), but a smaller ratio of cattle bones offered evidence of cut marks (11% of cattle NISP) (Daróczi-Szabó 2004:163). In traditional Turkish cuisine, meat is often cut into small pieces and grilled, ground to be mixed with rice or other grain in *pilaf* or stuffed into cabbage or grape leaves (plants that were identified in this assemblage). Processing meat to such an extent may have rendered conscious distinction between meat quality categories A and B largely irrelevant. Ottoman-period faunal assemblages from Vác, a city located upstream from Buda on the left bank of the Danube River, also contained high percentages of cattle bones from rather fatty body regions that may have been preferred in preparing beef this way (Bartosiewicz 1995:42).

Lean meat was in demand for curing. The Turkic horsemen of Central Asia traditionally preserved meat by placing slabs of it in their saddle bags, where it would be pressed by their legs as they rode (Çetinkaya 2008), an ancient technique also known to conquering Hungarians in the ninth century (Bartosiewicz 1998:173). This pressed meat is reputed to have been the forerunner of today's *basturma*, a Turkish term that means "being pressed." Evliya Çelebi (1985) praised the spiced beef of Kayseri in Turkey in his Book of Travels. Although *basturma* may also be made with mutton or goat's meat, beef was preferred. The seventeenth-century Hungarian word *pasztormány* (*pastrami* in Italian) for the same type of dried meat suggests that this delicacy became known under Ottoman rule in Hungary (Kakuk 1996:295).

In addition to vegetable oil, sheep suet was also popular in Moslem cooking. Indirect evidence to this is available in a sixteenth-century cookbook written by the Chef of the Mainz Elector, Marx Rumpolt (1581). At the description of *Turkish sheep*, Rumpolt shows a woolly, hornless individual from behind mustering a fat tail (Fig. 9). The last recipe for this animal in his cookbook explains how the tail is breaded to catch the tasty drippings. There was a fascination among western travelers with these large fat tails, sometimes weighing 20–30 pounds and fitted onto tiny carts pulled by the sheep (Raff 1846:339), as shown in a 1682 picture of

Fig. 9 Image of Turkish sheep (Rumpolt 1581)

Arabian sheep (*Ovis orientalis*) from Ethiopia (Zeuner 1963:82). Arabian sheep with a variety of large tail forms were also depicted by Topsell (1607).

5 Summary and Conclusions

The integrated evaluation of historical and archaeological sources, with a special emphasis on paleoethnobotanical and zooarchaeological remains, has offered a complex and colorful picture of Ottoman-period urban environment and diet at a late sixteenth/early seventeenth century household in a suburb of Buda. One of our main conclusions is that data in documents and recovered during the course of excavations can no longer be seen as substitutes for one another. Rather, they are complementary, forming a far more coherent body of information. One of the problems remains the different scales of information. For example, Turkish tax records attest to the large-scale importation of cereal grain from the south along the Danube, at times arguably exceeding the consumption of the military and civilian inhabitants. This suggests that producers in the southern areas and further southeast (in the Balkans) sought to sell their produce not only in the city itself, but sometimes used Buda as a center for further distribution. Naturally, both demand and the accessibility of trade routes varied throughout the hectic 150 years of Ottoman rule in Hungary.

In light of these data, it would be interesting to know to what extent the inhabitants of Buda were involved in growing their own fruits and vegetables or even keeping animals in the suburb. Local vegetation at the site could be fairly accurately appraised on the basis of plant remains from this pit. While the urban status of Renaissance Buda generally declined, during several generations the city went through cycles of crises and relative prosperity. The mid-Ottoman-period wild plant remains from the pit reflect a strong anthropogenic impact on the immediate environment. With these data, we are able to reconstruct a densely populated humid habitat, possibly with a concentration of decaying organic material. This general picture contrasts the relative luxury of the household as shown by the prestigious-looking imported and local pottery. The assemblage included tableware from a decent but not particularly rich household, found along with the remains of cultigens that were available during the Ottoman period in Hungary. Some of these (e.g., figs, pomegranate) are more characteristic of Turkish/Balcanic tastes than others. The varieties of grape seeds and wild fruits are also noteworthy.

The remains of sheep and cattle overwhelmingly dominated the animal bone assemblage from the pit. Both species possess cloven hooves and chew the cud. Their meat, therefore, was fit for consumption by observing Moslems. There seems to be a trend, however, that even the Christian population of Hungary developed a taste for mutton during this time, thus (like the noise described in the case of wine consumption) the religious indicator value of these two species is also prone to bias. However, the near absence of pig bones from the pit is rather telling. Contamination in the form of three pig bones was observed in a fourteenth-century sealed deposit from the first medieval Jewish quarters of Buda (Daróczi-Szabó 2002:254). Even if reduced in quantity, pork was consumed by Hungarians and other non-Moslem inhabitants of the occupied areas during the Ottoman period as is shown by a diachronic sequence of several urban deposits from the city of Vác (Fig. 10).

Without rigidly trying to specify the ethnic or religious affiliation of the people who left behind the organic remains discussed in this chapter, one may state that the finds represent a rather neglected human habitat, in which a Turkish style of life was characteristic after some three generations of Ottoman rule. This influence is apparent both in pottery styles and plant remains. The near lack of pig bones may be considered indicative of Moslem-style meat consumption.

Although the fragments of tableware and homogeneous sediments may be indicative of a singular filling event, plant remains are indicative of a broader, late spring to early fall time of deposition. This picture, however, may be an artifact of taphonomic processes, such as the secondary deposition of certain plant remains. In addition to the remarkable stylistic congruence shown by the best preserved, possibly contemporaneous pottery finds (Fig. 11), the possibility of a single filling

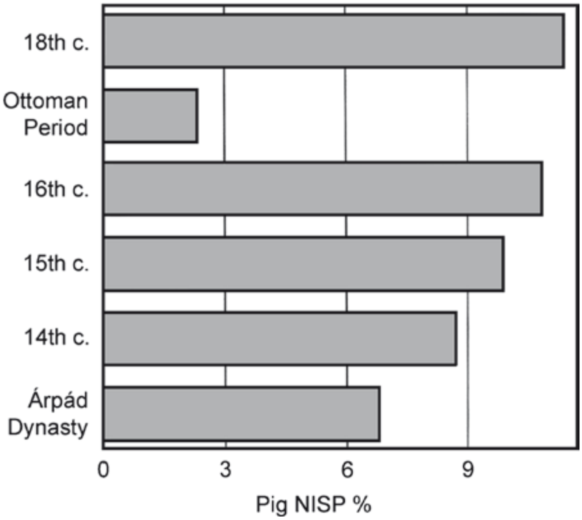

Fig. 10 Bar graph of pig NISP percentages through time in the city of Vác (Bartosiewicz 2003:62, Fig. 31)

Fig. 11 Photo of restored tableware from the pit

is also supported by zoological information. Refuse deposits usually attract small rodents, and thus open pits may act as natural traps. The absence of these small rodents (except for red squirrel, possibly introduced by humans) supports the hypothesis of a rapid, single filling episode. Alternatively, the lack of rodent remains could be attributed to sampling bias. Only a relatively small proportion of the fill was water-sieved, although comparatively abundant bird and fish remains seem to indicate the representative nature of sieved samples from a zooarchaeological point of view.

The Ottoman Empire expanded into Hungary in the early sixteenth century. The nature of the conquest had not only been military but cultural as well and the subsequent 150 years transformed everyday life. Table culture and dining customs underwent radical changes reflecting Ottoman tastes, which in addition to Moslem influence included elements of South-Slavic tradition. The inter disciplinary analysis of an Ottoman Turkish Period pit from an excavation near Buda castle in modern-day Budapest shows these changes on many levels. New vessel types, reflecting different cooking traditions, as well as new vegetables and fruits, offer evidence of new tastes and of transformed food market demands. This foreign cultural influx interacted with local medieval food traditions as part of the long process that has lead to what we know today as Hungarian culinary culture.

Acknowledgements Special thanks are due to the excavator András Végh and Eszter Kovács who helped with the archaeological section of this paper. Ferenc Gyulai offered help with plant identifications. The photographs were taken by Bence Tihanyi of the Budapest History Museum. Research by Erika Gál was supported by a grant from the National Science and Research Fund, Hungary (F 048818 of OTKA).

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The Farmed and the Hunted: Integrating Floral and Faunal Data from Tres Zapotes, Veracruz

Tanya M. Peres, Amber M. VanDerwarker, and Christopher A. Pool

The many case studies in this volume have addressed the integration of plant and animal data in myriad ways. As the final case study, this chapter picks up where the methods chapter on multivariate analysis left off (VanDerwarker, this volume; see also Hollenbach and Walker, this volume), using principal components analysis to consider the covariation of paleoethnobotanical and zooarchaeological data from the Formative Mesoamerican site of Tres Zapotes. Our primary question regarding the Tres Zapotes dataset is: Did different social status groups eat different foods, and if so, what were they eating (in both type and quantity) and why do these differences occur? Addressing this question requires a consideration of both temporal and spatial patterns in the faunal and floral data. These data span the Formative period as defined for southern Veracruz, Mexico (1400 BC–AD 300); we discuss site chronology in more detail below. In addition to time, we aggregate our data based on social context, with reference to the following categories: elite domestic and administrative areas, referred to as elite; ceremonial and/or mortuary deposits, referred to as ceremonial; and nonelite domestic deposits, referred to as domestic. It is these contextual categories on which we base our present analysis and interpretations.

