Method and Theory in Paleoethnobotany

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Paleoethnobotanical Method and Theory in the Twenty-First Century

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The origins of the study of relationships between people and plants in the past began as early as the nineteenth century with the identification of desiccated plant remains recovered from rockshelters in the American Southwest (Ford 2003:xii; 2004:x; Pearsall 2000:1) and waterlogged remains from Swiss lake-dwelling sites (Hastorf 1999:55). This field of study, first termed *ethno-botany*, today is termed either *paleoethnobotany* or *archaeobotany*, with the two synonymous terms generally preferred in North America and Europe, respectively (figure 1.1). Paleoethnobotany expanded tremendously as a field in the second half of the twentieth century, as reflected in the growing number of publications since the 1970s (see the extensive bibliographies in Hastorf 1999 and Pearsall 2000), and continues to make substantial contributions to archaeology today.

This volume is conceived as a reflection on the state of the field after the first decade of the twenty-first century. Paleoethnobotany has changed dramatically since its earliest days and since the publication of the first seminal volumes in the 1970s and 1980s (Hastorf and Popper 1988; Pearsall 1989; Renfrew 1973; van Zeist and Casparie 1984; van Zeist et al. 1991). It is time for a new and updated overview of the methods and theory of paleoethnobotany that addresses what we do and why we do it. This volume assembles a diverse group of authors to write about their areas of expertise in the practice and theory of paleoethnobotany. We cover topics from the formation processes of plant remains

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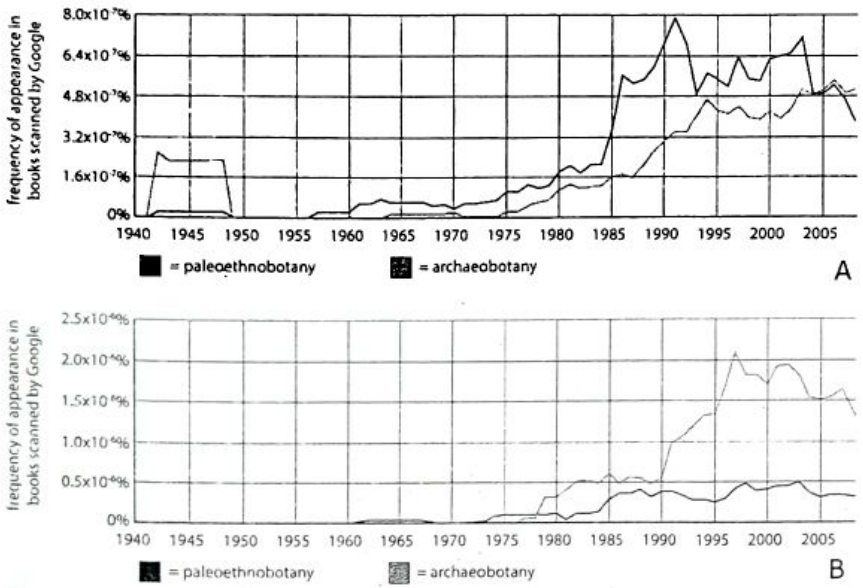

FIGURE 1.1. *Relative trends in the use of the terms* paleoethnobotany *and* archaeobotany *in American (a) and British (b) books published between 1940 and 2008, as three-year running averages, originally created using Google Ngram Viewer (https://books.google.com/ngrams, searched May 30, 2013). These data come from the Google Books project and include over 5.8 million texts, more than 4% of books ever published (Michel et al. 2011).*

in the archaeological record to methods for their recovery and analysis to diverse modes of interpretation, both alone and in concert with other types of archaeological analyses.

This book differs from prior contributions to the field in three ways. First, this is the only comprehensive edited volume focusing on method and theory to appear since the 1988 publication of *Current Paleoethnobotany* (Hastorf and Popper 1988), still an influential and frequently cited volume but now dated in bibliography and without the benefit of technical advances in the field since the 1980s. Due to the high quality of the chapters in that volume, we aim to supplement (rather than replicate) the topics covered in 1988 with new areas of inquiry (e.g., starch grain analysis, stable isotope analysis, ancient DNA, digital data management, and ecological and postprocessual theory) that have become central to contemporary archaeological debates. Second, we aim for worldwide coverage in the literature referenced, in contrast to many excellent recent volumes that synthesize regional bodies of data and literatures in

the Northeastern United States (Hart 1999, 2008), the Eastern United States (Gremillion 1997; Minnis 2003; Scarry 1993b), the Western United States (Minnis 2004), China (Zhao 2010), Africa (van der Veen 1999b), the tropics (Hather 1994), and Europe and the Near East (van Zeist and Casparie 1984; van Zeist et al. 1991). Finally, although Pearsall's (2000) *Paleoethnobotany: A Handbook of Procedures*, currently in its second edition, is a critical reference for all paleoethnobotanists (as well as archaeologists of other specialties), its focus lies on providing a broad overview of methods in the discipline, rather than a critical examination of particular areas of study. This volume, in contrast, includes chapters that focus narrowly on individual topics and assesses the current state of theoretical, methodological, and empirical work in each area. We intend for this book to be used alongside the seminal works listed above, as well as myriad monographs and articles, and to serve as the next milestone along the path of paleoethnobotanical knowledge.

This chapter serves two purposes: it reviews briefly the state of the field to date and it suggests future directions in paleoethnobotany. Rather than list or summarize the other chapters in this volume, we reference them within this discussion to show how the questions addressed in subsequent chapters fit into the overall trajectory of both recent advances and predicted future trends in the field. Paleoethnobotany is poised at the intersection between study of the past and concerns of the present, including food security, biodiversity, and global environmental change, and has much to offer to archaeology, anthropology, and interdisciplinary studies of human relationships with the natural world. This volume, as a whole, illustrates many of these connections and highlights the increasing relevance of the study of past human-plant interactions for understanding the present and future (cf. van der Leeuw and Redman 2002).

THE DEVELOPMENT OF PALEOETHNOBOTANY

THE STATE OF THE FIELD IN THE 1980S

The state of the field of paleoethnobotany through the 1980s is well summarized by books published late in that decade (Hastorf and Popper 1988; Pearsall 1989; van Zeist et al. 1991) and need not be repeated here (see Ford 2003, 2004; Hastorf 1999:55–57; Pearsall 2000:1–10; Popper and Hastorf 1988; Renfrew 1973:1–6 for excellent summaries of this period). Early work in the field stemmed from chance finds of desiccated or waterlogged plant remains in archaeological contexts, the analysis of which first began in the late nineteenth century and continued through the 1960s (Pearsall 2000:4–6). The

major tipping point for the study of paleoethnobotanical remains was the application of flotation to recover carbonized plant remains from archaeological sediments, a technique suitable for a wide variety of archaeological contexts. First publicized to the American archaeological community in 1968 (Struever 1968), flotation rapidly became adopted for use at an increasing number of sites across the Americas, Europe, and the Near East (Pearsall 2000:4–6). Coupled with the expansion of large salvage archaeology projects in the United States in the 1970s and 1980s (henceforth termed *Cultural Resource Management*, or *CRM*, projects), massive botanical data sets were recovered using flotation, studied, and published, driving the need for comprehensive methodological treatments of paleoethnobotany (i.e., Hastorf and Popper 1988; Pearsall 1989) that went beyond prior works that were more narrowly concerned with identification and interpretation of cultigens (e.g., Renfrew 1973; van Zeist and Casparie 1984).

Pearsall's (1989) and Hastorf and Popper's (1988) volumes had two far-reaching implications for paleoethnobotanical research in the 1990s and beyond. First, they popularized the study of plant remains as a theoretically grounded discipline that had the potential to address a variety of research questions. Chapters dealing with formation processes (Asch and Sidell 1988; Pearsall 1988), agricultural activities (Hastorf 1988), paleoenvironmental reconstruction (Smart and Hoffman 1988), and culture change (Johannessen 1988) highlight some of the applications of paleoethnobotanical data sets. Second, these books explained the recovery of plant remains in a way accessible to the general population of archaeologists (Toll 1988; Wagner 1988; and especially Pearsall 1989:chapter 2) and dealt with the basic quantitative methods employed in paleoethnobotanical analysis (Miller 1988; Pearsall 2000:chapter 3; Popper 1988). These references, and in particular the second edition of Pearsall's book, continue to be consulted by archaeologists during excavation as a "how-to" guide for the recovery of plant remains, especially when a paleoethnobotanist is not available to oversee sample collection and processing in the field. Undoubtedly these texts have contributed to the expansion of flotation and paleoethnobotanical analysis since the late 1980s.

Trends in Paleoethnobotanical Analysis since 1989

We identify seven trends that have occurred in paleoethnobotany since the late 1980s, leading to significant changes in the field today. We briefly outline these trends, and their implications, in this section. These trends include (1) improved understanding of the formation and depositional processes that affect botanical macro- and microremains; (2) improved methods for and frequency of paleoethnobotanical sampling, of both macro- and microremains; (3) new methods for quantification; (4) advances in computing and digital technologies, which have enabled new methods of interpretation; (5) the application of new theoretical approaches to the analysis of paleoethnobotanical remains; (6) the integration of paleoethnobotany with other methods of environmental archaeology; and (7) the increasingly mainstream role of paleoethnobotanical analyses and specialists within archaeological discourse. These trends are the result of a steady accumulation of knowledge within the field of paleoethnobotany, the increased number of trained paleoethnobotanists, and broader changes in the field of archaeology that have benefited paleoethnobotanical analysis.

Improved Understanding of Formation and Depositional Processes

Basic research continues on the processes that affect the deposition, decay, and preservation of botanical remains in a variety of archaeological contexts. These processes have not been a primary focus of earlier texts in the field (but see Pearsall 2000; Piperno 2006b; Torrence and Barton 2006). Five chapters in this book summarize recent advances in our understanding of the chemical, physical, and biological processes that affect botanical preservation at the macroscopic, microscopic, and biomolecular levels. Gallagher (chapter 2, this volume) describes both cultural and natural processes that affect the patterning of macrobotanical remains. Henry (chapter 3, this volume) and Pearsall (chapter 4, this volume), in contrast, focus on the physical and chemical structure of botanical microremains (starch grains, and pollen and phytoliths, respectively) and recent experimental work that gives insight into how and why certain microremains may be preserved (or not) in specific archaeological contexts. Finally, Warinner (chapter 14, this volume) and Wales et al. (chapter 15, this volume) discuss the factors that influence biochemical and biomolecular (DNA, RNA, and protein) preservation in archaeobotanical remains. This basic knowledge has improved the ability of paleoethnobotanists to make claims about the presence and absence of certain taxa at the time of deposition, rather than at the time of analysis.

Improved Paleoethnobotanical Sampling Methods and Increased Sampling Frequency

The "flotation revolution" of the 1970s was responsible for making the collection of plant remains a part of mainstream archaeological fieldwork in many parts of the world, as described above, and sampling has continued to

increase ever since. This is mainly the result of the penetration of flotation, and other appropriate methods for recovering botanical remains, into parts of the world where such work was not previously practiced. Archaeologists in South and East Asia and Africa, in particular, have only recently begun to adopt flotation on a large scale (e.g., Crawford 2006, 2009; D'Andrea et al. 2001; D'Andrea 2008; Di Piazza 1998; Fairbairn 2007; Fuller 2006; Fuller and Weber 2005; Gallagher 2010; Kajale 1991; Lee et al. 2007; Logan 2012; McConnell and O'Connor 1997; Neumann et al. 2003; van der Veen 1999b; Zhao 2010). Improvements in the identification and interpretation of microremains (here phytoliths and starch grains) from archaeological contexts, especially in tropical soils where macroremains are poorly preserved, have further expanded our understanding of plant use on a global scale (Denham et al. 2003; Fahmy 2008; Fahmy and Magnavita 2006; Pearsall 2000:chapter 5; Piperno 2006a, 2009; Piperno and Holst 1998; Torrence and Barton 2006). The availability of methods guides for sampling both macro- and microremains (Fritz 2005; Pearsall 2000; Piperno 2006b; Torrence and Barton 2006) has further increased the ubiquity of such sampling. D'Alpoim Guedes and Spengler (chapter 5, this volume) and White and Shelton (chapter 6, this volume) address recent trends in methods for sampling and recovering paleoethnobotanical remains, including recent improvements in flotation device efficiency and portability, such as the hand-pump flotation device (Shelton and White 2010).

New Methods in Quantification

An increase in computing technology and the development of statistical software programs have allowed major contributions to the quantification and interpretation of archaeological plant remains through multivariate statistics, especially correspondence analysis and various derivative methods (see discussion in A. Smith, chapter 10, this volume). These methods extract significant axes of variation from large and complex data sets and can be used for the direct integration of plant and animal remains from an archaeological site (VanDerwarker 2010a). The interpretation of multivariate statistics remains subjective and such statistical methods are not appropriate for every data set (Jones 1991). Multivariate approaches, however, have been essential to new advances in understanding large-scale patterning of archaeological plant remains at both the sitewide and regional scales (e.g., Colledge et al. 2004; Jones et al. 2010; Peres et al. 2010; Smith and Munro 2009; Torrence et al. 2004; van der Veen 1992a, 2007b; VanDerwarker 2006).

Improvements have also been made in the use of simple (i.e., non-multivariate) statistics and their applications to interpretation of paleoethnobotanical assemblages, especially related to hypothesis testing (see Marston, chapter 9, this volume). Such applications extend to the interpretation of both intrasite (VanDerwarker et al., chapter 11, this volume) and intersite (Stevens, chapter 12, this volume) variation in the deposition of plant remains.

Advances in Computing and Digital Technologies

Perhaps no change over the past thirty years has affected archaeology as much as the exponential increase in computing power and the increased availability and usability of digital imaging on devices ranging from microscopes to multispectral satellites. As Warinner and d'Alpoim Guedes (chapter 8, this volume) discuss, these advances have had profound implications for the field of paleoethnobotany by enhancing our ability to record, store, sort, analyze, publish, and share the results of our analyses. Powerful desktop and portable computers make possible the widespread use of multivariate statistics, as described above, and spatial analysis, including the analysis of remotely sensed data (Casana, chapter 16, this volume). Online archives have enabled unprecedented sharing of data and publications (Warinner and d'Alpoim Guedes, chapter 8, this volume) and enhance the utility of reference collections (e.g., botanical collections imaged and available online in high resolution; Fritz and Nesbitt, chapter 7, this volume). Computing advances have also greatly enhanced other areas of science, such as genomics, that have had tremendous implications for paleoethnobotany (Londo et al. 2006; Olsen and Schaal 1999; Smith 2001a, 2014; Smith and Zeder 2013; Zeder, Bradley, et al. 2006; Zeder, Emshwiller, et al. 2006; see also Wales et al., chapter 15, this volume).