In order to answer questions about the differential use of plants and animals among various social groups and functions, we first independently consider the plant and animal data, and then the integrated dataset. The significance of this particular case study goes beyond the simple task of integrating subsistence data using multivariate analysis; indeed, the results of the principal components analysis allow us to make interpretations about foodways that surpass our understanding based on independent analyses alone. Prior to data presentation and analysis, however, we present background information on the site of Tres Zapotes in order to form

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A.M. VanDerwarker and T.M. Peres (eds.), *Integrating Zooarchaeology and Paleoethnobotany: A Consideration of Issues, Methods, and Cases*,
DOI 10.1007/978-1-4419-0935-0_12,

a framework for interpreting our data at both local and regional scales. Our final discussion contextualizes our patterns within broader pan-Mesoamerican traditions.

1 Tres Zapotes in Regional Context

The Formative period (1400 BC–AD 300) marked the development of political complexity and the adoption of a mixed farming economy along the southern Mexican Gulf Coast. Large civic-ceremonial centers were established at San Lorenzo, La Venta, and Tres Zapotes during the Early, Middle, and Late Formative periods, respectively (see VanDerwarker, Figure 1, this volume for regional map). These large political centers served as seats of power for regional elites who oversaw large labor projects like extensive earthen and stone monument construction.

The Gulf lowland Olmec flourished during the Early and Middle Formative periods (1400–1000 BC and 1000–400 BC) at the sites of San Lorenzo and La Venta, respectively. Both sites witnessed extensive mound-building and monument construction, the most well-known being the colossal heads carved from basalt originating from the neighboring Tuxtla mountain region. The transition to the Late Formative period (400 BC–AD 100) has been characterized as the collapse of Olmec society (Bernal 1969; Diehl 1989; Diehl and Coe 1995), and it was during this time that Tres Zapotes was established as a regional center. Despite sharing some similarities with San Lorenzo and La Venta, the site of Tres Zapotes possesses some marked differences, leading to its classification as an epi-Olmec center.

Tres Zapotes is located on the western edge of the Sierra de los Tuxtlas, a volcanic mountain range that was active throughout the Formative period. The site is approximately 20 km west of the site of La Joya, discussed by VanDerwarker (this volume). Tres Zapotes is the largest known epi-Olmec center in the Olmec heartland. The archaeological record at Tres Zapotes documents occupations of considerable temporal depth, ca. 2000 years, which include the Olmec, Epi-Olmec, and Classic periods (Pool 2000). The site is home to more than 160 mounds, with civic-ceremonial construction concentrated in four mound-and-plaza groups (Fig. 1; Pool and Ohnersorgen 2003). While Tres Zapotes contained an Early Formative occupation, the first substantial settlement dates to the Middle Formative period (Pool and Ohnersorgen 2003). The colossal heads, Olmec-style stelae, and other Olmec-style monuments are also probably a Middle Formative manifestation. The first evidence for monumental mound construction, however, dates to the subsequent Late Formative period, and the majority of stone monuments date to this period as well (Pool and Ohnersorgen 2003). Most of the subsistence remains from Tres Zapotes also date to the Late and Terminal Formative (AD 100–300) periods.

Pool (2003b, 2008) interprets the Late/Terminal Formative political organization of Tres Zapotes as a confederation of factions headed by elites residing in the four mound-and-plaza groups. Such organization implies a weaker centralization of political authority and a more "horizontally integrated society" than is attrib-

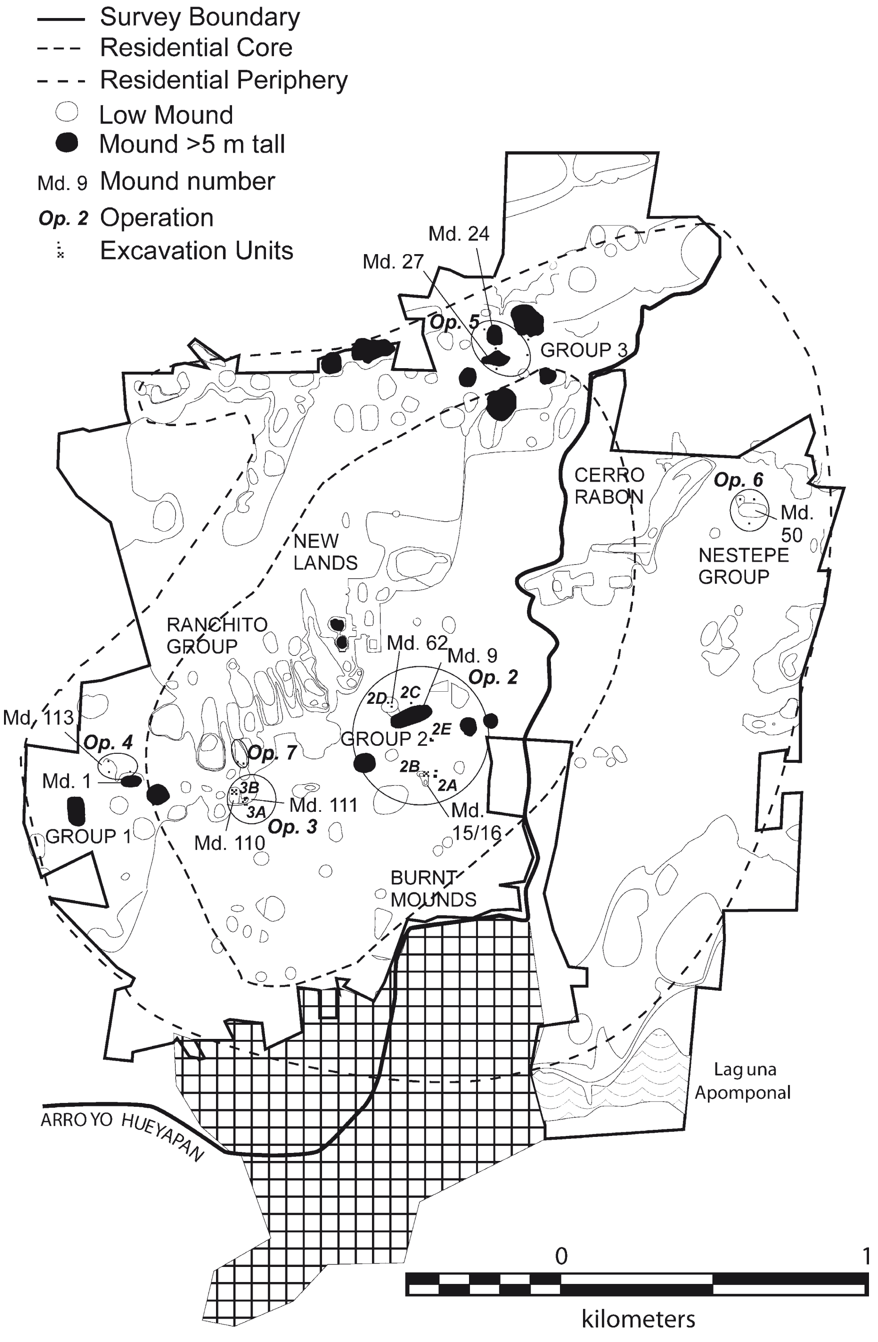

Fig. 1 Map of mound groups at the site of Tres Zapotes

uted to San Lorenzo (Pool 2003b:95). If the political organization of Tres Zapotes represents a situation in which elites were competing for followers, we might expect fewer elite/nonelite distinctions than we would at San Lorenzo, where these distinctions might be seen emerging. Indeed, this is the case with craft production at Tres Zapotes, where most production activities appear to have taken place in a wide range of household contexts, regardless of elite/nonelite status (Pool 2003b).

Geographically, the site of Tres Zapotes is located on a broad coastal plain in the Arroyo Hueyapan Valley at the edge of the foothills of the Sierra de los Tuxtlas, adjacent to a stream named for the valley (Pool 2003a). Known for its highly fertile soils, the Arroyo Hueyapan valley is currently an area of productive farmland for both maize (*Zea mays*) and sugarcane (*Saccharum* spp.) (Pool 2003a). Indeed, the site of Tres Zapotes is situated within a particularly fertile agricultural pocket of the valley. While the stream adjacent to the site would not have provided the diversity of aquatic remains that the Coatzocoalos River would have to the inhabitants of San Lorenzo, people living at Tres Zapotes could have made short trips to the Papaloapan River basin to the west of the site; the abundant swamps, lakes, and rivers from this water system could have easily provided a diversity of aquatic resources (Pool 2003a).

Excavations at Tres Zapotes were funded by a grant from the National Science Foundation (BCS-0242555) and led by Pool in the spring and summer of 2003, followed by a season of laboratory analysis in the summer of 2004. Excavation and analysis targeted different mound groups and elite residential areas identified from Pool's intensive site survey conducted in the 1990s. In addition to sampling elite and nonelite residential contexts, excavations also uncovered mortuary and ceremonial contexts. The analyses of plant and animal data presented here focus on these different social-spatial contexts at the site.

2 The Paleoethnobotanical Assemblage

The floral assemblage considered here is represented by macroremains from flotation samples and was analyzed by VanDerwarker. With the exception of soil collected from mortuary contexts, flotation samples were collected as 6.25 or 9-liter column samples from features and from each 10-cm level of the southwest corner of each 2×2 m unit. All samples from Tres Zapotes were floated using a modified SMAP flotation machine at the archaeological museum in the modern town of Tres Zapotes (see Watson 1976). For the present analysis, 117 samples were analyzed, including both heavy and light fractions. Of the 117 floral samples analyzed, 93 yielded carbonized plant remains. From these 93 samples, 10 were assigned to ceremonial contexts, 27 to nonelite domestic contexts, 54 to elite contexts, and 2 were from undefined contexts.

According to standard practice, samples were weighed and then sifted through 2.0, 1.4, and 0.7 mm geological sieves. Carbonized plant remains were sorted in their entirety down to the 0.7 mm sieve size with the aid of a stereoscopic microscope (10–40 X) in order to maintain comparability with other regional plant analyses (VanDerwarker 2006; see also VanDerwarker, this volume). While most paleoethnobotanical analyses only scan for small seeds beyond the 2.0 or 1.4 mm sieve sizes, most of the maize kernel and cupule fragments present in samples from this region are smaller than 1.4 mm. Thus, the identification of plant taxa from Tres Zapotes and surrounding sites demands a greater level of resolution. Residue less than 0.7 mm in size was scanned for seeds, which were removed and counted. Identifications were made with reference to modern comparative specimens and modern botanical guides (Manriquez and Colin 1987; Soriano et al. 1997). Data collected include counts, weights (in grams), and the portion of plant represented (e.g., maize kernel vs. cupule).

The present analysis of the carbonized plants identified at Tres Zapotes focuses on a comparison of samples from different time periods and different social-spatial contexts. Time periods under consideration include Middle Formative (MF), Late Formative (LF), Late/Terminal Formative (LF/TF), Terminal Formative (TF), Early Classic (EC), general Classic, and Historic; social-spatial contexts include elite, nonelite, and ceremonial/mortuary. Table 1 summarizes the distribution of flotation samples across these different contexts; only samples that yielded carbonized plant remains are included ($n = 93$).

Nearly 65% of samples yielding plant remains date to the Late and/or Terminal Formative periods, with most of these dating primarily to the Late Formative period (50%). The low number of samples from other time periods complicates a comparative temporal analysis at the site. In addition to the overrepresentation of Late Formative samples, samples from elite contexts are also overrepresented in comparison to those from nonelite and ceremonial/mortuary contexts; of the total samples yielding plant remains, 58% come from elite areas. Because samples were chosen randomly for analysis (via computer randomizer function in MSExcel by Dr. Christopher Pool), it is likely that the representation of samples from time and space reflects the larger sampling strategy of the excavations. Thus, the bias toward the Late Formative elite contexts probably suggests that these are the most prevalent contexts excavated at the site.

Maize and beans (*Phaseolus* sp.) were both identified in the Tres Zapotes samples (Table 2); maize kernels and cupules were identified in greater quantities than beans. Tree resources also appear to have contributed to the diet at Tres Zapotes (see Table 2). Seed fragments from possible sapote (*Pouteria sapote* cf.), coyol (*Acrocomia mexicana*), possible coyol (*Acrocomia mexicana* cf.), and possible coyol real (*Scheelea liebmannii* cf.) were all identified at the site. In addition to the edible fresh fruit (which is generally eaten by hand), the seed from the sapote fruit has a variety of uses, all of which entail grinding into a powder which is then used as an additive for foods, medicines, soaps/cosmetics, or to fix colors on painted gourds (Morton 1987:401). Use of the coyol palm has been documented for groups throughout Mexico and Central America (Lentz 1990). Coyol fruits are high in fat, protein, and caloric value (Lentz 1990:189); they can be used for a variety of purposes, including food, medicine, and wine production (Balick 1990; Greller 2000;

Table 1 Summary of samples with carbonized plant remains by social-spatial and temporal contexts

	MF	LF	LF/TF	TF	EC	Classic	Historic	Unknown	TOTAL	Percent
Elite		39	8		3	4			54	58.1%
Nonelite	6	6		5		1	1	7	26	28.0%
Ceremonial/ mortuary	6	2						3	11	11.8%
Unknown							1	1	2	2.2%
Total	12	47	8	5	3	5	2	11	93	
Percent	12.9%	50.5%	8.6%	5.4%	3.2%	5.4%	2.2%	11.8%		

Note: *MF* Middle Formative, *LF* Late Formative, *LF/TF* Late/Terminal Formative, *TF* Terminal Formative, *EC* Early Classic

Table 2 Inventory of plants identified at Tres Zapotes

No. of flotation samples		117	
Total plant weight (g)		12.25	
Total wood weight (g)		10.09	
Common name	Taxonomic name	Count	Weight (g)
Cultigens			
Bean	*Phaseolus* sp.	1	0.00
Bean cf.	*Phaseolus* sp. cf.	7	0.04
Maize cupule	*Zea mays*	32	a
Maize kernel	*Zea mays*	161	1.39
Maize kernel cf.	*Zea mays* cf.	6	0.01
Fruits			
Coyol	*Acrocomia mexicana*	25	0.25
Coyol cf.	*Acrocomia mexicana* cf.	6	0.01
Coyol real cf.	*Scheelea liebmanii*	3	0.01
Sapote cf.	*Pouteria sapote* cf.	2	0.00
Coyol/sapote	*Acrocomia/Pouteria*	2	0.00
Unidentified		69	0.29
Unidentified Seed		34	a
Total		348	2.00

[a] indicates negligible weight

cf. (compares favorably with) indicates a likely but uncertain identification

Henderson et al. 1995; Lentz 1990; Quero 1992). The coyol real produces fruits that are hard and fibrous, yielding one to three oily seeds (Mason and Mason 1987:268). Like the coyol, the coyol real is a valuable source of vegetable oil (Mason and Mason 1987:268), and its palm fronds can be used for thatching.

Ubiquity analysis mirrors the relative abundance of plants listed in the taxonomic summary in Table 2 (Table 3). Not surprisingly, wood is the most ubiquitous carbonized plant identified at the site (present in 57% of flotation samples), followed closely by maize at 50% (with maize kernels present in more samples than cupules). Coyol is the most ubiquitous tree fruit at 10%; all other resources were identified in less than 4% of samples.

Given the prevalence of maize and fruits in the Tres Zapotes plant assemblage, we focus the rest of the data analysis around these resources. We first consider the distribution of maize and maize parts (kernels and cupules). Because ratios are calculated for individual samples and the study assemblages are composed of numerous samples, we summarize the data using box plots (see also McGill et al. 1978; Scarry and Steponaitis 1997; Wilkinson et al. 1992). Box plots summarize distributions of data using several key features. The area of maximum constriction at the center of the box marks the median or center value of the distribution. The edges of the box, or hinges, represent the 25th and 75th percentiles of the distribution – the approximate middle 50% of the data fall between the hinges (Cleveland 1994:139). Vertical lines, or whiskers, extend outward from the box and represent the tails of the distribution. Outliers are depicted as asterisks, and far outliers as open circles.

Data are aggregated for the entire assemblage in a single box plot for the purposes of identifying samples that represent significant outliers. Maize counts are standardized to plant weight for each sample in which they appear; standardized counts for these samples represent the data points in the box plot. The box plot present in Fig. 2 has one outlier (FS# 9404), and two far outliers (FS# 9313 and 17497); these samples yielded significantly higher standardized maize counts than other samples that include maize remains. FS# 9404 and 9313 both derive from nonelite domestic contexts at the edge of Mound 111 from levels 11 and 8, respectively. FS# 9404 dates to the Middle Formative period and FS# 9313 probably dates to the Late Formative period. The greatest outlier, FS# 17497, comes from a Late Formative elite residential/administrative context in Group 3, north of Mound 28. It is interesting that all three outliers are samples that come directly from, or nearby, mound contexts.

We consider maize more closely through a consideration of the distribution of maize kernels and cupules. Maize kernels represent the consumable portion of the plant, whereas maize cupules are byproducts of shelling maize ears. Table 4 lists the distribution of kernels and cupules according to spatial and temporal contexts, in addition to calculating a maize kernel-to-cupule ratio. Since maize cupules represent

Table 3 Ubiquity values of plant taxa in descending order

	Samples present	Total samples	Ubiquity value
Wood	67	117	57.3%
Maize (all parts)	59	117	50.4%
Maize kernels	47	117	40.2%
Maize cupules	17	117	14.5%
Coyol	12	117	10.3%
Bean cf.	4	117	3.4%
Coyol cf.	4	117	3.4%
Bean	1	117	0.9%
Coyol real cf.	1	117	0.9%
Sapote cf.	1	117	0.9%

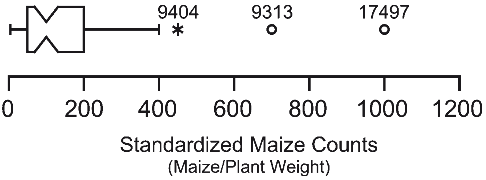

Fig. 2 Box plot of standardized maize counts, with outliers labeled

Table 4 Summary of maize kernels and cupules by social-spatial and temporal contexts (samples with uncertain contexts excluded)

	Maize kernel	Maize cupule	Kernel/(Cupule + 1)
Social context[a]			
Elite	88	26	3.3
Nonelite	36	4	7.2
Ceremonial/mortuary	31	2	10.3
Temporal context			
Middle Formative	17	0	17.0
Late Formative	49	26	1.8
Late/Terminal Formative	7	3	1.8
Terminal Formative	9	0	9.0
Classic	37	2	12.3

[a] Chi-square statistic = 5.492, *df* = 1, *p* = 0.019

processing discard, we can assume that contexts with more cupules probably indicate areas of more intensive processing. Thus, relatively lower kernel-to-cupule ratios indicate higher levels of processing and/or maize intensification (see VanDerwarker 2006 for detailed explanation).