New Theoretical Approaches

The major theoretical shift in archaeology during the 1980s and 1990s that culminated in the division of theoretical approaches between so-called processual and postprocessual theoretical stances is one of the defining trends of archaeology as a whole over the past three decades, as have been attempts to find common cause between these approaches (Fogelin 2007; Trigger 2006). Paleoethnobotany has traditionally fallen into the "processual" camp, as the rise in scientific analysis during the 1970s that included the flotation revolution was tied to the rise of the "New Archaeology" that formed the basis for processual approaches to archaeology (Trigger 2006; Watson et al. 1971). Paleoethnobotanical data, however, have always been amenable to a variety of interpretive approaches, and publications since the 1980s highlight that variation. The application of "postprocessual" gender theory (Hastorf 1991) and

Bourdieu's concept of *habitus* (Atalay and Hastorf 2006; Bourdieu 1977) to the interpretation of food remains has led to important insights into practices of food preparation and consumption, as well as the origins of agriculture (Asouti and Fuller 2013). Similarly, practice theory offers another approach to understanding the social setting for food preparation in the past (Morell-Hart, chapter 19, this volume).

Other theoretical approaches derived from biology, and especially ecology, have been important avenues for understanding plant gathering, domestication, and crop selection. Human behavioral ecology, the study of how people make foraging decisions under particular environmental conditions, has offered new perspectives on hunting and gathering, transitions to agriculture, agricultural risk management, and settlement location (Gremillion, chapter 17, this volume; see also Bird and O'Connell 2006; Gremillion 2002a, 2002b; Gremillion and Piperno 2009a; Gremillion et al. 2008; Kennett and Winterhalder 2006; Marston 2009, 2011; Zeanah 2004). Niche construction theory, which addresses the ways in which people shape their environments and the ecological and social implications of such practices, informs our understanding of pre-agricultural practices, including incipient stages of domestication (B. Smith, chapter 18, this volume; see also Odling-Smee et al. 2003; Smith 2007a, 2007b, 2009a, 2009b, 2011a, 2011b). Combined with more traditional evolutionary approaches to understanding domestication (e.g., Rindos 1984), biological theory offers a counterpoint to social theory as a meaningful framework for interpreting paleoethnobotanical assemblages.

Integrated Environmental Archaeology

The term *environmental archaeology*, which describes the broad suite of methods used to understand human-environmental interaction in the past and includes paleoethnobotany, has been used increasingly to describe integrated paleoenvironmental and archaeological analyses over the past twenty-five years as these integrated approaches have become more common, generally outpacing the growth of both paleoethnobotany and zooarchaeology as a key term (figure 1.2; Dincauze 2000; Reitz et al. 1996; Reitz et al. 2008). An integrated approach to environmental archaeology beginning at the stage of project design is highly recommended, as it allows for comprehensive sampling strategies and sharing of data between specialists, leading to a more nuanced understanding of human-environmental interactions in the past.

Recent publications have focused on the integration of animal and plant remains (Smith and Miller 2009; VanDerwarker and Peres 2010), a topic not addressed in this volume, but the integration of other environmental

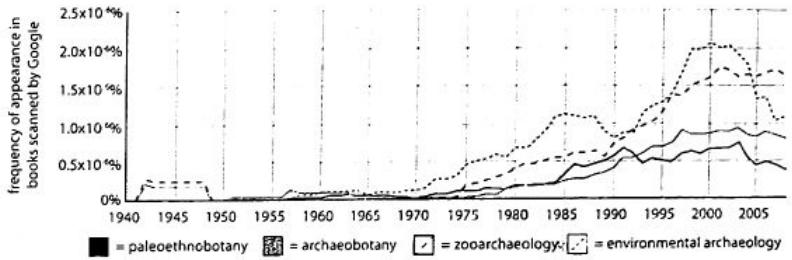

FIGURE 1.2. *Relative trends in the use of the terms* paleoethnobotany, archaeobotany, zooarchaeology, *and* environmental archaeology *in English-language books published between 1940 and 2008, using Google Ngram Viewer (https://books.google.com/ngrams, searched May 30, 2013). These data come from the Google Books project and include over 5.8 million texts, more than 4% of books ever published (Michel et al. 2011).*

archaeology techniques with paleoethnobotanical analysis has been pursued less often. Several chapters of this volume address how botanical remains can be used in concert with other data sets, including soil chemistry and geomorphology (Messner and Stinchcomb, chapter 13, this volume), human and plant stable isotope data (Warinner, chapter 14, this volume), and remote sensing satellite imagery (Casana, chapter 16, this volume). New methods and applications in the fields of genetics and proteomics are also presented, with an emphasis on the use of botanical remains in ancient DNA and paleoproteomic studies (Wales et al., chapter 15, this volume).

Paleoethnobotany Becomes Mainstream

Although paleoethnobotanists, much like other environmental archaeologists and archaeological scientists, were once considered specialists restricted to the analysis of specific bodies of data, now many paleoethnobotanists direct or codirect archaeological projects, putting paleoethnobotanical research questions at the forefront of excavation goals. A review of articles published since 1990 in *American Antiquity*, the flagship journal of the Society for American Archaeology and a methods-agnostic forum for publication of North American archaeology, shows an increase in publications that incorporate paleoethnobotanical methodologies in the mid-late 1990s (figure 1.3).

This period, the five to ten years following the publication of both *Current Paleoethnobotany* (Hastorf and Popper 1988) and *Paleoethnobotany: A Handbook*

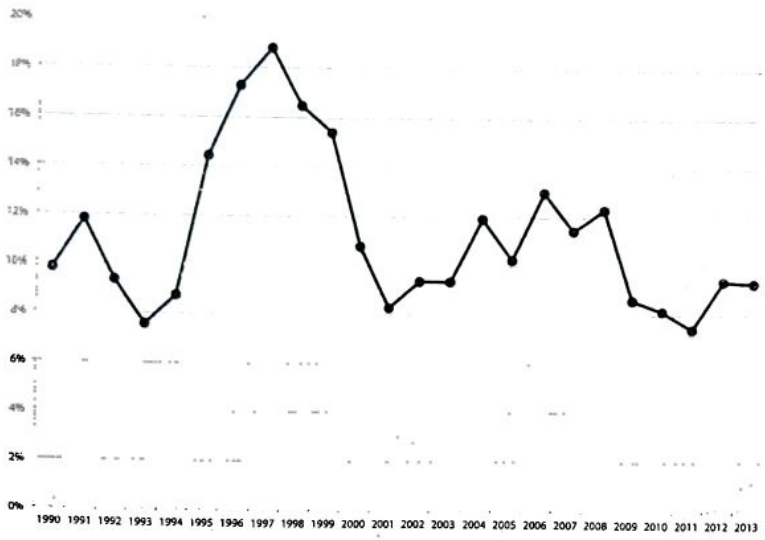

FIGURE 1.3. *Trends in the frequency of paleoethnobotany as a major research component of research articles published in* American Antiquity *between 1990 and 2013 (through April issue), represented as the three-year trailing average of the percentage of total research articles published (e.g., the 1990 data point is the average of the years 1988, 1989, and 1990).*

of Procedures (Pearsall 1989), also saw the publication of several major edited volumes in the field (e.g., Gremillion 1997; Hart 1999; Scarry 1993a). Since 2000, the number of articles focused on paleoethnobotany in *American Antiquity* has remained relatively constant at around 10 percent of the total. US National Science Foundation (NSF) funding for paleoethnobotanical research peaked during the early 1990s, after which funding rates for projects incorporating paleoethnobotany stabilized to approximately 5–20 percent of the total (figure 1.4).

Since 1988, the NSF has supported more than 200 projects involving paleoethnobotanical research, representing approximately 14 percent of all funded archaeological projects.[1] For more than half of these projects, paleoethnobotanical analysis is a major component of the project and is fundamental to the project goals. We suggest that the evident "bump" in NSF-funded paleoethnobotany projects between 1990 and 1993 may have further contributed to the increase in paleoethnobotanical articles published in *American Antiquity* between 1995 and 1999 (figures 1.3 and 1.4). The PhD students who have been

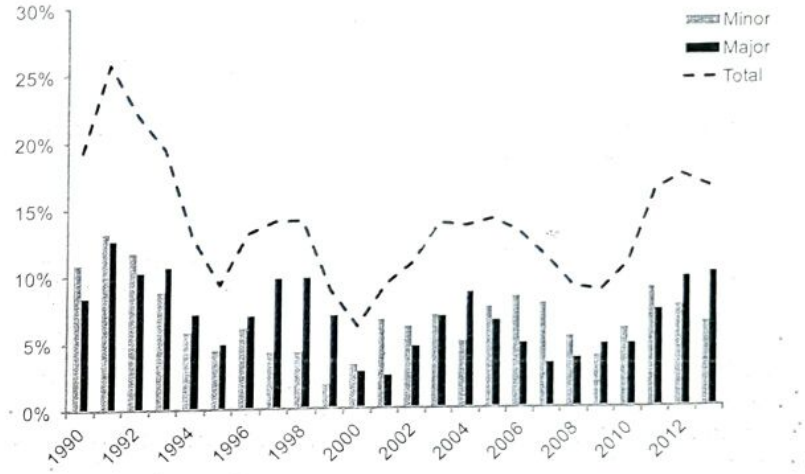

FIGURE 1.4. *Trends in the frequency of NSF-funded projects involving paleoethnobotanical research, 1988–2013, represented as the three-year trailing average of the percentage of total NSF-funded archaeology projects (e.g., the 1990 data point is the average of years 1988, 1989, and 1990). The contribution of paleoethnobotanical inquiry to the project as a whole was scored as major or minor.*

trained on these projects have gone on to start their own integrative, multidisciplinary projects, leading to an expansion of the use of botanical data in mainstream archaeological publications and a broadening of questions that paleoethnobotanical methods and data are used to address.

FUTURE DIRECTIONS IN PALEOETHNOBOTANY

According to an often-quoted line, it is always difficult to make predictions, especially about the future. Nonetheless, we see many of the trends listed above continuing into the future, in particular those related to increased collection and study of botanical remains, and further integration of paleoethnobotany with other environmental archaeology methods, especially those operating at the molecular level. In addition, we suggest three new ways in which we see the field of paleoethnobotany changing over the next twenty to thirty years: (1) increased accessibility of published data sets online, leading to broader-scale (and more powerful) analyses; (2) increased training

of paleoethnobotanists in developing countries and more publications from those countries; and (3) increased relevance of paleoethnobotany beyond archaeology, particularly in environmental and climate-change science. We outline briefly why we see these as likely future directions for the field and how we see these developments affecting the practice of paleoethnobotany and its role within archaeology.

Increased Accessibility of Paleoethnobotanical Data Sets

The Internet has proven to be a remarkable tool for sharing primary data sets. Well-managed public scientific data repositories, such as GenBank, have transformed research in other fields (e.g., evolutionary genetics and genomics), and similar databases show promise for improving archaeological practice as well (see Warinner and d'Alpoim Guedes, chapter 8, this volume). Existing paleoethnobotanical database websites host images (e.g., Paleobot.org) and distributional maps (e.g., the Archaeobotanical Database of Eastern Mediterranean and Near Eastern sites, http://www.cuminum.de/archaeobotany), as well as bibliographic references (e.g., Literature on Archaeological Remains of Cultivated Plants 1981–2004, http://www.archaeobotany.de/). The Archaeobotany Listserv (https://www.jiscmail.ac.uk/cgi-bin/webadmin?A1=ind1407&L=ARCHAEOBOTANY) accomplishes similar goals through email communication. In addition, the deposition of entire primary data sets into online data repositories such as PANGAEA, tDAR, OpenContext, and DRYAD is increasingly being encouraged by scientific journals and government funding bodies (see Warinner and d'Alpoim Guedes, chapter 8, this volume).

The possibility offered by centralized data repositories of primary archaeobotanical data is reuse of published data sets, which remains uncommon in the field, and integration of data sets to produce regional syntheses (e.g., Miller and Marston 2012). This has the potential to reduce Balkanization of the field and contribute to larger-scale and more powerful statistical analyses, leading to more significant and meaningful results. We see ongoing trends in computing and digital visualization contributing to this goal, allowing better sharing and more rapid analysis of large data sets. Perhaps most important, should governmental regulations for CRM institute mandatory digital archiving in a limited number of permanent online data repositories, such as those listed above, large numbers of botanical data sets that have been buried in gray literature will become accessible and contribute to future paleoethnobotanical research.

Increased Training in and Adoption of Paleoethnobotany in Developing Countries

Paleoethnobotany has historically been practiced by North American– or European-based scholars working in traditional areas of archaeological focus: the Americas, Europe, and the Mediterranean and Near East. Naomi F. Miller's 2010 survey of archaeobotanists identified 86 percent of respondents (total number of respondents was 118) as being based in North America (United States or Canada), the British Isles, or mainland Europe. Similarly, only 10 percent of respondents described their primary geographic area of specialty as something other than the Americas, Europe, or the Mediterranean and Near East (Miller 2010a:22; 2011a:10). Until the last two decades, nontraditional areas such as East and South Asia, Sub-Saharan Africa, Oceania, and the tropics of both the New and Old Worlds were studied infrequently and only by a few scholars. This is changing today and will continue to change as more paleoethnobotanists are trained in those countries and go on to careers in archaeology. Even a small number of well-trained specialists can have a dramatic impact on the amount of data analyzed in a developing country, and continued partnerships with well-established scholars in North America and Europe will facilitate publication and dissemination of the results of those analyses. Furthermore, training new generations of scholars with distinct educational and cultural backgrounds will broaden the diversity of the field and allow the practice of paleoethnobotany to move in new directions not previously pursued. More than any other trend, the growth of scientific archaeology worldwide will have tremendous implications for the future of paleoethnobotany and our collective understanding of the human past.

Relevance of Paleoethnobotany beyond Archaeology

Research attention (and funding) in many fields has moved toward understanding the human role in global environmental change, including climate change, and the future implications of ongoing present-day interactions between people and their natural environments. One thread in this research has focused on the past, partly to establish an accurate baseline for natural processes of climate change and extinction events in the pre-human past, and partly to establish how humans affected environmental systems in the pre-industrial period (Foley et al. 2005; Jackson et al. 2001; Lotze 2010; Pauly 1995). Archaeology as a whole has much to offer this effort, as it is the one discipline that directly investigates the holistic past across the entire span of human existence (Redman et al. 2004; van der Leeuw and

Redman 2002). Paleoethnobotany has a major role to play in this endeavor by providing robust data sets that reflect interactions between human and botanical communities over long spans of time and across economic, social, geographic, and climatic transitions. Recent work in the field highlights the value of such data: for example, synthetic analyses of long-term coupled changes in both human societies and vegetation communities in the Near East, as reconstructed through both macrobotanical (Riehl 2009) and pollen analysis (Rosen 2007), have clarified how climate and environmental change influenced agricultural practices on a regional scale over time. In some cases, however, paleoethnobotanical data are still largely neglected in the study of environmental change associated with agricultural systems (e.g., the case studies in Fisher et al. 2009), offering an opportunity for increased future contributions for paleoethnobotany.