In terms of social contexts (elite, nonelite domestic, ceremonial/mortuary), the aggregate sample from elite contexts yielded the lowest maize ratio, and the aggregate sample from ceremonial/mortuary contexts yielded the highest, with nonelite contexts falling between these two extremes. A chi-square test confirms that these differences are statistically significant ($p = 0.019$). These ratios suggest that very little maize processing occurred within ceremonial and/or mortuary areas, which is not all that surprising. It is surprising, however, that there is more evidence of maize processing in elite areas than nonelite areas. It is hard to interpret why this might be the case; this pattern may simply be a product of sample size bias toward elite context (see Table 4). If the pattern is not a result of sample bias, then it may indicate that elites had privileged access to infields, whereas nonelites had to use land located at a distance to the site (outfields). Because outfields are located at a distance from the residential areas, we can expect that most maize processing would have occurred there (see Killion 1990), resulting in less evidence of processing at Tres Zapotes proper.

In terms of time, samples from Late and Terminal Formative contexts yield the lowest maize kernel-to-cupule ratios, suggesting that these periods witnessed an intensification of maize processing, and perhaps maize production as well. This pattern fits well with the timing of maize intensification identified at other sites in the Sierra de los Tuxtlas (VanDerwarker, this volume; see also VanDerwarker 2006).

It is worthwhile to briefly consider the distribution of bean remains. Very few bean specimens were encountered (Table 5) at the site, only one of which could be definitively identified as *Phaseolus* sp.; the other seven specimens were classified as

Table 5 Inventory of *Phaseolus* beans identified in the Tres Zapotes flotation samples

Operation	Bag #	Context	Chronological info	Common name	Count
2D	5405	Elite	Late Formative	Bean cf.	1
2D	5665	Elite	Late Formative	Bean	1
2B	1026	Elite	Classic	Bean cf.	4
2B	1249	Elite	Late/Terminal Formative	Bean cf.	1
2B	1542	Elite	Late/Terminal Formative	Bean cf.	1

probable beans. It is interesting that all of these specimens come from elite contexts. It is difficult to know if their restriction to elite contexts was meaningful in the past. It is rare that beans are identified in great quantities in archaeological samples; as consumable portions, they do not have many opportunities for carbonization and thus do not often appear in the record. The analysis of additional samples from nonelite contexts may result in the identification of beans (or possible beans). Until then, however, we can only speculate about whether beans were an elite food item.

As with the maize data, we consider the distribution of samples with carbonized fruit remains using a box plot. Fruit counts are standardized to plant weight for each sample in which they appear; standardized counts for these samples represent the data points in the box plot. The plot in Fig. 3 reveals three far outliers (FS# 21047, 9287, and 9313); all three samples yielded significantly more fruit remains than other samples with fruits. FS# 9287 dates to the Middle/Late Formative and FS# 9313 and 21047 probably date to the Late Formative period. All three samples come from nonelite domestic contexts.

We also consider standardized counts of fruits aggregated by social and temporal contexts (Table 6). While sample sizes may be relatively small, there still appears to be a clear pattern in terms of the distribution of fruits across social space. Nonelite contexts yielded more fruits relative to other carbonized plants than elite or ceremonial/mortuary areas. Standardized counts of fruits from elite and ceremonial/mortuary areas are relatively comparable to each other. Standardized counts of fruits summed by temporal period are less informative. There are more categories for time than for social context, which break the data into smaller units. Thus, any differences through time with reference to standardized fruit counts are probably related to sample size.

The final measure that we calculate with respect to the plant data is a maize-to-fruit ratio; this is an independent ratio that divides maize counts by fruit counts according to social and temporal contexts (Table 7). This ratio allows us to assess the relative contribution of maize relative to fruits across space and through time at Tres Zapotes. Maize-to-fruit ratios are comparable for both elite and ceremonial/mortuary contexts; this ratio, however, is much lower in nonelite contexts, which indicates that the nonelite supplemented more heavily with fruits than their elite counterparts (a chi-square statistic, however, reveals that this pattern is not statistically

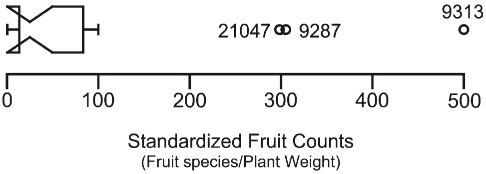

Fig. 3 Box plot of standardized fruit counts (coyol, sapote, coyol real), with outliers labeled

Table 6 Summary of tree fruits by social-spatial and temporal context (samples with uncertain contexts excluded)

	Count	Plant wt (g)	Standardized count (count/plant wt)
Social context			
Elite	16	0.95	16.8
Nonelite domestic	15	0.16	93.8
Ceremonial/mortuary	4	0.29	13.8
Temporal context			
Middle/Late Formative	3	0.01	300.0
Late Formative	13	0.59	22.0
Late/Terminal Formative	3	0.25	12.0
Terminal Formative	1	0.01	100.0
Classic	3	0.16	18.8
Historic	4	7.49	0.5

Table 7 Independent ratios of maize/tree fruits by social-spatial and temporal context (samples with uncertain contexts excluded)

	Maize	Fruits	Maize/fruit ratio
Social context			
Elite	114	16	7.1
Nonelite domestic	40	15	2.7
Ceremonial/mortuary	33	4	8.3
Temporal context[a]			
Middle Formative	17	3	5.7
Late Formative	75	13	5.8
Late/Terminal Formative	10	3	3.3
Terminal Formative	9	1	9.0
Classic	39	3	13.0

[a] Chi-square statistic = 4.773, *df* = 1, $p = 0.029$

significant). This pattern corresponds to the pattern in Table 6, in which nonelite contexts yielded significantly higher standardized fruit counts. This pattern is suggestive of a healthier, more varied diet among nonelites than elites.

In terms of changes in the ratio of maize-to-fruit through time, an interesting pattern emerges. Ratios are comparable for the Middle and Late Formative periods, but increase during the subsequent Terminal Formative and Classic periods. This increase in the relative amount of maize to fruit may be an indicator of intensification of maize production. A chi-square test reveals this pattern to be statistically significant ($p=0.029$). As mentioned above, such an intensification of maize during the Terminal Formative period corresponds to similar patterns identified at other sites in the broader region (VanDerwarker 2006; see also VanDerwarker, this volume).

One final caution regarding the maize-to-fruit ratios is that the social and temporal patterns may be linked. Most of the nonelite samples come from Middle and Late Formative contexts, which might account for the shared low maize-to-fruit ratios. This potential confounder highlights the importance of analyzing additional samples from Terminal Formative nonelite contexts, which is currently underway.

In sum, both maize and tree fruits appear to have been important plant resources in the diet of the residents of Tres Zapotes. While small sample sizes complicate the conclusions we can make about the plant-based diet, there are some spatial and temporal trends that were identified in the quantitative analysis that bear repeating here. First, there are several indications that elite and nonelite plant-based diets may have differed in the kinds and relative amounts of plant foods: (a) beans appear to be restricted to elite contexts; (b) fruits (coyol, coyol real, and sapote) appear in greater amounts in nonelite contexts; and (c) there is evidence of a higher degree of maize processing in elite contexts than nonelite contexts. This latter pattern may be confounded by time, as most of the elite contexts date to the Late and Terminal Formative periods; increases in maize processing have also been identified at other sites in the region (La Joya and Bezuapan) during these time periods (see VanDerwarker 2006). An additional point of interest is the relative comparability between elite and ceremonial/mortuary contexts in terms of maize-to-fruit ratios and standardized fruit counts.

Secondly, there are two major indicators that maize production intensified during the Late and Terminal Formative periods: (a) contexts from these time periods yielded the lowest kernel-to-cupule ratios, which suggest a higher level of maize processing, and by extension, maize production; and (b) maize-to-fruit ratios peak during the Terminal Formative and Classic periods, suggesting an increase in maize consumption relative to fruit consumption, which may translate to increased maize production at this time.

3 The Zooarchaeological Assemblage

Faunal remains were recovered with both 1/4 in. screening and from the heavy fraction component of flotation samples. Several studies (Gordon 1993; Peres 2001; Shaffer 1992; Wing and Quitmyer 1985) have shown that soils screened with larger mesh sizes (1/2 in. or 1/4 in.) are biased toward large animals (i.e., mammals), and give a skewed picture of the relative abundance and importance of one class of animals compared to another (for a more thorough discussion, see Peres, this volume). The use of smaller (i.e., 1/8, 1/16, and 1/32-in.) meshes allows for a more complete recovery of delicate animal remains. Due to the use of 1/4-in. screens, flotation, and piece-plotted specimens, the faunal assemblage from Tres Zapotes represents a fairly complete sample of the range of animals that were deposited at the site.

The analysis of the faunal assemblage was performed by Peres using the Zooarchaeology Comparative Collection housed at the University of Kentucky's William S. Webb Museum of Anthropology, and the Zooarchaeology Comparative Collection housed in the Environmental Archaeology Laboratory at the Florida Museum of Natural History. Standard zooarchaeological procedures were used during this analysis as set forth by Reitz and Wing (2008) and described by Peres (this volume). All remains were initially rough sorted into broad taxonomic categories, and identified to *Genus* and *species* when possible. Identified elements were sided where appropriate. Any evidence of use-wear, thermal alteration, or butchering was recorded. Weights and Number of Identified Specimens (NISP) were recorded for all specimens.

Biomass estimates were calculated for this assemblage using the archaeological specimen weights and the regression formula described in Peres (this volume). Sample biomass refers to the estimated total weight represented by the archaeological specimen (Reitz and Wing 2008). Calculating the biomass of an animal requires data on the correlations between skeletal weight and total body weight (Casteel 1974; Reitz et al. 1987; Reitz and Wing 2008). These data are collected on modern specimens for application to biomass estimates. In many cases, biomass estimates were calculated using values at the family or class level, based on published values in Reitz and Wing (2008:68) and Wing (2001). These data are valid and important for dietary interpretations.

The Minimum Number of Individuals (MNI) estimates were determined using the standard accepted procedure: the most abundant diagnostic element of each taxon was counted as the MNI (Grayson 1984; Reitz and Wing 2008). If this element was a paired element (i.e., left and right), then the higher count of the two was used; size differences were also taken into account when appropriate. MNI was determined for each taxon within each field specimen lot, and then recalculated by provenience (i.e., feature).

As with the paleoethnobotanical analysis, the analysis of the animal remains identified at Tres Zapotes focuses on a comparison of samples from different time periods and different social-spatial contexts. Specific time periods represented in the zooarchaeological sample include: Early Formative (EF), Middle Formative (MF), Late Middle Formative (LMF), Middle/Late Formative (MLF), Late Formative (LF), Terminal Formative (TF), Terminal Formative/Early Classic (TF/EC), and Early Classic (EC). The small sample sizes from different time periods (i.e., Early Formative, distinctly Terminal Formative, distinctly Early Classic) make comparisons with them difficult, and thus we collapse time periods where appropriate, and focus on the Middle and Terminal Formative occupations. The Middle Formative period, as discussed here, includes those contexts assigned to the Middle and Late Middle Formative periods; the Terminal Formative period includes those contexts assigned to the Late and Terminal Formative periods. Social-spatial contexts are the same as those used for the plant analysis. Of the 1,063 samples that have specific contextual data, 87 derive from ceremonial contexts, 321 from elite contexts, and 655 from nonelite domestic contexts (Table 8).

The faunal remains were recovered from features, piece plots, and flotation samples, and all were analyzed as part of this project. These samples yielded a total of 8,448 specimens, weighing 4,750.52 g (Table 9). Approximately 6% of the sample was identifiable to family, genus, or species. A variety of animal remains were recovered, primarily extant species that are native to the area under study. These remains are undoubtedly affiliated with pre-Columbian deposits, and reflect the pre-Columbian animal taxa that were used by the inhabitants of Tres Zapotes, primarily for subsistence. Several historic contexts were analyzed ($n = 9$), resulting in a small historic subassemblage (NISP = 104), but are not included in the present discussion.

The assemblage is composed of 21 taxa representing all classes of vertebrates except amphibians. Those identified taxa that favor aquatic habitats include: turtles (Testudines), fish (Osteichthyes and Chondrichthyes), shark (*Carcharhinus* spp.), and manatee (*Trichecus manatus*). Those animals that are classified as terrestrial include: white-tailed deer (*Odocoileus virginianus*), peccary (*Peccary* spp.), giant pocket gopher (*Heterogeomys hispidus*), domestic dog (*Canis familiaris*), and snakes (Serpentes). Using the aquatic/terrestrial environment dichotomy, aquatic animals comprise 92% of the NISP (70% of the total assemblage biomass), while terrestrial animals comprise 8% of the NISP (30% of the total assemblage biomass). It appears that the overall subsistence strategies practiced at Tres Zapotes centered on fishing, trapping, and gathering aquatic resources.

The Middle Formative comprises 45% (NISP) of the subassemblage. Within the Middle Formative sample, aquatic animals, including turtles, pond and mud/musk turtles (Emydidae and Kinosternidae), the giant Mexican musk turtle (*Staurotypus triporcatus*) (called galapagos by modern residents of San Lorenzo [Wing 1980b]), bony fish, catfish (Ictaluridae), snook (*Centropomus unidecimalis*), and cartilaginous fish, comprise the majority of the represented taxa in every data category (Table 10). In terms of biomass, the giant Mexican musk turtle comprises the majority of the assemblage (41%, 1.45 kg) (Fig. 4). The data suggest that aquatic animals were eaten more often than terrestrial ones in the Middle Formative period at Tres Zapotes.

The Terminal Formative context contains the majority of the faunal remains (55% NISP). Within the Terminal Formative sample, aquatic animals, including manatee, pond and mud/musk turtles, the giant Mexican musk turtle, eastern box turtle (*Terrapene carolina*), catfish (Ictaluridae and Ariidae), and snook, comprise the majority of the weight (58% vs. 39% terrestrial) and MNI estimates (67% vs. 33% terrestrial). Terrestrial animals (all other taxa listed in Table 11, except Vertebrata) comprise the majority of the NISP (41% vs. 37% aquatic) and biomass

Table 8 Summary of samples with animal remains by spatial and temporal contexts

	EF	EF/MF	MF	MF/LF	LF	TF	TF/EC	EC	Classic	Historic	Unknown	Total	Percent
Elite	1		151		167	2						321	20.5%
Nonelite domestic	9	10	342	67	9	214			1	3		655	41.8%
Ceremonial/ mortuary	3		7		57	5	14	1				87	5.6%
Unknown			2	18	7					6	471	504	32.2%
Total	13	10	502	85	240	221	14	1	1	9	471	1567	
Percent	0.8%	0.6%	32.0%	5.4%	15.3%	14.1%	0.9%	0.1%	0.1%	0.6%	30.1%		

Note: *EF* Early Formative, *EF/MF* Early/Middle Formative, *MF* Middle Formative, *MF/LF* Middle/Late Formative, *LF* Late Formative, *TF* Terminal Formative, *TF/EC* Terminal Formative/Early Classic, *EC* Early Classic

Table 9 Inventory of animals identified at Tres Zapotes

Common name	Taxonomic name	Count	Weight (g)
Terrestrial			
Vertebrates	Vertebrata	3730	309.39
Mammal or turtle	Mammalia or Testudines	6	2.27
Mammals	Mammalia	1236	353.49
Large mammals		282	504.22
Medium to large mammals		347	266.39
Medium mammals		47	47.44
Small to medium mammals		38	10.6
Small mammals		3	0.32
Carnivores	Carnivora	80	49.22
Domestic dog	*Canis familiaris*	37	52.71
Even-toed ungulates	Artiodactyla	2	2.63
Peccary	*Peccary* spp.	1	1.54
cf. Peccary	cf. *Peccary tajacu*	1	0.24
Deer, elk, wapiti	Cervidae	7	8.07
White-tailed deer	*Odocoileus virginianus*	66	196.87
Rodents	Rodentia	16	1.85
cf. Pocket gopher	cf. *Heterogeomys hispidus*	1	0.29
cf. Agouti	cf. *Dasyprocta punctata*	1	5.58
Primate	Primata	1	0.05
Human	*Homo sapiens*	1	1.4
Birds	Aves	33	17.9
Small to medium birds		3	0.43
Reptiles	Reptilia	1	0.16
Snakes	Serpentes	2	0.63
Aquatic			
Manatee	*Trichecus manatus*	4	55.09
cf. Manatee	cf. *Trichecus manatus*	22	23.22
Turtles	Testudines	1892	1908.37
Snapping turtles	Chelydridae	1	1.21
Mud and musk turtles	Kinosternidae	104	39.01
Giant Mexican musk turtle	*Staurotypus triporcatus*	163	639.5
cf. Giant Mexican musk turtle	cf. *Staurotypus triporcatus*	2	28.69
Water and box turtles	Emydidae	39	81.29
Eastern box turtle	*Terrapene carolina*	4	9.84
cf. Eastern box turtle	cf. *Terrapene carolina*	1	0.47
Bony fish	Osteichthyes	219	82.76

(continued)

Table 9 (continued)