CONCLUSIONS

Paleoethnobotanical inquiry is a rich and varied field, providing everything from basic science on depositional processes to interpretation about human adaptation to local environments on a global scale. The field has expanded in the number of practitioners, frequency of sampling and analysis, areas of the world in which such work is routinely conducted, and breadth of research questions addressed. The flotation revolution of the 1970s is still expanding in Africa and Asia, and the theoretical debates of the 1980s have brought a multivocal perspective to the interpretation of plant remains. In addition, the technological improvements of the 1990s and 2000s have led to unprecedented opportunities for data analysis, publication, and sharing. This volume highlights the implications of these developments and complements earlier volumes in the field that have driven research inquiry over the past quarter century.

Furthermore, we argue that the field is poised for further contributions to study of not only the human past but also the human present and future. We believe that paleoethnobotanical data sets are rich and robust sources of information on human adaptation to climate change and offer case studies of successful and unsuccessful agricultural and land-use systems in the past that are directly relevant to assessing the sustainability of such systems in the present. Despite persistent challenges in funding, employment, and integration with other areas of archaeology and the social and natural sciences (Miller 2011a:9), paleoethnobotany is poised for a new set of revolutions. We hope this volume contributes to that bright future.

NOTE

1. Survey conducted on all active and expired records with start dates from 1988 to 2013 with the Field of Application = anthropology and/or Search Award For = archaeology. The first complete year for which the public NSF project records include abstracts, allowing project content statistics to be calculated, is 1988. Abstracts for records related to archaeology and including the terms *botan**, *plant*, or *flora* were then read and scored for content. The paleoethnobotanical content of each abstract was scored as: 0 = none, 1 = minor, and 2 = major. Projects were deemed as having paleoethnobotanical content if they involved the direct investigation of ancient plant remains (macroscopic, microscopic, biomolecular, or biochemical) or involved targeted work towards producing modern reference collections or data sets for the interpretation or modeling of ancient plant remains. Surveys of modern vegetation without the purpose of being used for paleoethnobotanical interpretation were excluded.

2

Formation Processes of the Macrobotanical Record

Daphne E. Gallagher

THE MACROBOTANICAL RECORD

The macrobotanical record consists of all plant remains that are large enough to be seen with the naked eye and that can usually be identified with a low-power microscope (Ford 1979:301; Pearsall 2000:11). Macroremains can range in size from tobacco seeds (< 1 mm diameter) to a preserved dugout canoe several meters long. They can encompass every part of the plant including roots, stems, wood, fibers, sap, leaves, spines, flowers, fruits, nuts, seeds, and more. Consequently, the macrobotanical record has the potential to illuminate a wide range of human-plant interactions from management and environmental impact to cultural modification of plant products and the plants themselves. Given the scope of plant materials included and the comparatively minimal laboratory requirements for their recovery and study (see White and Shelton, chapter 6, and Fritz and Nesbitt, chapter 7, this volume), it is unsurprising that the majority of archaeological studies of plants focus on various classes of macroremains, although with improved techniques and awareness, studies of microremains from archaeological sites (i.e., pollen, phytoliths, and starch) are becoming more common (see Henry, chapter 3, and Pearsall, chapter 4, this volume).

Despite the potential diversity of plant parts in the macrobotanical record, analysis of macrobotanical samples and, consequently, research on how these plants enter the archaeological record, has tended to

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focus on two primary categories of macrobotanical remains: wood and seeds (the latter conceptualized broadly to include seedlike structures such as caryopses and achenes). This emphasis is for the most part practical. First, wood and seeds tend to be dense and highly durable, and consequently are good candidates for preservation, particular in conditions where macrobotanical remains are carbonized (see below). Second, both may be comparatively easy to identify. Many species of seeds have unique anatomy and, given their small size, are more likely to be preserved as complete specimens, whereas the nature of wood anatomy is such that identifications can be made from very small fragments (see Fritz and Nesbitt, chapter 7, this volume).

PRESERVATION OF MACROBOTANICAL REMAINS

Macrobotanical specimens in most exposed and subsurface settings decompose as a result of biological, chemical, and geochemical weathering processes (Beck 1989; Ford 1979). Soil-based bacteria, saprophytic fungi, and other microorganisms, as well as earthworms, insects, and other invertebrates, are the primary agents that break down the anatomical structures of deposited plants into their constituent elements (Swift et al. 1979). In general, environments that are warmer, wetter, more alkaline, and that have higher soil carbon and nutrient content will result in faster decomposition. However, these relationships are complex and linked to the nature and biodiversity of both the local decomposing organisms and the plant community (Beck 1989; Berg and McClaugherty 2008; Hättenschwiler et al. 2005; Swift et al. 1979). These biochemical processes can be aided by a variety of natural processes, including exposure to the elements (wind, rain, etc.), in addition to freeze-thaw and wet-dry expansions and contractions of the surrounding matrix that can cause mechanical damage (Beck 1989). Anthropogenic processes also contribute to decomposition of plant remains in archaeological sites. Humans not only grind, cut, pound, trample, and otherwise mechanically damage plants, but also frequently enrich local soil chemistry through the deposition of waste (Beck 1989; Holliday 2004).

Despite these combined effects, which typically destroy the majority of plant material initially deposited, macrobotanical remains are regularly preserved in archaeological contexts. All factors being equal, different plants and plant parts will decompose at different rates. For example, "woody" parts (those high in lignin) will take longer to break down than leaves (Beck 1989; Berg and McClaugherty 2008), and some species and plant parts may be differentially targeted by rodents and insects (Gasser and Adams 1981). Some

plant parts are particularly durable. Certain fruit pericarps, such as hackberry (*Celtis* spp.), undergo a process of biomineralization in which they naturally produce carbonates during their lifespan. These deposited carbonates render the pericarp resistant to decomposition, such that they frequently preserve in contexts where other plant parts do not (Fairbairn et al. 2002; Shillito and Almond 2010). Similarly, the hard involucres of Job's tears (*Coix lacryma-jobi*), which are often used as beads, are also resistant to decomposition (Ford and Jones 1974). However, in most cases, preservation in archaeological contexts depends less on the durability of the plant itself and more on environmental conditions and/or processes, such as carbonization, that improve the chances of preservation.

In general, plant material will preserve best in settings that inhibit decomposers. These include environments that are lacking moisture or oxygen, have consistently high or freezing temperatures, and/or have acidic or nutrient-poor substrates. Plants can also preserve in settings where they have undergone transformations pre- or post-deposition (e.g., carbonization, mineralization) that make them resistant to decomposition. Finally, plants may also leave impressions in durable substances that can then be identified after the plant has decomposed. In this section, we examine four frequent contexts of preservation, and the effects of each on archaeological specimens. Note that many archaeological sites include multiple types of preservation.

Dry Preservation

Dry preservation (desiccation) occurs in environments where the sustained absence of moisture inhibits the microrganisms that drive decomposition. Since almost all botanical specimens will preserve (often for thousands of years) in these settings, desiccated assemblages are frequently dense and species rich, sometimes to the point where the sheer quantity of material poses problems for sampling (Bryant 1989; Rowley-Conwy 1994; van der Veen 2007a). For example, at the site of Zinchecra, Libya, almost 800 desiccated plant remains were recovered from each liter of sediment (van der Veen 1992b).

Dry preservation is typically associated with desert environments, where rainfall and humidity are low, but even in these regions, caves frequently yield the best-preserved botanical specimens, as they have been more consistently protected from the elements (e.g., di Lernia et al. 2012; Emslie et al. 1995; Knörzer 2000; Smith 1967). For example, in the Great Basin of the Western United States, caves with dry preservation have yielded foodstuffs, bedding, textiles, baskets, sandals, wooden tools, and other macrobotanical remains

dating from over 10,000 BP through the historic period (figure 2.1; Fowler and Fowler 2008). In ancient Egypt and the Xinjiang region of China, man-made subterranean tombs provide similar protection (e.g., Chen et al. 2012; Jiang et al. 2007; Kunth 1826); in Egypt even delicate floral garlands have been recovered intact (Hamdy 2007). Dry preservation can also occur at open-air sites in particularly arid locations, such as coastal Peru, where rich botanical assemblages including well-preserved woven textiles are common (e.g., Beresford-Jones et al. 2011; Doyon-Bernard 1990).

Despite its common association with arid environments, dry preservation can also occur in regions with high rainfall, provided the archaeological site is sufficiently protected. Some of the most famous examples of dry preservation in temperate environments are from a series of caves in Kentucky, among them Newt Kash Hollow, where a wide variety of tools, baskets, and foodstuffs, including early examples of domesticated chenopod (*Chenopodium berlandieri*) and sumpweed (*Iva annua* var. *macrocarpa*), were recovered (Gremillion 1996b; Jones 1936; Smith and Cowan 1987; Yarnell 1972). Excavations in Europe have demonstrated that even in sites that are predominantly subject to decomposition, dry preservation can occur in specific contexts such as protected gaps and holes within medieval buildings (e.g., Ernst and Jacomet 2006).

In cases of dry preservation, much of the water evaporates from the plant specimen. Although this process can cause shrinking and twisting, particularly of softer, moisture-rich plant parts such as leaves, flowers, and fruits, more rigid anatomical structures such as wood and seeds can appear virtually identical to their modern counterparts (Cappers 2006; Neef et al. 2012; Van Bergen et al. 1997). Depending on the speed of desiccation, colors will frequently fade, although van der Veen (2007a:969) notes that in some cases desiccated grains and chaff acquire a darker reddish-brown hue. In all cases, anatomical features, including delicate ones such as hairs, are often intact, improving the possibility of identification to the species level (van der Veen 2007a). The quality of preservation frequently extends to the biomolecular level, where dry specimens are generally good candidates for analysis, although certain lipids may chemically degrade (Brown and Brown 2011; Van Bergen et al. 1997; see Wales et al., chapter 15, this volume, for further discussion). Desiccated specimens have also been used for isotopic analysis (e.g., Reynolds et al. 2005).

Wet Preservation

Plant material can also be prevented from decomposing within an anaerobic environment, a situation that most frequently occurs in waterlogged

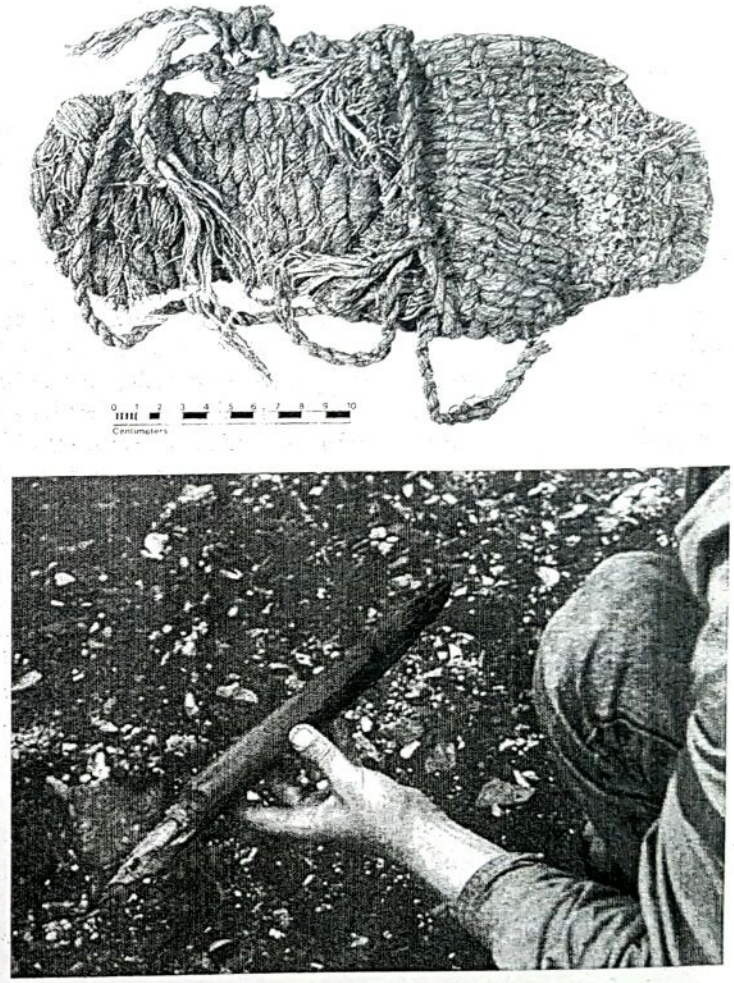

Figure 2.1. *Examples of desiccated and waterlogged botanical preservation. Top: Fort Rock–style sandal from Catlow Cave, Oregon (MNCH cat #1-3563) dated to ca. 9350 cal BP (Connelly and Cannon 1999); photo courtesy University of Oregon Museum of Natural and Cultural History. Bottom: Wood stake from intertidal fish weir dated to earlier than 3000 cal BP, Favorite Bay, Admiralty Island, Alaska; photo courtesy Madonna Moss.*

conditions. Although water saturation will inhibit many microorganisms and slow decomposition in a variety of settings, in practice the degree of preservation also depends on the exposure of the specimen (seasonal fluctuations, burial in sediment, etc.) and the chemical composition of the water (particularly pH and reduction potential) (Caple and Dungworth 1997; Florian 1987; Menotti 2012). For this reason, the density of plant remains in wet sites will vary, but waterlogged assemblages are generally large and species rich (Jacomet 2013).

Some of the best anaerobic preservation occurs in peat bogs, highly acidic wetlands with low reduction potential in which almost all organic matter preserves, although these areas rarely include habitation sites (e.g., Brunning and McDermott 2013; Burov 2001; Coles and Coles 1989 Hillman 1986; Holden 1986; Kaplan et al. 1990; Sands 2013). Other types of inland waterlogged sites, particularly those in colder climates with minimal circulation and inflow (which oxygenate the environment), also have excellent preservation. A well-studied example is the now submerged Late Neolithic lakeside sites of alpine Switzerland, France, and Italy, where wooden house foundations, tools, foodstuffs, and other botanical culture of entire villages have been preserved (e.g., Brombacher 1997; Ebersbach 2013; Jacomet 2009, 2013; Jacomet and Brombacher 2005). These conditions can also occur in warmer climates, such as central Florida, where precontact wood canoes are frequently recovered from lakes lowered by drought (Newsom and Purdy 1990; Wheeler et al. 2003).