Common name	Taxonomic name	Count	Weight (g)
Marine catfish	Ariidae	9	0.8
Catfish	Ictaluridae	11	4.77
Mullet	*Mugil* sp.	1	0.04
Snook	*Centropomus* sp.	29	36.64
Jack crevalle	*Caranx hippos*	2	3.8
Snapper	*Lutjanus* sp.	1	0.02
Flat-nosed and long-whiskered catfish	Pimelodidae	1	1.15
Sharks, rays, skates	Chondrichthyes	1	0.16
Total		8448	4750.52

cf. (compares favorably with) indicates a likely but uncertain identification

Table 10 Taxa Identified from Middle Formative contexts at Tres Zapotes

	Count	Weight (g)	Biomass	MNI
Vertebrates, indeterminate	928	119.55	0.00	0
Mammals, indeterminate	576	405.06	5.84	0
Rodents, indeterminate	12	1.17	0.01	1
Pocket gopher	1	0.29	0.01	1
Carnivores	3	2.36	0.06	0
Domestic dog	11	11.76	0.24	1
Artiodactyls	1	2.11	0.05	0
White-tailed deer	12	76.48	1.3	2
Birds, indeterminate	14	3.94	0.07	1
Turtles, indeterminate	713	760.68	2.69	0
Water and box turtles	2	11.38	0.16	1
Mud and musk turtles	68	25.48	0.28	0
Giant Mexican musk turtle	115	302.85	1.45	2
Snakes	1	0.02	0.09	1
Bony fish	90	37.64	0.56	0
Catfish	4	1.07	0.03	1
Snook	16	15.24	0.27	2
Sharks, rays, and skates	1	0.16	0.03	1
Total	2568	1777.24	13.14	14

(51% vs. 44% aquatic) (Fig. 5). These numbers show that both aquatic and terrestrial animals were important categories of food for the inhabitants of Tres Zapotes. While the overall specimen weight of the aquatic animals is greater, the terrestrial animals are represented by larger animals (i.e., deer and dog vs. fish and turtles), which can account for the higher biomass estimates; however, the MNI estimates suggest that aquatic animals were exploited more often. The abundance of these animals in the local environment, ease of access and capture, translated into them being eaten on a regular basis.

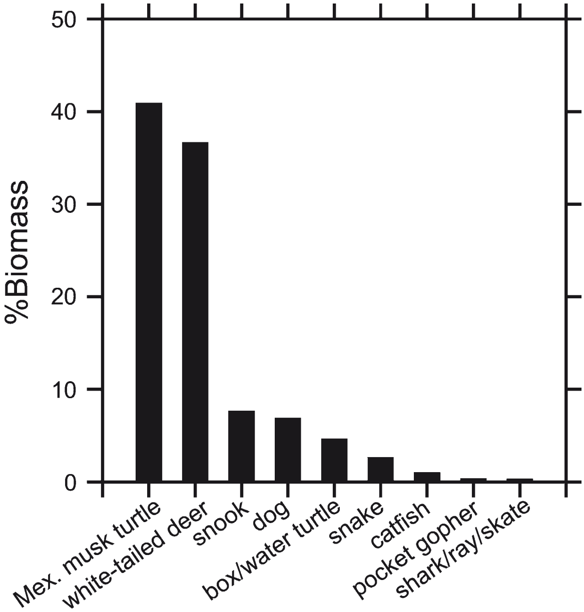

Fig. 4 Bar chart of biomass values for Middle Formative animal taxa

Table 11 Taxa identified from Terminal Formative contexts at Tres Zapotes

	Count	Weight (g)	Biomass (kg)	MNI
Vertebrates, indeterminate	1588	95.6	0.00	0
Mammals, indeterminate	725	312.2	4.62	0
Carnivores, indeterminate	18	15.87	0.32	0
Domestic dog	24	29.2	0.55	1
Deer family, indeterminate	7	8.07	0.17	0
White-tailed deer	49	72.46	1.24	1
Manatee	4	55.09	0.97	1
Nonhuman primate	1	0.05	0	1
Birds, indeterminate	3	0.49	0.01	1
Bony fish, indeterminate	50	17.32	0.3	0
Marine catfish	3	0.49	0.02	1
Freshwater catfish	4	0.47	0.02	1
Snook	4	4.24	0.10	1
Snapper	1	0.02	0.00	1
Turtles, indeterminate	617	445.85	1.88	0
Mud and musk turtles	11	4.36	0.08	0
Giant Mexican musk turtle	16	35.51	0.35	1
Box and water turtles	32	48.11	0.42	0
Eastern box turtle	2	4.95	0.09	1
Snakes, indeterminate	1	0.61	0.09	1
Total	3160	1150.96	11.23	12

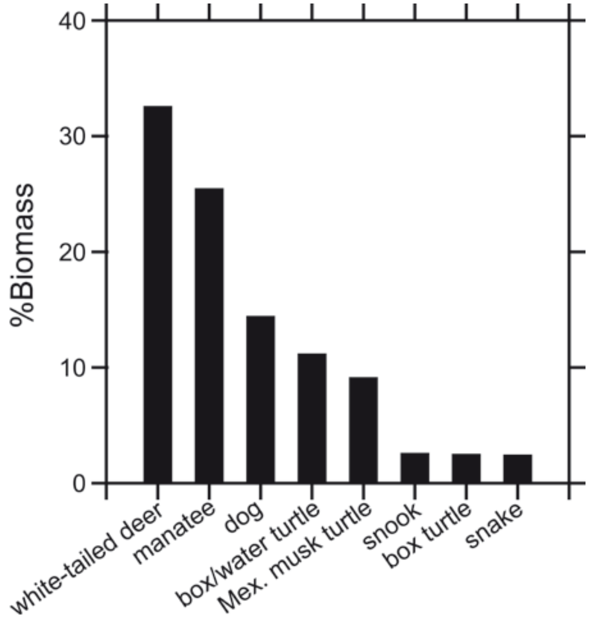

Fig. 5 Bar chart of biomass values for Terminal Formative animal taxa

There appears to be an increase from the Middle to Terminal Formative in the importance of terrestrial animals in the diet at Tres Zapotes. Notable is the increase in reliance on deer as a protein source during the Terminal Formative. While aquatic animals, especially turtles, are important throughout the occupation of the site, they are less so during the Terminal Formative. Additionally, dogs increase in importance in the diet from the Middle Formative through the Terminal Formative. There is a marked decrease in the importance of the giant Mexican musk turtle during the Terminal Formative.

We compare the animal remains from all time periods according to social-spatial contexts discussed above. The combined ceremonial contexts contain a total of 751 specimens weighing 203.9 g. Of the 486 identified to specific taxon, 72% are aquatic and 28% are terrestrial. The combined elite contexts yielded a total of 2,447 specimens weighing 968.92 g. Of the 1,147 identified to specific taxon, 38% are aquatic and 62% are terrestrial. The nonelite domestic contexts yielded a total of 2,719 specimens weighing 1,874.63 g; 1,789 of these specimens were identifiable. Aquatic animals comprise 62% and terrestrial 38% of the identifiable taxa from the nonelite domestic contexts.

The faunal data suggest that deer and dog were being consumed and/or used in greater quantities in elite contexts than in domestic and ceremonial contexts. Domestic contexts, however, yielded the largest quantities of fish and turtle relative to elite and ceremonial contexts. Ceremonial contexts yielded deer, fish, and turtle remains in relatively small quantities. The small sample size recovered from the ceremonial contexts is not surprising given their non-domestic nature.

Ethnographic and archaeological research carried out at San Lorenzo Tenochtitlan by Wing (1980a, b) and Coe and Diehl (1980) paint a picture of the subsistence strategies practiced by pre-Columbian and modern people who relied, and still rely, on the local aquatic resources for much of their livelihood. The results of Wing's (1980a) analysis of faunal remains from the Olmec site of San Lorenzo Tenochtitlan suggests that the Olmec relied heavily on aquatic resources, effectively capturing fish, turtles, and manatees on a regular basis. As Coe and Diehl (1980:146) note: "Any individual of either sex old enough to walk could bring home enough fish to supplement the daily fare, and Olmec children probably contributed...to the family larder." The animal data from Tres Zapotes show a similar pattern.

4 Quantitative Integration of Plant and Animal Data

Perhaps the best way to get a sense of how the plant and animal datasets co-vary with respect to these different contexts is to step back and take a broader look through the use of multivariate analysis. Earlier in this volume, VanDerwarker explores the use of multivariate analysis toward this end, specifically with reference to correspondence analysis.

Here we pick up this thread using principal components analysis (PCA). PCA is a statistical method that considers a set of variables to determine which variables are relatively independent of one another (Shennan 1997; Wulder 2004). Whereas correspondence analysis calculates associations between cases and variables using chi-squared distances, PCA uses a Pearson's *r* correlation co-efficient. Instead of using raw abundance data as is necessary with correspondence analysis, we standardized our respective datasets. It is this standardization process that makes PCA the appropriate choice for multivariate analysis. Once the relatedness of variables was determined through the calculation of correlation co-efficients, like variables were grouped into subsets and combined into factors. The resulting factors represent associations among quantities of taxa within the various cases.

In this analysis, our cases are our contexts: ceremonial, domestic, and elite. The variables include the following plant and animal categories: maize, tree fruit, dog, deer, fish, and turtle. All food variables were identified in all contexts, with the exception of dog, which does not appear in any of the ceremonial contexts. The purpose of PCA is to assess the relative importance of these variables with respect to each other and to the different social contexts. Plant data were standardized by summing the total counts of each category by context, divided by total weight of plant materials identified in those respective contexts. Animal data were standardized by summing the total NISP of each category by context, divided by the total bone weight recorded for each context. Thus, both datasets were treated similarly prior to inclusion in the PCA.