In maritime and coastal contexts, the degree of preservation depends not only on the temperature and chemistry of the marine environment but also on the exposure of the artifacts to wave action and other erosional forces (Florian 1987). Most organic material will eventually decay in a marine context (Søreide 2011), but decay can be slowed by cool temperatures, calm, deep water, and, most important, burial in sediment (particularly > 50 cm) (Florian 1987). For example, plant foods, basketry, and wooden objects survived buried 250 m offshore at the Mesolithic site of Tybrind Vig, Denmark (Anderson 1986; Kubiak-Martens 1999). In an area with more wave action, the bases of buried wood stakes forming intertidal fish weirs on the Northwest Coast of North America have been protected by sediment and can be mapped at low tide (figure 2.1; Moss 2013; Moss et al. 1990).

Burial in wet sediment is not confined to underwater contexts. Its significance in producing anaerobic conditions is perhaps best illustrated by the coastal site of Ozette, Washington. Sometimes referred to as the "North American Pompeii," a late prehistoric mudslide at the site covered and preserved the material culture of several plank houses, including boats, hunting and fishing tools, weaving tools, gaming pieces, baskets, boxes, bowls, carvings,

nets, foodstuffs, and the houses themselves, providing a precontact perspective on the rich botanical culture of the Makah (Samuels 1991; Whelchel 2005).

Finally, plant material can also be preserved in frozen contexts. Though often technically "wet," in these cases the freezing temperatures are also a major contributor to the preservation. The most famous cases of frozen macrobotanical remains are those associated with individuals preserved in the ice, notable Ötzi in the Austrian Alps and Kwäday Dän Ts'inchí in British Columbia. In both cases, analysis of gut contents has provided direct evidence of plant foods, while associated possessions have included plant-based tools, medicines, and foods (Acs et al. 2005; Beattie et al. 2000; Bortenschlager and Oeggl 2000; Dickson et al. 2003; Dickson et al. 2004; Heiss and Oeggl 2009; Oeggl 2009).

In ideal conditions, wet preservation will maintain plant specimens in a condition similar to that of modern specimens, with both anatomical structures and cellular characteristics intact (Jones et al. 2007). However, in many cases specimens may be preserved less well than their appearance suggests. The majority of research on what precise changes occur in waterlogged specimens has focused on wood: despite seeming intact, cell walls are frequently weakened so that a specimen can collapse if it is allowed to dry (Gratten 1987). Waterlogging can cause degradation of biomolecules, although DNA has been recovered from waterlogged plant material in some cases. The exception is frozen sites, which have excellent preservation of biomolecules (Schlumbaum and Edwards 2013; see also Wales et al., chapter 15, this volume).

Carbonization and Mineralization

Although the wet and dry contexts discussed above produce the most diverse and best-preserved plant assemblages, these conditions only occur in a small percentage of archaeological sites. In the majority of cases, the decomposition processes discussed in the introduction to this section will break down organic material unless the specimen has undergone a transformative process to convert organic compounds to inorganic structures (figure 2.2).

In rare cases, this occurs through mineralization in which organic material within plant structures is gradually replaced by precipitated minerals from the surrounding substrate, preserving the anatomical structure. This process occurs frequently in phosphate-rich contexts (often latrines or coprolites) (Green 1979; McCobb et al. 2003) but is also documented in cases where deposited plants are in direct association with a corroding metal such as bronze, copper, or iron (Chen et al. 1998; Keepax 1975; Miksicek 1987; Moulherat et al. 2002). Mineralized specimens will frequently be unevenly preserved, as the process

FIGURE 2.2. *Examples of biomineralized and carbonized seeds from Iron Age archaeological sites in West Africa. Left to Right: biomineralized* Scleria *sp., carbonized* Pennisetum glaucum, *carbonized Solanaceae.*

may proceed at different speeds for different anatomical parts (Green 1979). In contrast to mineralization, which is confined to very specific contexts, carbonization is a common phenomenon accounting for the bulk of macrobotanical remains recovered from archaeological sites.

Carbonization or charring is a process through which exposure to heat, usually in a low-oxygen environment, converts organic material to an inorganic structure consisting primarily of carbon (Bryant 1989; Märkle and Rosch 2008). The advantage of carbonized remains is that, once burned, they preserve in a wide variety of environments, although they can still break down in alkaline contexts and are vulnerable to mechanical damage (Bryant 1989). Consequently, carbonized assemblages are found in sites around the world and account for a significant portion of the macrobotanical record (e.g., Gremillion 1997; Hastorf 1999; Hastorf and Popper 1988; Minnis 2003, 2004; VanDerwarker and Peres 2010). However, carbonization usually only affects a small portion of the original assemblage of deposited macrobotanical remains; even in cases of catastrophic burning, it is rare for every element of the original assemblage to carbonize in identifiable form. For example, at the West African site of Kirikongo, only wood, likely from posts or roof beams, and seeds have been identified in a burned ritual structure that likely included a wider range of botanical culture (Dueppen 2012). Consequently, researchers have invested significant effort in modeling both the relationship between the carbonized sample and the original plant assemblage in use at the site, as described later in this chapter, and the actual carbonization process.

Under ideal conditions, carbonization produces a perfectly preserved specimen. However, specimens also pop, twist, or reduce completely to ash. In addition, the carbonization process frequently shrinks specimens, a phenomenon that has substantial implications for the identification of domestication based on seed size (e.g., Braadbaart and Wright 2007; Smith 2014; Wright 2003, 2008). Extensive experimental research designed to determine the conditions under which various species and plant parts carbonize and the effects of carbonization on morphology has demonstrated that the process is complex and situational (e.g., Boardman and Jones 1990; Braadbaart and Bergen 2005; Braadbaart et al. 2004; Braadbaart and Poole 2008; Braadbaart et al. 2007; D'Andrea 2008; Dezendorf 2013; Guarino and Sciarrillo 2004; Gustafsson 2000; Hather 1993; Hubbard and Azm 1990; Lopinot 1984; Margaritis and Jones 2006; Märkle and Rosch 2008; McParland et al. 2010; Prior and Alvin 1983; Rossen and Olson 1985; Sievers and Wadley 2008; Smith and Jones 1990; Terral and Durand 2006; Théry-Parisot 2001; Théry-Parisot et al. 2010; Théry-Parisot and Henry 2012; Wilson 1984; Wright 2003, 2008). As Wright (2003:577) summarizes, whether and how a specimen carbonizes depends on the species and plant part, the condition of the specimen (e.g., moisture content), and the conditions under which it is exposed to heat (e.g., temperature, oxygen, time, etc.). However, creation of intact carbonized specimens is most likely to occur in reducing (low oxygen) conditions and when fires burn at lower temperatures (e.g., ca. 200–600°F) for shorter amounts of time (Boardman and Jones 1990; Wright 2003). In addition, as specimens with different characteristics (e.g., seeds of different sizes and starch/oil contents) favor different carbonization conditions, systematic preservation biases may occur in particular archaeological sites or contexts.

Although any part of the plant can be preserved through carbonization, the majority of the above studies have focused on seeds and seedlike plant parts (achenes, caryopses), nutshell, and wood charcoal, because, as described above, they preserve well, forming the bulk of most carbonized macrobotanical assemblages. However, studies have demonstrated that other carbonized material can be identified, including roots, tubers, leaves, and fibers, although in many cases these identifications require observation of anatomical features under high-power microscopy (e.g., Cortella et al. 2001; Good 2001; Hather 1993). At a molecular level, DNA, lipids, and other molecules are usually damaged or destroyed by the carbonization process, although there is a growing number of case studies of successful extraction from charred archaeological specimens (e.g., Brown and Brown 2011; Schlumbaum et al. 2008; Wales et al., chapter 15, this volume).

Plant Impressions and Representations

Thus far, this discussion has focused on preserved plants in the archaeological record. However, there are two significant categories of macrobotanical data in which the plant itself is not preserved at all. Plants can leave impressions on pliable substances that have since hardened. Impressions may result from the intentional use of plants in decoration, such as the use of *Blepharis* sp. roulettes in West Africa (Haour et al. 2010) or cord decoration on Neolithic beakers in Europe (Grömer and Kern 2010). Plants can also leave impressions when incorporated as a temper for pottery vessels or mud brick or as the underlying structure of wattle-and-daub architecture (e.g., Hovsepyan and Willcox 2008; Peacock 1993; Sherard 2009). Finally, many impressions are the result of fortuitous accidents, such as a jute textile draped over a clay pot prior to firing at Harappa circa 2000 BCE (Wright et al. 2012).

Impressions are often imperfect and lacking in detail. However, when identifications can be made, they may provide a data source in sites with otherwise poor preservation. Perhaps most significant, impressions have been used to document particularly early examples of plant use. Some of the early identifications of cordage from the Upper Paleolithic were based on impressions (Soffer et al. 2000). Likewise, the oldest examples of domestic pearl millet seeds are known from impressions in pottery at Karkarichinkat, Mali (Manning et al. 2011). In other cases, impressions can provide a perspective distinct from other elements of the macrobotanical record. For example, the use of nonlocal plants as temper has been used to identify trade ceramics (Mariotti Lippi et al. 2011; Nixon et al. 2011).

Finally, a brief mention should be made of the importance of artistic representations of plants. Plants in paintings, carvings, and other artistic media can be richly interpreted within an art historical framework as decorative elements; they may also be identified by paleoethnobotanists, who draw on these representations not only to understand the cultural significances of the plants, but also to discover evidence of the use of plants not otherwise present in the archaeological record (e.g., Akers et al. 2011; Eubanks 1999; Ford 1994; Hays-Gilpin and Hegmon 2005; McMeekin 1992; Miller 2000, 2013).

FORMATION OF MACROBOTANICAL ASSEMBLAGES IN ARCHAEOLOGICAL CONTEXTS

As is clear from the descriptions above, preservation conditions will significantly affect the range of macrobotanical specimens recovered from a site. However, to interpret the archaeological assemblage fully, it is equally necessary to understand how these assemblages are initially created and how they are affected by post-depositional processes.

In order to interpret paleoethnobotanical assemblages, as a first step archaeologists model the relationships between living and dead assemblages. Although these models are often most effective when developed for specific environmental and cultural contexts (see below), generalized models provide a basic framework. A recent example is that developed by Lee (2012:651–53), who distinguishes between a life assemblage (living plant population), death assemblage (plants brought into sites), deposited assemblage (discarded and buried plants), and fossil assemblage (preserved plants). At each stage, some elements of the assemblage are lost, consumed, or otherwise removed, a process that, as Ford (1979) reminds us, is shaped by cultural patterns of use and disposal. Ultimately, Lee's and other models formalize the basic concept that plants enter archaeological sites through a variety of routes or paths and once at an archaeological site, they are affected by cultural and noncultural processes that in turn affect their preservation (the sample is then further narrowed by recovery and analysis; see White and Shelton, chapter 6, this volume; Fritz and Nesbitt, chapter 7, this volume). In this section, we look first at three major pathways by which plant species enter sites: direct anthropogenic (plant species intentionally brought to sites by humans), indirect anthropogenic (plant species unintentionally brought to sites, or brought to sites as a secondary effect of another activity), and non-anthropogenic (all other routes by which plants enter sites). We then briefly examine some of the most common post-depositional processes that affect the interpretation of macrobotanical remains.

Direct Anthropogenic

Human societies gather and cultivate a wide range of plants for a large variety of purposes. Plants may be used for food, fuel, fodder, construction material, bedding, basketry, medicine, ritual objects, dyes, fiber and cordage, tools, toys, and more: for example, Burkill (2004) indexes 7 primary and 116 secondary categories of plant use in West Africa. In each case, a plant is intentionally selected for its properties and frequently brought to a cultural space where it may eventually be preserved in an archaeological deposit. The choices made in bringing these plants into archaeological sites can provide insight into the cultural and environmental contexts in which these choices were made (e.g., Lentz and Hockaday 2009; Lepofsky and Lyons 2003; Marston 2009).

Once the choice has been made to bring a plant into the cultural sphere, the mode in which it is collected, transported, processed, used, and discarded

will affect its entry into the archaeological record in different ways in different preservation contexts (Dennell 1976; Ford 1979; Miksicek 1987; Minnis 1981). These activities are frequently routinized and reflect local social and cultural practices (Atalay and Hastorf 2006; van der Veen 2007b). Therefore, modeling the processes that ultimately create the archaeological record not only aids in identifying what activities took place at a site, but also allows researchers to utilize the macrobotanical assemblage to address issues such as identity and cultural change.

Given the dominance of carbonized assemblages in the global paleoethnobotanical record, many studies pay particular attention to when plants are exposed to heat, either intentionally or accidentally. As an example, consider the typical representation of three economically valuable West African trees in wood charcoal assemblages. Although the leaves and fruits of the baobab (*Adansonia digitata*) are edible, the tree produces a very poor fuel and construction wood and is therefore virtually never present in archaeological wood charcoal assemblages. In contrast, the wood of the shea tree (*Vitellaria paradoxa*) burns well and at a high temperature, but the tree is more valued for its oil-rich nuts and therefore is frequently protected. Finally, the woods of *Combretum* spp. burn very well and the trees have few other economic uses, making them common in wood charcoal assemblages (Neumann 1999).

Many of the most interesting and comprehensive studies on the entry of plants into the archaeological record have focused on food processing (e.g., Abbo et al. 2008; Atchison et al. 2005; Chernoff and Paley 1998; D'Andrea 2008; Dennell 1974; Fuller and Harvey 2006; Fuller and Stevens 2009; Hastorf 1988; Jones 1987; Jones and Halstead 1995; Munson 1984; van der Veen 1989). A recent example is Margaritis and Jones's (2006) exploration of grape processing in Hellenistic Greece. Through a combination of historical research, ethnographic observation, and experimental charring, they were able to link specific combinations of whole fruits, pips, pressed skins, and other parts of the grape cluster (pedicels, peduncles, and rachises) to various stages in red, white, and rosé wine production as well as fresh and dried grape production. Margaritis and Jones's research is fairly unusual in its focus on fruit, as the majority of crop processing research has been on grains, due not only to the significance of cereal crops, but also to their complex processing, as best demonstrated by Hillman (1981, 1984a, 1984b, 1985). His particularly detailed studies covered plant part distribution, waste production, and opportunities for carbonization for approximately thirty stages from harvest to processing to cooking of Near Eastern grain crops (wheat, barley, rye, and oats).

Indirect Anthropogenic

Though the direct anthropogenic assemblage is a significant component of the plants found at an archaeological site, many plants are brought to sites by humans unintentionally. These plants are frequently accidentally collected with other, desired species or acquired incidentally (e.g., while collecting dung, as described below) and, although not expressly targeted, can still yield a great deal of information. Particularly fruitful has been the study of weeds, which are frequently collected with crops during harvest. Weed assemblages are often particular to certain crops, soil types, and cultivation practices, and can consequently be used to address such questions as the range of crops grown, the farming practices in use, and the health of the field system (Bogaard et al. 2005; Charles et al. 2003; Jones 2002; Jones, Bogaard, Charles, and Hodgson 2000; Jones et al. 2010; Jones et al. 2005).

Determining whether a useful plant was intentionally or unintentionally transported to an archaeological site can be challenging. For example, many "weeds" with edible plant parts may be intentionally encouraged in fields and Behre (2008) notes that cleaning these edible "weeds" from harvested crops can provide an opportunity to collect them in large quantities, encouraging their consumption. In contrast, simply because a plant is edible does not mean it was necessarily brought to a site for that purpose. For example, kram-kram (*Cenchrus biflorus*), a wild small-seeded grass, is documented ethnographically in West Africa as a food plant, but is also a burr that clings to clothing and animal fur, making it easy to transport accidentally to a site.

Particularly well studied by archaeologists working in areas where livestock are common is distinguishing the use of dung as fuel from the direct collection of wild plants (Anderson and Ertuğ-Yaras 1996; Bottema 1984; Charles 1998; Hastord and Wright 1998; Miller 1984; Miller and Smart 1984; Murray 2005; Reddy 1998; Shahack-Gross 2011). Dried dung may be burned directly or mixed with dry plant matter prior to being formed into cakes, although in either case, the included seeds, chaff, and other plant parts can carbonize when the dung is burned. Miller and Smart (1984) have noted that dung burning must be considered as a possibility in sites where burned dung and macrobotanical assemblages with high numbers of fodder seeds are recovered in regions with little wood fuel, particularly if the recovery contexts suggest fuel use rather than food waste. If not recognized, dung-derived samples can be misinterpreted to suggest higher reliance on wild plants in human diets. However, once identified, their analysis can contribute significantly to understanding the local agropastoral system (e.g., Delhon et al. 2008; Miller 1996).

Non-Anthropogenic

Finally, it is important to consider that many of the plants recovered from archaeological contexts may have entered the site through non-anthropogenic means. Seeds are widely dispersed independently of human activity by wind, water, and other vectors (including insects and seed-consuming animals), a process often referred to as "seed rain" (Cappers 1993, 1995; Minnis 1981). Many plants produce hundreds to thousands of seeds, which can be spread over significant distances (particularly by water) although most seed rain assemblages will be fairly localized (Cappers 1993; Minnis 1981). Rodents, ants, termites, and other taxa can also transport seeds both into and within sites (see below). Overall, as Minnis (1981) describes, seed rain can easily contribute thousands of specimens to an archaeological site before, during, and after an occupation.

Many of these incidentally introduced seeds will be uncarbonized and therefore unlikely to preserve in most settings. As Miller (1989) notes, animals and insects will tend to transport uncarbonized and therefore edible seeds. However, non-anthropogenic seeds can become charred through a variety of processes. Seeds that have entered the soil prior to occupation through seed rain can be carbonized when a fire is built over them, seeds can blow into anthropogenic fires during occupation, and wind can easily disperse seeds carbonized in a naturally occurring wildfire. Although much of the research on non-anthropogenic contributions has focused on seeds due to their dispersal mechanisms, many of these same processes apply to other plant parts (e.g., Smart and Hoffman 1988).

Despite their nonhuman-centered pathways to entering the site, these elements of the plant assemblage have interpretive value. Humans have impacts on their surrounding vegetation, even in cases of fairly low-density population (e.g., Smith 2011b; see also B. Smith, chapter 18, this volume). For example, the background flora may include species that colonize recently cleared areas, wind-dispersed weeds from nearby fields, or disproportionate numbers of seeds from useful wild plants, the growth of which may have been encouraged by local populations.

Post-Depositional Processes

Finally, it is worth considering the post-depositional effects that can alter the botanical assemblage once an archaeological site has been abandoned. As already discussed above, plants deposited in archaeological sites will preserve differently depending on the local environment and the condition (e.g., carbonized or not) of the plant when it was deposited. However, all archaeological sites are subject to a range of post-depositional processes, including sediment shifting, cracking, trampling, flooding, bioturbation, and erosion (e.g., Miksicek 1987; Rolfsen 1980; Schiffer 1987; Théry-Parisot et al. 2010; Wood and Johnson 1978).

Burrowing animals and invertebrates, notably rodents, earthworms, ants, and termites, can move both seeds and sediment within a cultural deposit (sometimes over several meters in depth), mixing specimens from different contexts (Bocek 1986; Borojevic 2011; Canti 2003; Johnson 1989; McBrearty 1990; Miksicek 1987; Stein 1983; Tryon 2006; Wood and Johnson 1978). Some of these animals stockpile seeds, creating diverse caches that can give the impression of human harvesting (Borojevic 2011; Gasser and Adams 1981; Miller 1989; Minnis 1981). Roots can also cause compression, soil movement, and damage to macrobotanical specimens (Lopinot and Brusselí 1982; Miksicek 1987). Sediment in archaeological sites can shift and move slightly for other reasons, and in some cases may crack, for example due to drying (Erlandson and Rockwell 1987; Wood and Johnson 1978). This can cause seeds to move up and down within the deposit. Although these effects are minimal in most cases, particularly in instances of old, rare, or unexpected finds, it is essential to ensure that the site stratigraphy is intact at both the macro and the micro level. Many post-depositional effects are clearly visible in excavation stratigraphies, but macrobotanical remains are often quite small, and as such may be significantly affected by processes that are not always immediately apparent (Borojevic 2011; Fowler et al. 2004; Miksicek 1987).

CONCLUSION

Macrobotanical assemblages from archaeological sites are cultural but are significantly shaped by the local environment both at the time of site occupation and in post-depositional contexts. As demonstrated above, successfully modeling how plants enter and become preserved in archaeological sites is a complex process that must take into account the intrinsic properties and ecology of those plants being studied; how the plants may be culturally managed/cultivated, processed/modified, and used/consumed; and the effects of differential preservation on the diverse elements of the botanical assemblage.

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3

Formation and Taphonomic Processes Affecting Starch Granules

AMANDA G. HENRY

Like pollen and phytoliths, starch granules have proven to be a valuable source of information about ancient plant use. Their semi-crystalline structure and insolubility in water, as well as the sheer numbers in which they are produced in plants (Pérez et al. 2009; Swinkles 1985), all help preserve them in the archaeological record. Their taxon-specific morphology and the manner in which they preserve signs of intentional processing are powerful markers of human dietary behavior. However, because of starch granules' unique biological origins, they can be damaged or destroyed by certain biological, chemical, and human-induced factors. In order to fully interpret and properly analyze the appearance of starch granules in the archaeological context, we must first have a good grasp of the processes leading to the formation and destruction of these granules. Paleoethnobotanists have been using starch granules as a means of identifying ancient use of plants since at least the early 1980s, but our understanding of starch granule formation, damage, and destruction comes primarily from the food science industry, where the properties of starches have been studied for several hundred years (Schwartz and Whistler 2009). The information presented here is more extensively reviewed in the food science literature, and those interested in a more detailed description, particularly of starch formation and gelatinization processes, are encouraged to read Galliard (1987), Tester and colleagues (2004), and BeMiller and Whistler (2009). Finally, a brief note on

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7

Laboratory Analysis and Identification of Plant Macroremains

GAYLE FRITZ AND MARK NESBITT

The laboratory handling and identification of archaeological plant remains is the crucial step between their recovery in the field (chapters 2–6, this volume) and their interpretation (chapters 9–19, this volume). Accurate identification of plant remains is fundamental to the sophisticated interpretation of foraging and agricultural systems. Inaccurate identification can, at worst, lead to serious errors in the identification of early domesticates or plant introductions, as discussed by Harlan and de Wet (1973) in a classic article that is still relevant today. Even in less extreme cases, poor-quality identifications obscure changing patterns of plant use and present a major challenge to the compilation of regional or supraregional syntheses.

Given the importance of plant identification, and a history of high-quality archaeobotany that extends as far back as 150 years in some regions, it might seem surprising that this essential skill is still highly subjective, based on nuances of shape and texture that are hard to describe, taught by apprenticeship (with varying degrees of support) in an established archaeobotanical laboratory, and then often practiced in isolation. The good news is that work in the last 20 years has addressed these issues, with digital media taking a central role in providing new tools, and enabling easier distribution and exchange of information (Warinner and d'Alpoim Guedes, chapter 8, this volume).

Our aims in this chapter are threefold. First, we set out core practice for the handling and identification

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of (mainly) charred plant macroremains in a manner that will be both useful for the beginner and of interest as a baseline for comparison for experienced practitioners. In the available space we can only seek to complement existing handbooks for the New World (Pearsall 2000) and Old World (Jacomet and Kreuz 1999). Second, we highlight examples of good practice in the development and application of identification techniques. Although many of these are drawn from Europe, the Near East, and North America, reflecting the concentration of archaeobotanists working in those regions, there are lessons applicable to other parts of the world. Third, we offer something of a personal perspective on how identification practice has changed and how we would like to see it develop. As becomes clear in the chapter, there is still much to do, and exciting prospects lie ahead for new researchers.

TAPHONOMY AND PRESERVATION

In most cases only a small proportion of plant parts become incorporated into the sediments of an archaeological site and survive until the present day (Gallagher, chapter 2, this volume). Three agents are at work. Humans select which plants and which parts of plants are brought onto archaeological sites. It is often the case that only the edible portion of the plant, typically a propagule such as a seed or fruit, or storage organ such as a root, is harvested and brought back to the site. Other plant parts will only be brought on site if they need processing to separate them from the useful part, or if the other plant parts are also useful. A good example of both is cereals such as rice and wheat, for which the grains are most efficiently stripped from the culms (stems) by bulk processing at or near the settlement, and whose straw is of value as animal feed, fuel, or as a material for craft production or construction (van der Veen 1999a).

The second agent is that of natural and anthropogenic decay. In tropical and temperate climates plant material that is not consumed by humans will be eaten by animals such as rodents or insects or by fungi and other microorganisms. In arid areas such as the Nile valley, American Southwest, and parts of the Andes where these processes are slowed, the quantity of material surviving can be so great as to be overwhelming (van der Veen 2007a). At the same time, the preservation is so good, extending even to color, that conventional techniques of botanical identification can be applied. A recently published example of such sites (with exemplary color illustrations) is the Roman and Islamic ports at Quseir al-Qadim, Egypt, with fresh-looking material such as fragments of sugar cane, ginger rhizome, and banana skin (van der Veen 2011). Comparable preservation can occur with frozen plant remains, as in the case of the Alpine Iceman (Bortenschlager and Oeggl 2000). Dry conditions can also occur in wet countries, for example the medieval sheaves of wheat and accompanying weeds found deep inside thatched roofs in northern Europe (de Moulins 2007). Waterlogged, thus anaerobic, conditions can also lead to the preservation of a remarkably wide range of material. The weaker cells, such as starchy endosperm, however, usually decay, leaving flattened plant remains that look very different from fresh material. Cell patterns in wet preserved material are often much more obvious and useful for identification, but will require comparison to reference material treated with acid to replicate the effects of waterlogging. Waterlogged plant remains are locally abundant in northern Europe and in other areas with waterlogged landscapes such as Florida in the southeast United States, but we do not have space to cover their specialized processing and identification in this chapter (Birks 2007).

The most widespread form of preservation is through charring by fire. Even waterlogged and arid plant assemblages contain significant amounts of charred material. Charring converts plant materials to more or less inert carbon, while preserving its shape. Fire is also destructive: the lighter parts of plants, such as leaves and the bracts surrounding the grain, are likely to burn to ash (Boardman and Jones 1990) and not be recovered (except in the form of phytoliths: see Pearsall, chapter 4, this volume). Both the quantity and quality of plant remains vary enormously by site, in relation to what are still poorly understood factors of burning and site deposition. Because charring often occurs in domestic hearths and ovens in which wood is the main fuel, wood charcoal often forms a significant part of the assemblage.

Archaeological recovery is the third and final destructive agency to act before plant remains reach the laboratory. Although water flotation is proven as the most effective way to retrieve charred plant remains dispersed in archaeological matrix, it is inevitably destructive of fragile material such as light chaff and oil-rich seeds (Märkle and Rosch 2008; White and Shelton, chapter 6, this volume; Gallagher, chapter 2, this volume).

In summary, a series of processes intervenes between a human encounter with plants and the deposition of plant material in archaeological matrix. In most parts of the world, this leads to charred wood and seeds (broadly defined here to include other plant parts such as parenchyma) as being the main form of plant macroremains retrieved and studied by archaeobotanists.

TAXONOMIC GOALS AND LIMITATIONS

In an ideal situation, we could identify all or most archaeological plant remains to the level of species or even subspecies or variety, and we could distinguish clearly between domesticated plants and their wild ancestors or weedy relatives. Generations of archaeobotanists have, in fact, devoted considerable research efforts to recognizing anatomical features and other morphological characteristics that enable key species or subspecies-level identifications to be made, including those that signal domestication. Still, real-world assemblages, whether they consist of charred remains recovered by flotation, or waterlogged or desiccated remains, usually include many specimens that are too fragmentary, too eroded, or too obscured by sediment to be recognized beyond a more inclusive level, whether it be genus, family, or even a broad category such as "nutshell" or "parenchyma." In many cases, too, seeds of different taxa may be so similar in appearance that identification will never be possible beyond genus level, regardless of the quality of preservation.

James Massey, former professor of botany and a plant taxonomy instructor at the University of North Carolina at Chapel Hill, referred to paleoethnobotanists as "wizards" given our apparent ability to recognize a species by examining a barely visible speck of charred matter, whereas botanists usually work with at least a herbarium-sized plant specimen containing leaves, stems, roots, and well-preserved flowers, fruits, or seeds. Of course, we are not wizards, and one of the skills gained by experience is knowing when a specimen is unidentifiable and when it is best to categorize it broadly rather than specifically. Archaeobotanical analysis is guided by research questions and goals, as well as by constraints imposed by preservation. In North America, for example, it may make little difference whether or not one distinguishes between the six or more species of wild grapes (*Vitis* spp.) native to a given region, whereas in Southwest Asia and Europe, the presence of domesticated grapes (*Vitis vinifera*) as opposed to wild grapes has significant cultural and economic consequences. The amount of time and attention spent on species-level identification, therefore, varies according to interpretive yield. More time is usually given to unknown seeds that occur in the greatest quantity or ubiquity.

BASIC SORTING PROCEDURES AND EQUIPMENT

Analysis of plant remains recovered by flotation or a comparable, fine-mesh recovery method entails examining like-sized particles under low-power magnification and recording counts, weights, and often measurements or other attributes of items according to taxonomic grouping. The procedures described here are based on those used in the archaeobotany laboratory at Washington University in St. Louis, but broadly similar procedures are used in most laboratories. Figure 7.1 is an example of an analysis form used at Washington University, and table 7.1 is a list of standard laboratory tools.