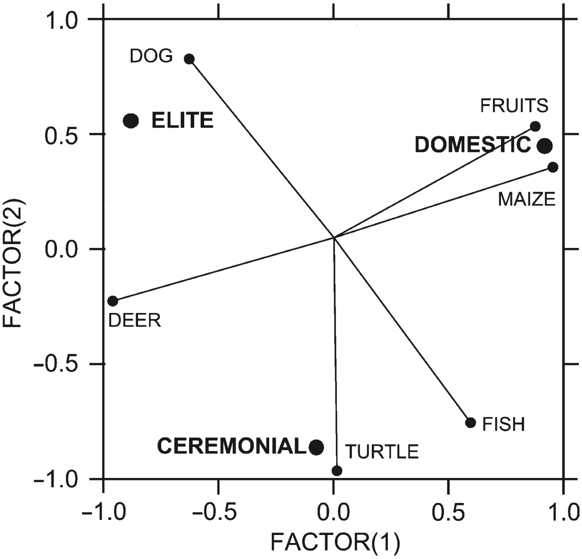

Fig. 6 Principal components plot of plant and animal taxa from Tres Zapotes social-spatial contexts

Figure 6 shows the results of the PCA, plotting the variables along with the cases. What is most interesting is that the plant foods separate out from the animal foods. Maize and tree fruits are more closely associated with ordinary nonelite domestic contexts than elite and ceremonial contexts; indeed all of the plant food variables plot directly in the nonelite domestic space on the PCA graph. The independent analysis of the plant data revealed a distinction between the distribution of maize and fruit, such that maize seemed to be more prevalent in elite areas than in nonelite areas. Upon quantitative integration of the plant and animal data, however, the distinction between staple foods and special foods becomes clear. Maize and tree fruits plot so clearly in nonelite domestic space because these are the core foods that formed the basis of the everyday diet. Everyone had access to these foods – but not everyone had access to animal foods.

Fish plot midway between domestic and ceremonial contexts, indicating the dual importance of fish resources in these respective domains. Based on their research, Coe and Diehl (1980:146) believe that the quantity and variety of aquatic resources at San Lorenzo Tenochtitlan kept them from being controlled by one or few groups; thus little political restriction was placed on the procurement of aquatic resources, allowing them to become more pivotal resources than terrestrial animals. As mentioned above, most aquatic resources were abundant, relatively easy to procure, and required little group organization; thus, nonelites would have relied on these resources as regular sources of protein to complement the vegetal portion of the diet.

Notable among the identified aquatic taxa recovered from elite contexts is shark, represented by a single tooth. A plausible explanation for this specimen's presence in an elite context is that it was used as a tool for bloodletting (Joyce et al. 1991). Shark's teeth have been described as bloodletting tools from other Olmec contexts (Coe 1977:188; Drucker 1952; Drucker et al. 1959), and the "shark's tooth motif" as imagery that alludes to bloodletting by the elite (Joyce et al. 1991). Indeed, Joyce et al. (1991:9) note: "for the Olmec, the archetypal perforator had a marine source, particularly in the stingray spine and shark's tooth." The presence of other fish taxa may be explained by their relation to the fish zoomorph described by Joyce et al. (1991). Thus, the aquatic resources identified in elite contexts at Tres Zapotes may be the material remains of a shared iconography of autosacrifice that helped legitimize the power of local rulers and their descent by lineage, and solidify their status as dignitaries to the supernatural world (Joyce et al. 1991:10).

It is interesting that turtle falls clearly within ceremonial contexts. While we do not dispute that turtle was likely a food source, it is clear that its role in epi-Olmec life went beyond subsistence. Emery (2003) notes that musk turtles were not generally eaten at the Classic Maya site of Piedras Negras, due to their musky flavor. One musk turtle carapace identified from elite deposits at Piedras Negras was perforated and carved, suggesting that it was used as an adornment or as a drum (Emery 2003). Miller and Taube (1993:174) note that turtle shells were often used as musical instruments, especially the use of carapaces as drums, possibly as an allusion to thunder. Additionally, in the "grand center" of Tikal, turtles accounted for the majority of reptile remains (Pohl 1990). With the present data we cannot say unequivocally if the turtles identified at Tres Zapotes were used as food, musical instruments, some other ceremonial purpose, or a combination of these.

Equally interesting is the clear association between dogs and elite contexts. Many studies of Mesoamerican faunal remains have noted the importance of dogs in elite contexts (Rosenswig 2007; White et al. 2001, 2004). The importance of dogs in pre-hispanic Mesoamerican societies is known from iconographic as well as archaeological research. Dogs are often depicted on ceramics, as effigy vessels, and even in the Popol Vuh alongside the Hero Twins (Miller and Taube 1993:80). Miller and Taube (1993:80) note that in Central Mexico, it was thought that a person born on the fourth day (Dog) in the *trecena* 1 (Deer) (in the tonalamatl, the 260-day period was divided into a trecena – a period of 13 days) would be a gifted breeder of dogs and would never lack food. Additionally, several humans were buried with dogs at the Late Formative site of Chupicuaro, which has been interpreted as an early expression of dogs serving their masters in death as guides through the Underworld, particularly in crossing bodies of water (Miller and Taube 1993:80; Noe Porter 1956). The idea of dogs as guides to the land of the dead is widespread in Mesoamerican lore (Wing 1984).

More recently, stable isotope analyses of archaeological dog remains from La Joya and Bezuapan, while from domestic non-elite contexts, show that the Formative dogs in the Tres Zapotes hinterland had a diet consisting almost exclusively of C4 (maize) plants (VanDerwarker 2006). It is not clear if the dogs were purposefully being fed maize to fatten them up before eating them, or merely scavenging maize refuse. However, the isotopic signatures of dog remains recovered from ritual feasting contexts at the Late Classic site of Lagartero suggests that these animals were being purposefully fed maize to be ritually consumed (White et al. 2004:156). Wing (1978:39–41) suggests that the dependence on dog as a food staple is similar to the Old World dependence on domestic livestock. Rosenswig (2007:20) suggests that the use of dogs at Cuauhtemoc may have been similar to the use of pig in the Pacific, with the animals being raised and eaten at elite-sponsored feasts.

Whether dogs were being raised as food staples or feasting delicacies, we cannot say with certainty. Clearly the dogs at Tres Zapotes are mostly restricted to elite contexts, although not completely absent from nonelite domestic contexts. A future avenue of research for this dataset will be to analyze the carbon and nitrogen isotopic signatures of dogs in multiple contexts to discern any differences in dietary composition between individuals from various social contexts. However, in the absence of stable isotope data for the Tres Zapotes dogs, we cannot be certain of their diet at this site at this time. Nevertheless, their primary presence in elite contexts is highly suggestive of the dualism of Mesoamerican food and iconography.

Like the fish, deer does not plot clearly onto a single context, but instead falls midway between ceremonial and elite contexts, suggesting a dual importance of deer in both ritual and elite activities at Tres Zapotes. It is generally accepted that deer played an important role in the pre-hispanic diets of Mesoamericans, and other natives of the Americas, in general. In subsistence systems that depended a great deal on agriculture, a garden-hunting model is often applied (Linares 1976). This model states that as humans clear fields for crops, secondary disturbed-habitat vegetation thrives in the newly created edge-environments. This abundance of highly edible vegetation, which would include the wild secondary vegetation as well as cultivated plants, attracts game animals to it, such as deer, turkey (*Meleagris gallopavo*), rabbit (*Sylvilagus* spp.), and others. As agriculture intensified, and thus absorbed an increasing amount of the occupants' time, people would hunt and trap the animals that were attracted to the edge-environments around agricultural fields. This would serve the dual purpose of supplying the people with protein and ancillary animal resources (i.e., fur, hides, antler), and of controling the amount of damage inflicted on the crops by these pests. While we cannot substantiate this at present, people may have been provisioning elites with deer (both meat and hides) (see also Miller and Taube 1993:75), which could explain the higher incidences of this animal in elite versus domestic contexts. Elite-sponsored feasting could be another explanation for the disproportionate representation of deer in elite contexts; in a community rife with political factionalism like Tres Zapotes seems to have been (see Pool 2003b), competitive feasting could have served as a means for elites to compete for followers (see Dietler and Hayden 2001).

Using stable isotope analysis of deer remains at several Maya sites, White et al. (2004:150–152) suggest that some of the deer specimens were surely food remains, however, the dietary signatures of two deer from the site of Lagartero stand out. One of these individuals appeared to have been fed maize over a very long life (ca. 25 years) (White et al. 2004:150). The unusually long lifespan (25 years versus an average of 5 years, and a maximum known of 15 years from modern data [Georgia Museum of Natural History 2000]) coupled with an incredibly C4-restricted diet suggests that this deer was being raised in captivity. The other anomalous deer identified at Lagartero yielded isotopic signatures that suggests it was consuming both meat and plant refuse (White et al. 2004:151). White et al. (2004:151–152) suggest that these two individuals may have been kept in captivity and tamed for use in ceremonial reenactments, or in ritual sacrifices marking period endings, as represented on ceramic vessels from ceremonial dumping contexts. Stable isotope data for deer from La Joya and Bezuapan suggests that some deer may have been semi-domesticated (VanDerwarker 2006; see also Dillon 1988; Gerry and Krueger 1997; Pohl 1990); however it is likely that these animals fed on maize and maize refuse from fields. As VanDerwarker (2006:192) states: "Maize fields undoubtedly provided easy and convenient forage for deer – and deer loitering in the maize fields would have provided easy and convenient hunting for people." While this comparative narrative includes data from Mayan sites, it shows that deer played an important role in both ceremonial and elite life. It has yet to be determined what type of ceremonial role deer filled at Tres Zapotes, but it is significant that deer do not plot clearly into a single context.

5 Discussion and Conclusion

How do we understand these patterns in the plant and animal data? One way to think about this is in terms of plants as everyday staple foods that were a daily component of the diet. Maize can be stored. Coyol was likely rendered for oil to be used in cooking and can also be stored. These were foods eaten on a daily basis. Perhaps unlike plant foods, animal foods were not something that everyone had access to on a daily basis. Because animal products cannot be stored as easily as plant foods, they were probably not on hand as regularly. It is likely that meat was not as consistently procured and eaten as plants, but incorporated into everyday domestic meals when encountered. In all probability, people did not bring home prey every day, and so high-level meat consumption would have been restricted for special occasions and for people of higher status, which explains why it shows up more frequently in elite and ceremonial contexts. Several explanations for the higher abundance of fish in domestic contexts relative to other animal foods include their relative ease of capture, local abundance, and because they can be preserved more easily through salting and drying (Zohar and Cooke 1997).

The case study presented here is significant in that it demonstrates how quantitative integration of plant and animal data can expand our understanding of ancient diet beyond what is possible with strictly independent analyses of these datasets. The distinction between plants as everyday staple foods and meats as special, high-status, ceremonial foods was not made clear in the independent analyses that considered one variable at a time. The inclusion of multiple variables across the contexts of interest and the use of principal components analysis allowed us to discern this basic, yet important, difference in plant and animal foodways. The analyses presented here provide tantalizing clues regarding the organization of foodways in different social contexts at Tres Zapotes, and we believe sheds light on broader patterns of ancient Mesoamerican subsistence. Clearly, a dual consideration of plant and animal data via quantitative integration has the potential to unlock new possibilities and interpretations.

As a whole, the case studies in this volume exemplify the interpretative power of subsistence data integration. Whether combining macrobotanical data with microbotanical data (Dickau, this volume), zooarchaeological data with ethnoarchaeological and stable isotope data (Jones and Quinn, this volume), or, as the majority of cases in this volume have done, integrating zooarchaeological and paleoethnobotanical data, it is clear that the potential for deepening our understanding of ancient subsistence, past environments, archaeological formation, and status-related foodways is enormous. With careful attention paid to the methodological, taphonomic, and quantitative issues particular to a given type of subsistence data, the implementation of qualitative or quantitative methods for integrating multiple lines of subsistence evidence allows us to surpass sub-disciplinary boundaries and consider the holism of anthropological foodways.

Acknowledgments This research was funded by a grant from the National Science Foundation (BCS-0242555) awarded to Dr. Christopher Pool. Analysis of the faunal remains was carried out in part using the zooarchaeology comparative collection housed in the Environmental Archaeology Range at the Florida Museum of Natural History in Gainesville, Florida.

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Apppendix A

Important fish species collected in modern fishing expeditions on the islands of Aiwa Levu, Aiwa Lailai, Nayau, and Lakeba. Modes of collection include: L – long line, G – gillnet, S – spear, N – hand net, T – trolling, and H – handline.

Common name	Taxa- scientific name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Herrings	**Clupeidae**				
Bluestripe herring	*Herklotsichthys quadrimaculatus*			G	
Flyingfishes	**Exocoetidae**				
Flyingfish	*Cypselurus* sp.			N	N, T
Needlefishes	**Belonidae**				
Keeled needlefish	*Platybelone argalus platyura*			G	G
Reef needlefish	*Strongylura incisa*			G	G
Hound needlefish	*Tylosurus crocodilus crocodilus*			G	G
Squirrelfishes, Soldierfishes	**Holocentridae**				
Soldierfish	*Myripristis* sp.	S	S, G	S, G	S, G
Long jawed squirrelfish	*Sangocentron spiniferum*	S	G	S	S, G
Violet squirrelfish	*Sargocentron violaceum*				S, G
Groupers	**Serranidae**				
Peacock grouper	*Cephalopholis argus*	S	S		G, T
Tomato hind	*Cephalopholis sonnerati*				G, T
Honeycomb grouper	*Epinephelus merra*	S, G, H	S, G	S, G	G
Giant grouper	*E. lanceolatus*				S, T
Marbled grouper	*E. polyphekadion*			S, G	G, T

(continued)

Appendix A (continued)

Common name	Taxa- scientific name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Grunters	**Therapontidae**				
Crescent-banded grunter	*Terapon jarbua*			G	G
Jacks, Trevallys	**Carangidae**				
Pennantfish	*Alectis ciliaris*				S, G, T
Giant trevally	*Caranx ignobilis*				S, G, T
Bluefin trevally	*C. melampygus*	H, T	S	S, G	S, G, T
Snappers	**Lutjanidae**				
Snappers	*Lutjanus* spp.				S, H, T
Paddletail	*Lutjanus gibbus*				S, H, T
Sweetlips, Grunts	**Haemulidae**				
Sweetlips	*Plectorhinchus* spp.			S, H, T	S, H, T
Emperors	**Lethrinidae**				
Yeallowspot emperor	*Gnathodentex aureolineatus*		G		G
Blue-lined large-eye bream	*Gymnocranius grandoculis*	S			S, G
Redaxil emperor	*Lethrinus conchyliatus*			G	
Orangefin emperor	*Lethrinus erythropterus*			S, G	G
Blackspot emperor	*Lethrinus harak*			G	G
Yellowlip emperor	*L. xanthochilus*			G	G
Big-eye bream	*Monotaxis grandoculis*			S, G	G
Goatfishes	**Mullidae**				
Yellowstripe goatfish	*Mulloidichthys flavolineatus*	G			G
Yellowfin goatfish	*Mulloides vanicolensis*		G	G	
Half-and Half goatfish	*Parupeneus barberinoides*		G	G	G
Yellowsaddle goatfish	*P. cyclostomus*		G	G	G
Indian goatfish	*P. indicus*			G	G
Longbarbel goatfish	*P. macronemus*			G	G
Multibarred goatfish	*P. multifasciatus*	S	G	G	G
Sidespot goatfish	*P. pleurostigma*			G	G
Butterflyfishes	**Chaetodontidae**	S	G	G	G
Vagabond butterflyfish	*Chaetodon vagabundus*			G	G
Damselfishes	**Pomacentridae**				
Banded sergeant	*Abudefduf septem fasciatus*	S, G		S, G	
Wrasses	**Labridae**				
Blackspot Pigfish	*Bodianus vulpinus*				S, G
Doublehead Maori Wrasse	*Cheilinus undulatus*			G	S, G
Carpet Wrasse	*Novaculichthys taeniurus*				S, G
Wrasses	*Thalassoma* spp.			G	G
Peakcock wrasse	*Iniistius pavo*				S, G
Parrotfishes	**Scaridae**				
Carolines parrotfish	*Calotomus carolinus*			G	G

(continued)

Appendix A (continued)

Common name	Taxa- scientific name	Aiwa Levu	Aiwa Lailai	Lakeba	Nayau
Globehead parrotfish	*Scarus globiceps*	S		S	S
Redlip parrotfish	*Scarus rubroviolaceus*	S, G		G	G
Dusky parrotfish	*S. prasiognathos*			G	S, G
Steephead parrotfish	*Chlorurus microrhinos*				S, G
Bullethead parrotfish	*Chlorurus sordidus*	S	S, G		
Blue parrotfish	*S. oviceps*	S, G	G		S, G
Mullets	**Mugilidae**				
Flathead mullet	*Mugil cephalus*	G	G	G	G
Bluetail mullet	*Valamugil buchanani*	G	G	G	G
Squaretail mullet	*Liza vaigiensis*				G
Barracudas	**Sphyraenidae**				
Great barracuda	*Sphyraena barracuda*	H		G, S	S, H, T
Striped seapike	*Sphyraena obtusata*	H			S, H, T
Surgeonfishes	**Acanthuridae**				
Blueband surgeonfish	*Acanthurus lineatus*	S			G
Whitespotted surgeonfish	*A. guttatus*			G	G
Convict tang	*A. triostegus triostegus*	G, S	G	S, G	G
Striped bristletooth	*Ctenochaetus striatus*	S	G	S	S, G
Orangespine unicornfish	*Naso lituratus*			G, S	S, G
Bluespine unicornfish	*N. unicornis*		S	G, S	S, G
Rabbitfishes	**Siganidae**				
Forktail rabbitfish	*Siganus argenteus*			G	G
Little spinefoot rabbitfish	*S. spinus*	S		G	G
Tunas, mackerels	**Scombridae**				
Mackerel	*Scomberomorus* spp.	T	T	T	T
Triggerfishes	**Balistidae**				S, G, H
Bluefinned triggerfish	*Balistoides viridescens*				S
Ebony triggerfish	*Melichthys niger*				S, G
Puffers	**Tetraodontidae**				
Starry pufferfish	*Arothron stellatus*			G	S, G
Threetoothed puffer	*Triodon macropterus*				S, G
Porcupinefishes	**Diodontidae**				
Porcupinefish	*Chilomycterus reticulatus*			G	S, G
Porcupinefish	*Diodon hystrix*			G	S, G

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