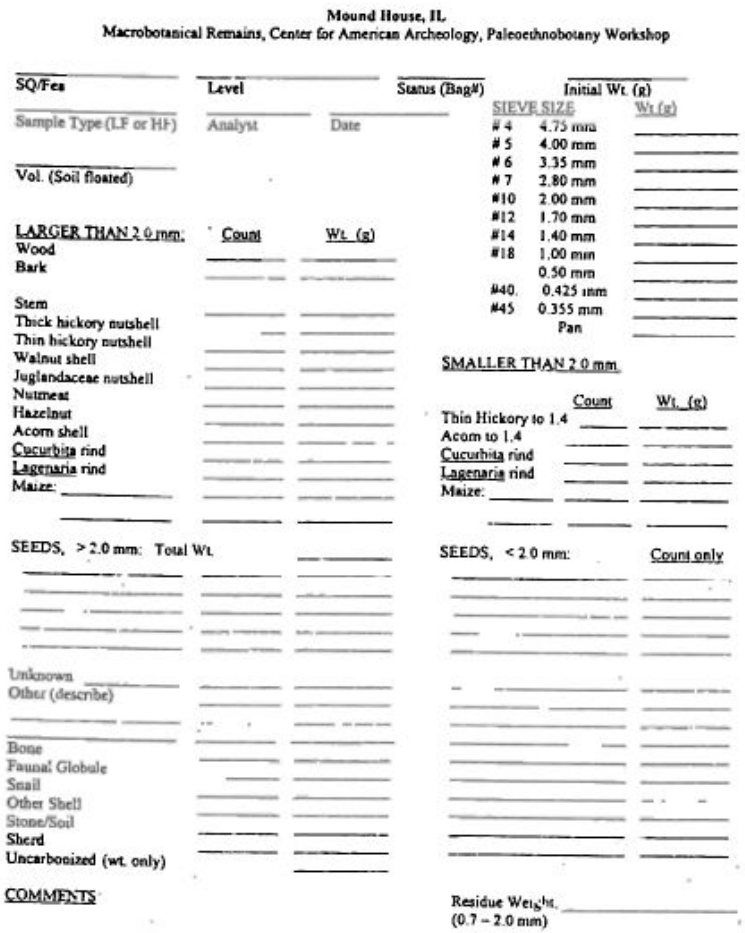
Selection of Samples

Where relatively few seeds have been recovered, all samples known to be from secure stratigraphy can be analyzed. However bulk flotation of richer sites, such as those in the Near East, may produce hundreds of samples varying from a few seeds to thousands. Here samples may be chosen on the basis that they are likely to contain at least 500 seeds, as recommended on the basis of statistics (van der Veen and Fieller 1982). Smaller samples might be included because they fill gaps in time periods, or because they come from archaeological contexts of special interest. Any sample might be excluded if its dating is not secure, although AMS radiocarbon dating does allow the dating of individual items of key chronological concern.

Sorting Procedures

If a sample consists of both light and heavy fractions (see White and Shelton, chapter 6, this volume), each is usually analyzed separately, although the numerical data can be combined when reported. Each sample (or each light and heavy fraction) is weighed to the nearest 0.01 g and the contents passed through a series of nested geological sieves, resulting in "splits" of similar-sized objects. It is standard in North America to use a 2.0-mm sieve because this is the cutoff point for complete sorting of larger particles versus removal of selected smaller items that are difficult to identify when smaller than 2.0 mm. When charred items larger than 2.0 mm are very rare, a smaller mesh size can be the cutoff point; however many plant types lose recognizable features with fragmentation below 2.0 mm. All ancient seeds and recognizable seed fragments are pulled from the smaller fractions, regardless of size, along with distinctive plant parts such as gourd rind, maize kernel, and acorn shell fragments, which are too fragile to be well represented in the > 2.0 mm splits. In Europe, where a mesh smaller than 2.0 mm is likely to let through large numbers of cereal grain fragments, the contents of the 1.0 mm sieve may be fully sorted, albeit after subsampling in the case of large samples.

Wood and nutshell might be abundant enough to warrant using as many as four or five splits with mesh sizes larger than 2.0 mm, but samples from sites where charred plant remains are rare or consist mainly of seeds and other



Mound House, IL
Macrobotanical Remains, Center for American Archeology, Paleoethnobotany Workshop

SQ/Fea | Level | Status (Bag#) | Initial Wt. (g)

Sample Type (LF or HF) | Analyst | Date

Vol. (Soil floated)

LARGER THAN 2.0 mm:	Count	Wt. (g)
Wood		
Bark		
Stem		
Thick hickory nutshell		
Thin hickory nutshell		
Walnut shell		
Juglandaceae nutshell		
Nutmeat		
Hazelnut		
Acorn shell		
Cucurbita rind		
Lagenaria rind		
Maize:		
SEEDS, >2.0 mm: Total Wt.		
Unknown		
Other (describe)		
Bone		
Faunal Globule		
Snail		
Other Shell		
Stone/Soil		
Sherd		
Uncarbonized (wt. only)		

COMMENTS

SIEVE SIZE		Wt (g)
# 4	4.75 mm	
# 5	4.00 mm	
# 6	3.35 mm	
# 7	2.80 mm	
#10	2.00 mm	
#12	1.70 mm	
#14	1.40 mm	
#18	1.00 mm	
	0.50 mm	
#40	0.425 mm	
#45	0.355 mm	
	Pan	

SMALLER THAN 2.0 mm	Count	Wt. (g)
Thin Hickory to 1.4		
Acorn to 1.4		
Cucurbita rind		
Lagenaria rind		
Maize:		
SEEDS, <2.0 mm:	Count only	

Residue Weight (0.7 – 2.0 mm)

FIGURE 7.1. *Sample analysis sheet for recording data from a flotation sample.*

relatively small items may require no sieves greater than 2.0 mm. Smaller-sized sieves may include 1.0 and .5 mm (or in Europe, often .3 or .25 mm) only, but intermediate splits might be needed, depending on sample size and composition. Once a sample has been passed through the graduated sieves, the largest items are examined under low-power magnification and grouped

TABLE 7.1. List of basic equipment needed for analysis of macroremains in a paleoethnobotany laboratory

Function	*Equipment*
Microscopy	Microscope(s); light source for each microscope
Sample sorting	Standard USDA (or other) geological sieves; sorting pans or dishes; pouring spout; riffle-type sample splitter
Sample weighing	Weighing scales; analytic balance (optional)
Sample handling	Dissecting needles; featherlight forceps; spatulas; fine paintbrushes
Sample storage	Gelatin capsules and/or plastic centrifuge tubes; glass vials; 2-mL-density plastic bags; metal tins or glass bottles; acid-free paper for tags
Reference materials	Reference manuals; comparative reference collection

according to taxon or plant type, followed by examining the contents of progressively smaller splits. All items greater than 2.0 mm are normally counted and weighed to the nearest 0.01 g, although we do not always count wood when there is a great deal of it. If a taxon such as walnut shell is found only in a < 2 mm split but is nonetheless clearly identifiable, it can be pulled and given a count of 1 and weight of .01 g in order in include it in ubiquity frequencies (% of samples in which a plant type occurs; Marston, chapter 9, this volume). For items greater than 2.0 mm, quantified categories include charred seeds, sorted as close to species-level as advisable, and fragile but clearly recognizable plant parts such as gourd rind or other distinctive cultigens, as discussed above. In North America, seeds less than 2.0 mm are not weighed, but only counted, but in Europe the 1mm fraction may also be fully counted and weighed.

Uncharred seeds are not pulled from assemblages when they are all modern contaminants, and learning to tell the difference between dark-colored modern seeds and their charred counterparts is one of the challenges of archaeobotanical training. But when samples come from unusual contexts in which ancient seeds and other remains survived without charring, a different strategy is obviously necessary. Samples from Cahokia's sub-Mound 51, for example, consist of 1,000-year-old feasting remains that were purposefully, rapidly, and deeply buried under mound fill after the structures in which feasting activities had taken place were partially burned, leaving both charred and uncharred wood and thousands of seeds in both physical states (Pauketat et al. 2002). In these situations, analysis sheets and published tables should be modified to include separate columns for charred and uncharred materials. Reporting

the different frequencies of both uncharred and charred ancient seeds makes it possible to compare results to assemblages in which only the latter are preserved (cf. for ancient Egypt Smith 2003).

Preferences for sorting tools and techniques vary, with choices guided in part by the available microscope base and working area. Plastic dishes or trays are problematic due to static that causes seeds to undergo damage or loss, so glass Petri dishes are used under the microscope. Round metal baking tins, 8–10 cm in diameter, work well for sorting large fractions, but they should not be too dark or so shiny that they blind the analyst with reflected light. Dissecting needles work well for moving items around in the sorting dish, especially if the tip is bent to form an obtuse angle. Some analysts prefer fine paintbrushes for sorting, and these work very well for picking up seeds to transfer them to capsules, tubes, or other containers for curation. Entomologists' forceps serve well to pick up seeds, but must be of the soft ("featherweight") type to avoid breakage. During routine sorting at 10× to 15× magnification, some analysts move fragments across the field of vision, separating them into taxonomic groups. Others recommend dividing the remains according to a grid system and examining them systematically by square (Bohrer and Adams 1977). A small dish filled with clean sand is an essential tool for detailed examination, allowing seeds to be positioned and examined at a variety of angles.

The end result is a set of tins, vials, boxes, tubes, and/or capsules divided into the respective groups of completely sorted (> 2 mm or > 1 mm) plant types, along with all seeds and other "special" remains pulled from the smaller splits, and the resulting residual fragments (< 2 mm or < 1 mm). All containers must be clearly labeled with site name or number and provenience information, and with sample data including plant type, split size, and light versus heavy fraction status. Acid-free paper can be cut into little tags to fit inside capsules or tubes if the containers themselves are too small to label. Careful attention should be given to labeling and storage so that seeds can be restudied. It is also important that the original records of laboratory subsampling and scoring are clear and are retained.

Subsampling

Samples too large to analyze in their entirety can be subsampled by determining the weight of the whole sample and then pouring it through a riffle box sample splitter, using a back-and-forth motion along the length of a riffle box while pouring to divide the sample in half. The procedure is repeated with one-half of the sample in order to acquire a 25 percent subsample. It should not be assumed, however, that all taxa—especially rare ones—will be represented in each split, or that common taxa will be equally divided into the final groups (see Pearsall 2000:112–13, for uneven results of one sorting test).

Major Pieces of Laboratory Equipment

The most expensive laboratory requirement is a good binocular stereomicroscope with continuous zoom magnification beginning at either 7× or 10× at the low end, going up to at least 30× and ideally higher. One eyepiece should be equipped with an optical micrometer, and a microscope model with a phototube for camera mounting is highly recommended. Desirable extras include a camera lucida, for drawing seeds, and a teaching tube with a second pair of eyepieces, so that two people can look at material together. Student-quality or field-quality microscopes are available with built-in, direct, halogen lighting from above (usually combined with florescent or halogen lighting from below in order to view transparent material through a glass stage), but these cause more eye fatigue than dual-armed fiber-optic light sources, which also allow for angle adjustment. Fiber-optic lighting is also cool and will not damage seeds by heat. Higher-power (40× to at least 400×), phase-contrast, compound microscopes are necessary for analysis of microbotanical remains. A metallurgical ("epi-illuminating") microscope with incident and transmitted light is needed for wood analysis.

A small electronic digital balance that weighs to at least the closest 0.01 g is a required piece of equipment, and archaeobotanists who record the weights of individual seeds or low numbers of small seeds need to invest in a more sensitive, enclosed analytic balance. A set of standard, graduated geologic sieves is the last significant expenditure. We recommend buying high quality, heavy-gauge, brass or steel sieves, eight inches (200 mm) in diameter, with stainless steel mesh, and avoiding smaller, cheaper, plastic versions. Laboratory sieves should never be used for fieldwork or be loaned to colleagues working with sediments that might clog up the finer holes.

IDENTIFICATION TOOLS

Charred plant material loses its original color (an important character in many seed guides written for agricultural or botanical use) but retains its shape and sculpturing, with minor changes (Braadbaart and Bergen 2005; Braadbaart and Wright 2007; Märkle and Rosch 2008), and can therefore be identified by comparison to modern reference material. More subtle characters, such as surface cell patterns, are lost in many cases. Charring, however, can sometimes make them more visible by removing the waxy cuticle.

The basis of archaeobotanical identification is the comparison of unknown to known material, whether in a photograph or as a plant specimen. Familiarity with seed reference material is fundamental to both the learning process and to checking identifications in routine work. At the same time, having a mentor to personally tutor students plays a major role in learning seed identification, both in passing on short cuts for identification of common or difficult types, and in developing confidence.

Books and Manuals

The production of a seed atlas is a major undertaking, both in terms of gathering a comprehensive suite of reference material to be illustrated, and in drawing or photographing it. Traditional, film-based, photography of modern and ancient seed is challenging because of the difficulty in avoiding shadows and in maintaining sufficient depth of focus. As an illustration of the work involved, the pioneer archaeobotanist Hans Helbaek took superb photographs of charred seeds in the mid-twentieth century and personally oversaw the production of lithographic printing plates in Copenhagen to ensure the quality of the published result.

The arrival of digital photography (Warinner and d'Alpoim Guedes, chapter 8, this volume) still allows the taking of bad pictures. Nonetheless, digital photography, when combined with skillfully used software, has enabled the production of seed atlases on a larger scale and of higher quality than could have been imagined twenty years ago. So far the Old World has been the beneficiary of the superb photographic seed atlases produced by René Cappers and collaborators in Groningen (Cappers et al. 2006; Cappers et al. 2009; Neef et al. 2012). Drawings (Bojňanský and Fargašová 2007; Nesbitt 2006) and scanning electron microscopy (SEM) (Knapp 2006, 2010; Schoch et al. 1988) continue to be important, with drawings able to show aspects of morphology that would be obscure in photography, and SEM imagery the medium of choice to record complex surface patterning. Fewer seed manuals have been produced recently in North America, where digital photography has tended to be presented on websites (table 7.2).

Most archaeobotanists work closely with several seed atlases in the lab. Much useful information on specific taxa, particularly crops, also exists in the identification sections of published archaeobotanical reports. Some of this work, for example the exemplary publications of Willem van Zeist relating to the Near East (e.g. van Zeist and Bakker-Heeres 1982), is well-known. However, as the volume of publications increases, and existing bibliographies

Table 7.2. Standard seed identification references[a]

	Title	*Year*	*Authors*
Printed Books and Manuals			
Worldwide	Digital Atlas of Economic Plants, 3 vols.	2009	R. T. Cappers, R. Neef, and R. M. Bekker
	Fruits and Seeds of Genera in the Subfamily Mimosoideae (Fabaceae)	1984	C. R. Gunn
	The Seeds of Dicotyledons, 3 vols.	1976	E. J. H. Corner
New World	Seeds of Amazonian Plants	2010	F. Cornejo and J. Janovec
	Weed Seeds of the Great Plains: A Handbook for Identification	1996	L. W. Davis
	An Illustrated Taxonomy Manual of Weed Seeds	1970	R. J. Delorit
	Seeds of the Continental United States: Legumes (Fabaceae)	1986	R. J. Delroit and C. R. Gunn
	Colorado Weed Seeds	1921	G. E. Eggington
	Identification of Disseminules Listed in the Federal Noxious Weed Act	1988	C. R. Gunn and C. A. Ritchie
	Bobwhite Quail Food Habits in the Southeastern United States with a Seed Key to Important Foods	1976	J. L. Landers and A. S. Johnson
	Seeds of Central America and Southern Mexico: The Economic Species	2005	D. L. Lentz and R. Dickau
	Seed Identification Manual[b]	1961	A. C. Martin and W. D. Barkley
	Seeds and Fruits of Plants of Eastern Canada and Northeastern United States	1977	F. H. Montgomery
	Identification of Crop and Weed Seeds	1963	A. F. Musil
	Arizona Ranch, Farm and Garden Weeds	1958	K. F. Parker

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TABLE 7.2—*continued*

PRINTED BOOKS AND MANUALS

	Title	*Year*	*Authors*
	Seeds of Woody Plants in the United States	1974	C. S. Shopmeyer
	Woody-plant Seed Manual	1948	US Forest Service
Old World	Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 4: Resedaceae-Umbelliferae	1994	A-L Anderberg
	Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 2: Cypreraceae	1969	G. Berggren
	Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 3: Salicaceae-Cruciferae	1981	G. Berggren
	Zadenatlas der Nederlandsche Flora (Seed Atlas of Netherlands Flora)	1947	W. Beijerinck
	Atlas of Seeds and Fruits of Central and East-European Flora: The Carpathian Mountains Region	2007	V. Bojňanský and A. Fargašová
	A Manual for the Identification of Plant Seeds and Fruits	2013	R. T. Cappers and R. M. Bekker
	Digitale Zadenatlas van Nederland/Digital Seed Atlas of the Netherlands	2006	R. T. Cappers, R. M. Bekker, and J. E. A. Jans
	Digital Atlas of Economic Plants in Archaeology	2012	R. T. Cappers, R. M. Bekker
	Ackerunkräuter Europas mit ihren Keimlingen und Samen, 4th ed. (Arable Weeds of Europe and their Sprouts and Seeds)	1999	M. Hanf
	Atlas and Keys of Fruits and Seeds Occurring in the Quaternary Deposits of the USSR [In Russian]	1965	N. J. Katz, S. V. Katz, M. G. Kipiani

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TABLE 7.2—*continued*

PRINTED BOOKS AND MANUALS

	Title	*Year*	*Authors*
	Samenatlas, Teil 1: Caryophyllaceae; Teil 2: Ranunculaceae (Seed Atlas, Part 1: Caryophyllaceae; Part 2: Ranunculaceae)	2006	H. Knapp
	Samenatlas, Teil 3: Fabaceae; Teil 4: Hyperiaceae (Seed Atlas, Part 3: Fabaceae; Part 4: Hyperiaceae)	2010	H. Knapp
	Bestimmungsschlüssel für subfossile Juncus-Samen und Gramineen-Früchte (Key to Subfossil Juncus Seeds and Graminae Fruits)	1964	U. Körber-Grohne
	Archaeobotany—Research on Seeds and Fruits [in Chinese]	2008	C-J Liu, J-Y Lin, and Z-C Kong
	Identification Guide for Near Eastern Grass Seeds	2006	M. Nesbitt
	Botanische Makroreste / Botanical Macro-Remains / Macrorestes Botaniques	1988	W. H. Schoch, B. Pawlick, and F. H. Schweingruber

ELECTRONIC RESOURCES

	Title and URL[a]	*Authors*
Worldwide	USDA Family Guide for Fruits and Seeds, http://nt.ars-grin.gov/seedsFruits/rptSeedsFruitsFam.cfm	J. H. Kirkbride, C. R. Gunn, and M. J. Dallwitz
	Paleobot.org, http://www.paleobot.org	Open Source
New World	Identification Criteria for Plant Remains Recovered from Archaeological Sites in the Central Mesa Verde Region, http://www.crowcanyon.org/ResearchReports/Archaeobotanical/Plant_Identification/plant_identification.asp	K. R. Adams and S. Murray

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TABLE 7.2—*continued*

ELECTRONIC RESOURCES

	Title and URL[d]	*Authors*
	Seed Identification, http://seedbiology.osu.edu/seed_id	Dept. of Horticulture and Crop Sciences, Ohio State University
	Laboratory Guide to Archaeological Plant Remains from Eastern North America, http://pages.wustl.edu/fritz	G. Fritz, ed.
	USDA Woody Plant Seed Manual, http://www.nsl.fs.fed.us/nsl_wpsm.html	US Forest Service
Old World	Archaeobotanical Online Tutorial, http://archaeobotany.dept.shef.ac.uk/wiki/index.php/Main_Page	M. Charles, et al.
	Digital Seed Atlas of the Netherlands website, http://seeds.eldoc.ub.rug.nl/?pLanguage=en	
	A Millet Atlas: Some Identification Guidance (2006),[e] http://www.homepages.ucl.ac.uk/~tcrndfu/archaeobotany.htm	D. Q. Fuller
	HYPPA (HYpermedia for Plant Protection Database of European Weeds), http://www2.dijon.inra.fr/hyppa/hyppa-a/hyppa_a.htm	
	Identification of Cereal Remains from Archaeological Sites (2008), 3rd ed., https://ipna.unibas.ch/archbot/pdf	S. Jacomet, et al.
	Photos of Charred Remains from Early Agricultural Sites in the Near East, http://g.willcox.pagesperso-orange.fr/archaeobotanical%20images/indexi.htm	G. Willcox

a See bibliography for full bibliographic details.
b A more recent issue of this manual is in print, but the quality of the printed images is not as high.
c A newer print edition is available as USDA FS Agriculture Handbook 727, April 2008, and is also available online (see Electronic Resources section).
d All websites accessed on 09/24/2014.
e Additional helpful resources are also available on the parent website.

become increasingly out-of-date (Delcourt et al. 1979; Jensen 1998; Nesbitt and Greig 1989; Royal Botanic Gardens 1985), there is a risk that existing knowledge embedded in archaeobotanical literature will be forgotten.

DIGITAL RESOURCES

Archaeobotanists have made good use of the Internet as a means to show images (Warinner and d'Alpoim Guedes, chapter 8, this volume) and as a means to distribute laboratory manuals (e.g., from the laboratories of Dorian Fuller, Gayle Fritz, and Stefanie Jacomet; for details see table 7.2). The series of volumes produced by René Cappers is a valuable hybrid, whereby purchasers of the books also have access to a website on which a wider range of images can be searched using selected identification criteria such as seed size.

We consider that printed and digital resources complement each other: books offer easy browsing and a structure that usually stresses plant family affinities—an excellent learning tool, as an understanding of family-level seed characters is the basis of practical identification skills. However, the identification keys in books are usually binary keys that are hard to use on archaeobotanical material that is often fragmentary and missing characters (but see Nesbitt 2006 for an alternative approach to keys). Digital media allow presentation of a far larger number of photographs and are likely to allow more sophisticated searches based on multi-access keys, which are hard to present in printed form.

Automated identification of seeds has been investigated for many years by agronomists, but so far has been largely unsuccessful. Archaeological material is particularly challenging in that seeds all tend to be black, may belong to a wide range of taxa (100–200 species are often found in major archaeobotanical reports), and are often fragmented. Even with restricted data sets and well-orientated and photographed material, as in the case of distinguishing wild and domesticated sunflower seeds, computerized shape analysis has proved unsuccessful (Tarighat et al. 2011). This will undoubtedly change, but probably on the basis of work done in better-funded areas such as face recognition. Careful application of image analysis to cultigens has proved valuable in identifying morphological groups within one taxon that map onto geographical origins, for example in olive, grape, and the date palm (Terral 1997; Terral et al. 2010; Terral et al. 2012), and this technique should be explored further for other crops with subtle variation in seed shape, such as wheat.

Seed Reference Collections

Recently collected seed specimens are the basis of the seed identification aids discussed above, and direct comparison with reference material is always valuable (and often essential) in confirming an identification. Reference material is particularly useful in that it can be cut apart, allowing examination of internal characteristics, which can be particularly helpful if even the plant family cannot be determined using gross morphology (Corner 1976; Martin 1946). Reference material is also useful as seed specimens often bear other plant parts, such as pedicels or bracts, which may also be found in archaeobotanical samples. Finally, a major benefit of regular use of a reference collection is also increased familiarity with seed characteristics by plant family, easing identification of unknown archaeological seeds.

Although we consider the seed reference collection to be an essential resource for seed identification, we also recognize that making a good quality collection is a significant investment (see Nesbitt et al. 2003 for detailed guidance on collection and curation). The seeds may come from different sources: botanic gardens, genebanks, shops, herbaria, and from living plants collected during fieldwork. In general, the ease with which a sample is obtained is in inverse proportion to the reliability of the identification, with seeds from botanic gardens being most likely to be misidentified or mislabeled (Aplin and Heywood 2008). A further advantage of seeds collected directly from the wild or from farmers' fields in the region of interest is that their size will often be more typical of ancient material than that of seeds grown in a garden environment. However, a well-balanced reference collection will draw on all these sources, as some species will be too rare, or even locally extinct, to collect oneself. Building up multiple accessions of the same taxon from different sources has two advantages: first, any incorrect identifications of reference material are more likely to become apparent as specimens will not match each other and, second, the specimens will better represent the diversity of size and shape present in different populations in nature. It is dangerous to build identification criteria on the basis of a single accession of reference material.

The work involved in identifying and housing voucher herbarium specimens (essential for material collected from the field) can be greatly reduced by collaboration with local botanists (for more on voucher specimens and collaboration, see Bye 1986; Nesbitt et al. 2010). At the same time, active participation by the archaeobotanist in collecting seeds and herbarium specimens in the field is an excellent way of increasing understanding of plant ecology and agricultural practices in an area of archaeological interest.

Care must be taken in storing reference collection seeds after field collection. Like all plant material, seeds are vulnerable to pests. They are often stored in clear plastic or glass containers that allow rapid assessment of seed appearance and restrict the movement of insects. The best safeguard for any collection is use: early detection of pests enables rapid treatment, such as freezing to deal with insects or reduction of relative humidity to deal with mold. With the decline of agricultural research, older seed collections in botanical and agricultural institutions are sometimes neglected. Archaeobotanists should seek out these collections; they are often rich in local weeds and crops that are now rare.

BASIC IDENTIFICATION PROCEDURES AND ISSUES

Principles

Seed identification (here *seed* is used in the general sense of non-wood plant remains) depends on both the ability to recognize different shapes and a knowledge of the range of candidate species. Identifying candidate species is important because identification criteria must not only enable matching with a species but also *exclusion* of other candidate species. Identification criteria should be based on a study of all likely species. It will be easier to arrive at a narrowly defined identification if there are fewer species in the study area.

Assessment of candidate specimens requires careful consideration of the ecology and abundance of species: for example, at a lowland site it may be possible to exclude mountain species and rare species restricted to specific habitats. However, it is important to be aware that the distribution of species can change and that this is increasingly true the further back in the past one investigates. Sometimes plants become extinct, as in the case of a suite of North American domesticates such as *Iva annua* var. *macrocarpa* and *Chenopodium berlandieri* ssp. *jonesianum* (Smith 1989). In general crop plants are much more likely to see major changes in distribution because of deliberate transfer through cultivation or trade.

Poorly documented wild plant floras can also lead to confusion: for example, it has only recently become clear that two species within the sedge genus *Bolboschoenus* occur today in the Near East. Nutlets of this genus are abundant in pre-agrarian archaeobotanical assemblages and have previously been identified as *B. maritimus*. Reassessment of the genus by taxonomists has shown that *B. glaucus* is the dominant species of inland areas today, and is also the species represented in archaeological samples (Wollstonecroft et al. 2011). There are important ecological (and, potentially, culinary) differences between

the two species, but the correct identification was impossible until the current day taxonomy and distribution of these species was understood.

Documenting Identifications

It is good practice to include photographs and, if space allows, written descriptions and measurements of seeds in site reports. In short reports these may be restricted to unusual species or cases in which novel identification criteria have been developed. In full reports, it is also desirable to discuss and illustrate common taxa, both to allow the reader to confirm the analyst's identifications and to show the variability in seed size and shape that is always present for the more abundant taxa. Drawings are still useful for highlighting differences between closely related taxa, although time and cost mean they must be used sparingly.

Seeds and Fruits

Family-level characteristics are as excellent a starting point for seeds as they are for whole plants, enabling the bypass of general identification keys and a focus on a smaller part of the plant kingdom. Many families have highly distinctive seeds: for example, the legumes (Fabaceae), daisy family (Asteraceae), grasses (Poaceae), and cress family (Brassicaceae). Once a family has been identified, identification to genus is the next step. This is usually more manageable than for species. For example, worldwide (these proportions will be reflected in the smaller regional numbers) the Fabaceae has 740 genera but 19,000 species. As seeds often differ substantially in appearance at genus level, initial identification may be a matter of relatively rapid scanning of reference specimens or illustrations.

At species levels, identification criteria may be much more subtle, and it is here that our limited ability to describe differences in shape is most problematic. Although botanists have developed an extensive vocabulary for plant morphology (Beentje 2010), it is probably true to say that communication of differences in shape of seeds and surface cell patterns is best carried out using images. Measurements can be valuable, but we have doubts about the blanket application of absolute figures, whether for distinguishing wild species or wild and domesticated forms. Not only does charring introduce significant and unpredictable changes in shape and size, it is also uncommon for simple measurements of plant parts to clearly distinguish species even on fresh whole plants, where there are often overlaps in size between species. Instead, plotting

scattergrams of measurements of archaeological material from one or multiple sites is often an effective way of identifying groups of differently sized seeds that may correspond to different taxa. In other words, absolute differences in size that are visible on fresh material are valuable tools for investigating relative differences in size that are apparent in archaeobotanical material. An example of the problem is the separation of wild and domesticated Old World grape pips (*Vitis vinifera*). Over a century of observations that wild grapes have squatter pips with short beaks have not yet translated into a formula that can distinguish charred material of the two forms across all sites, even though the difference is obvious to the eye, and numerical criteria such as ratios sometimes work within one site (Jacquat and Martinoli 1999; Smith and Jones 1990).

Differentiating between Wild and Domesticated

Crops usually possess a "domestication syndrome" of several characters that make them relatively easy to distinguish from their wild ancestors (Harlan 1975). These characters include larger propagules, loss of ability to disperse seed, and changes in growth habit that, in the case of some plants, such as maize, radically change the appearance of the plant. However, bearing in mind that it tends to be the propagules that end up in archaeological deposits, morphological changes in growth habit, or even in lighter (i.e., more fragile) parts of the fruit such as legume pods, will not be visible. Thus in the case of cereals and legumes, identification of domestication in archaeobotanical macroremains has focused on increase in seed size (in the case of grasses, strictly the grain or caryopsis size), and loss of seed dispersal mechanisms. In the case of amaranths and chenopods, there are clear changes in the thickness of the seed coat, discussed below.

Although a clear size difference is often visible between the seeds or grains of wild and domesticated taxa from recent populations, this difference appears more obscure in early populations of domesticates. In part this is because charred material from early sites is often in poor condition, but it is also likely to reflect the fact that early domesticates are just that: populations that have only been exposed to selection for larger seed size for perhaps a millennium or less, unlike current day landraces of crops that have been exposed to selection over subsequent millennia of agriculture. Further complicating factors include evidence, discussed below, of incomplete domestication processes in early agriculture and the varying effects of charring on seed size (see for example, the case of teff, *Eragrostis tef*, D'Andrea 2008). It is thus rare that

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seed or grain size can be used as a simple indicator of domestication at early agricultural sites. However, when individual seed sizes are plotted as scattergrams and compared to those of earlier and later levels, both within one site and at other sites, an overall increase in seed size is visible through time, corresponding to domestication. The application of this technique to wheat and barley grain in the Near East has shown gradual increases in grain size during the Pre-Pottery Neolithic period (Willcox 2004); distinct episodes of increased grain size are also seen in ancient pearl millet (*Pennisetum glaucum*) in Africa and India, after domestication (Manning et al. 2011). In the New World, sunflower achenes have presented similar problems; size differences between wild and domesticated taxa that are clear in modern material are obscure in early material, contributing to the controversy over the location and timing of sunflower domestication (Yarnell 1978).

In principle the loss of seed dispersal mechanisms offers more robust criteria for identification of cereal domestication. For example, in wild wheat, barley, rice and many other cereals, the spikelets disarticulate at maturity to allow the grains to disseminate. This natural disarticulation leads to a smooth abscission scar at the spikelet base. In domesticated forms, the spikelets are torn apart during threshing by farmers, leading to torn abscission scars. There are complications: threshing of immature ears of wild grain can lead to torn scars, and the basal spikelets of wild wheat and barley do not disarticulate in the wild, and thus bear torn scars if threshed (Fuller et al. 2009; Kislev 1997; Tanno and Willcox 2012). The use of low numbers of torn spikelet scars to determine domestication status is therefore unwise. Although chaff remains are usually scarcer than grains in archaeological samples, the application of bulk flotation to early sites in the Near East and in China has led to the recovery of a large number of spikelet remains (Fuller et al. 2009; Kislev 1997; Tanno and Willcox 2012). The persistence of large numbers of wild-type scars in farmer's fields in the millennia following the first domestication of cereals suggests that full domestication was a slower and more complex process than thought a decade ago, with implications for the ease of identification of domesticates by morphological criteria (Fuller 2007b; Tanno and Willcox 2006).

Many crops have seeds that are similar in morphology to those of their wild ancestors. Here, changes in the quantity and distribution of archaeobotanical finds can point toward domestication. It is assumed that an increase in the abundance of a seed or its appearance at sites outside the distribution of the wild ancestor are indicators of domestication. These are inevitably subjective criteria, and can be hard to apply when the distances are small and the distribution of the wild ancestor uncertain. Major changes, however, such as the move of olives inland from the coastal strip of wild olives in the eastern Mediterranean can be good evidence for domestication (Liphschitz et al. 1991; Neef 1990).

Crops

The biggest challenge in identifying crop remains is that human selection has led to the evolution of myriad closely related taxa that vary subtly in morphology, agronomy, and culinary properties. This led to endless taxonomic problems in the past, when overemphasis was given to relatively minor differences with the description of tens or hundreds of species within what is today considered a single biological species. Modern taxonomy handles this by taking a "lumping" approach in which interfertile taxa are considered to belong to a single species and major morphological variants are then recognized at either subspecies or variety level, or as in the case of sorghum, by informal groups (de Wet et al. 1986; Harlan and de Wet 1971). Within these distinct forms are then thousands of landraces characterized by further minor morphological variations. Wheat, maize, rice, and sorghum are examples of highly variable crops that are abundantly represented in archaeobotanical remains.

Similar problems face the archaeobotanist, and beginners faced with highly variable crop seeds have a strong tendency to over-split, creating too many categories. A useful tool to counter this is to arrange seeds in a series by, for example, increasing length, in order to judge whether the "different" types are in fact simply extreme forms of a continuum. Measurement can also be helpful in deciding if more than one taxon is involved, for example when measurements are plotted as a scattergram to show whether more than group can be distinguished.

Once coherent groups of crops have been identified within a site assemblage, the question arises of whether they can be assigned to current-day taxa. This question of candidate species is simpler for wild taxa; as discussed above, the current wild flora of the region (and reference material collected from that region) is likely to match archaeobotanical material, with some provision for species that have since become rare in the locality. The case of crops is more complex, since taxa may have been widespread in the past that are rare or extinct now, as with a highly robust form of emmer wheat once found in the Near East and parts of central Europe (Jones, Valamoti, and Charles 2000), or the once important sumpweed (*Iva annua* var. *macrocarpa*) and goosefoot (*Chenopodium berlandieri* ssp. *jonesianum*) in eastern North America (Smith 1989). In these cases rigorous and multiple identification criteria were

established that support the identification of a novel taxon. However, it is more often the case that there are only minor morphological differences between archaeobotanical remains and modern reference material, which in matters such as cereal grain size are partly accounted for by the effects of charring. In this case, it is usually better to document the characteristics of the crop and to explain how they differ from other archaeobotanical or modern material, without assigning it to a novel taxon.

Given the difficulties explained above, archaeobotanists have developed good tools for identification of crops to finer detail than simply that of biological species (e.g., for wheat Jones 1998 and for maize Adams 1994). A major factor in this process is the development of regional identification manuals, and the ease with which material can be shown to colleagues via electronic means and at meetings such as the International Work Group for Palaeoethnobotany. However, we believe there is more room to standardize identification criteria, in discussion formats such as the London workshop on wheat identification (Hillman et al. 1996), and by the blind-testing that has led to greater rigor in the identification of microfossils.

Parenchyma and Vegetative Remains

In charred remains, wood and plant propagules (at most sites, seeds and fruits) will account for the majority of the plant remains found. When other plant parts occur, they are often associated with the plant propagules: for example, fruit pedicels. Charred roots and tubers are often present and have become increasingly recognized by archaeobotanists after the pioneering studies of Jon Hather (1993, 2000). Intact tubers superficially resemble fruits, but often have scars where rootlets or scales were attached. Their interior has more or less spherical cells, rather than the elongated cells of wood fragments. Lumps of different cell types aggregated together are also common, and these are probably fragments of charred food. These have been little studied, but preliminary work suggests that their disaggregation and study by scanning electron microscopy would be worthwhile (Hansson 1994; Valamoti et al. 2008).

In waterlogged and desiccated conditions, it is common to find a far more diverse range of plant materials, including non-woody stems, buds, and leaves. Because waterlogging leads to the decay of the waxy cuticle and of fleshy interiors, including endosperm in grass grains, waterlogged remains are often translucent, allowing their cell patterns to be studied through transmitted light microscopy. Reference material may need to be treated by soaking or heating in dilute acid or a solution of potassium hydroxide in order to arrive at the same translucency. There is an extensive literature on the specialist identification of waterlogged material (Birks 2007; Mauquoy and Van Geel 2007).

Wood and Stem Material

Wood is often abundant in macrobotanical samples, representing fuel and burned architectural features and providing information about the surrounding vegetation and how people of the past used and altered it. Wood anatomy is a specialized field of study and careful analysis of wood requires a higher-powered microscope (at least 400×) than needed for standard sorting of seeds and nutshell. We recommend training with an expert in wood identification of a particular study area, especially in regions of high tree diversity. A start can be made even by nonspecialists by examining transverse (cross) sections of charred wood under a low-power dissecting microscope, with conifers easily distinguished from hardwoods, and ring-porous taxa distinguishable from diffuse-porous ones. Oaks are identifiable by their multiseriate rays (see Pearsall 2000:144–53 and sources cited therein for an excellent overview). Charcoal is usually studied by breaking it so that the structure can be seen in three sectional views, and then examining each section through a high-powered metallurgical microscope.

The structure of charred and waterlogged wood is well preserved. A major difference from seed identification is that work by wood anatomists, under the auspices of the International Association of Wood Anatomists, has led to highly standardized character states that have been recorded for a large number of tree species. Excellent identification manuals exist for many regions and can be used in combination with the comprehensive website *Inside Wood* (2004).

Microbotanical Remains

Palynology has been a fundamental element of archaeobotanical research since the mid-twentieth century (Faegri and Iversen 1975), and it has been joined more recently by the study of phytoliths and starch grains. Combination and integration of macro- and microbotanical remains greatly expand the scope of our understanding of past plant-people relationships, but for one person to acquire the skills and access to laboratory facilities to conduct all of these types of analyses is challenging. Pearsall's (2000) *Paleoethnobotany* handbook contains separate chapters on pollen and phytolith analysis, and

Piperno's (2006b) book on phytoliths is, as the title states, a comprehensive guide. Analysis of starch grains from ancient tools and features is being applied with increasing frequency and exciting results (Messner 2011; Piperno et al. 2004). All of these endeavors utilize potentially caustic chemicals and require scientific laboratory facilities—including fume hoods and centrifuges—for extraction of the remains and preparation of slides, which need to be studied under high-power microscopes (up to 1000×). A cross-polarizing filter is necessary for microscopic analysis of starch grains in order to see the extinction crosses (see Henry, chapter 3, this volume).

Non-Plant Inclusions

Flotation samples frequently contain insect eggs, fecal pellets from very small animals, and fungal sclerotia that can easily be mistaken for seeds by an untrained observer. When archaeologists presort light fractions before handing them over to an expert, considerable time might be wasted pulling hundreds of round, black sclerotia from the smaller-than-2.0 mm splits (figure 7.2). Therefore, we briefly address the morphological characteristics of these ubiquitous objects. Most assemblages including fungal sclerotia will include enough whole ones to demonstrate the lack of any embryo or hilum scar. Sclerotia may be very round and smooth, but vary morphologically by species. Schoen (1983) gives the general size range as 0.5 to 3.0 mm and illustrates a number of different genera and species. Most that we have observed are smaller than 1.0 mm in diameter. The outer rind or cortex layer appears smooth at low magnification, lacking reticulation or other sculpturing commonly exhibited on seed testas. Sclerotia are easily dissected with one's fingernail or razor blade. The inner filling, called the medulla, when present, is a slightly spongy-looking, solid mass that differs from seed endosperm by its homogeneity, absence of cotyledons, and lack of starchiness. Fungal sclerotia are considered in most cases to be background noise in soil, modern contaminants that usually go unmentioned. However, Matsumoto et al. (2010) recently reported carbonized sclerotia from two sites on the island of Hokkaido, northern Japan, that appear to be from good archaeological contexts, including ash-coated fireplace vestiges. The authors, using scanning electron microscopy, identified the objects to the species *Typhula ishikariensis* and inferred that the fungal bodies entered the archaeological record associated with plant material deposited in the fireplace and elsewhere. European sclerotia are usually identified as *Cenococcum geophilum* and are usually considered modern (Alonso and López 2005).

Figure 7.2. *Fungal sclerotia, species unknown, recovered during flotation of sediments from the Berry Site, Burke County, North Carolina, United States. A: outer, convex surface. B: cross section of different, slightly smaller specimen.*

Specific Example: Identifying Amaranth

Identification of seeds in the genus *Amaranthus* can be tricky for several reasons. First, wild amaranth seeds are black even when uncharred, so it takes close inspection and sometimes physical pressure using one's fingernail or metal tool to determine if an unbroken specimen is modern or ancient. Second, wild or weedy amaranth species produce seeds that look very much alike, and there may be little research incentive to attempt identification below the genus level. The third challenge involves distinguishing between amaranths and their close relatives, especially species in the genus *Chenopodium* (table 7.3), which often occur in the same deposits. Fourth, there are three domesticated species of amaranth—*A. hypochondriacus*, *A. cruentus*, and *A. caudatus*—all native New World cultigens, making it necessary to detect morphological changes that signal agricultural production rather than wild harvesting (Fritz 2007).

Undomesticated amaranth seeds (figure 7.3) have relatively thick, hard seed coats (testas) that cover the interior perisperms (endosperms) and encircling embryos. Analysts should collect and study the seeds of plants native to their research area and observe how they are borne in inflorescences consisting of clusters of chaffy tepals, bracts, and fruits called pyxes (a pyxis is a single-seeded, circumcisally dehiscent utricle.) Unlike chenopods, amaranth seeds are not covered by adhering pericarps.

Native eastern North American amaranth seeds overlap in diameter with local *Chenopodium* species, but whole amaranth seeds are rarely larger than 1.1 mm, whereas most whole chenopod seeds in this region are bigger. In the

TABLE 7.3. Means of distinguishing charred amaranth from chenopod seeds

Trait	*Cultigen Amaranth Seeds*	*Wild/Weedy Amaranth Seeds*	*Wild/Weedy Chenopod Seeds*
Seed coat thickness	Very thin(2–15 μm, usually)	Thicker(17–32 μm)	Thick(20–30 μm for weedy; 40–80 μm for wild)
Diameter	c. 1.0 mm, ± a few mm, usually	c. 1.0 mm, ± a few mm, usually	Can be as large as 2.0 mm, but some species are as small as amaranths
Beak morphology	Liplike meeting of embryo ends	Liplike meeting of embryo ends; some species have one end that projects slightly	Distinctly overlapping beak, but varies by species
Pericarp (presence or absence)	No pericarp adhering to seed	No pericarp adhering to seed	Papery pericarp adheres to seed, but rarely survives charring except as fugitive trace
Seed coat texture	Smooth (but *A. cruentus* seed coats are slightly rugose)	Relatively smooth, with some species exhibiting marginal texture, (e.g., diamondlike pattern)	Can be distinctly pitted (alveolate) or caniculate, but varies by species
Dorsal sulcus (presence or absence)	Absent	Absent	Present, running from center to beak, but varies by species
Cross-section shape	Enlarged, oval embryo creates semi-truncate cross-section; One or more ridges may be present around circumference	Biconvex, lenticular, with circular embryo cross-section	Biconvex, lenticular

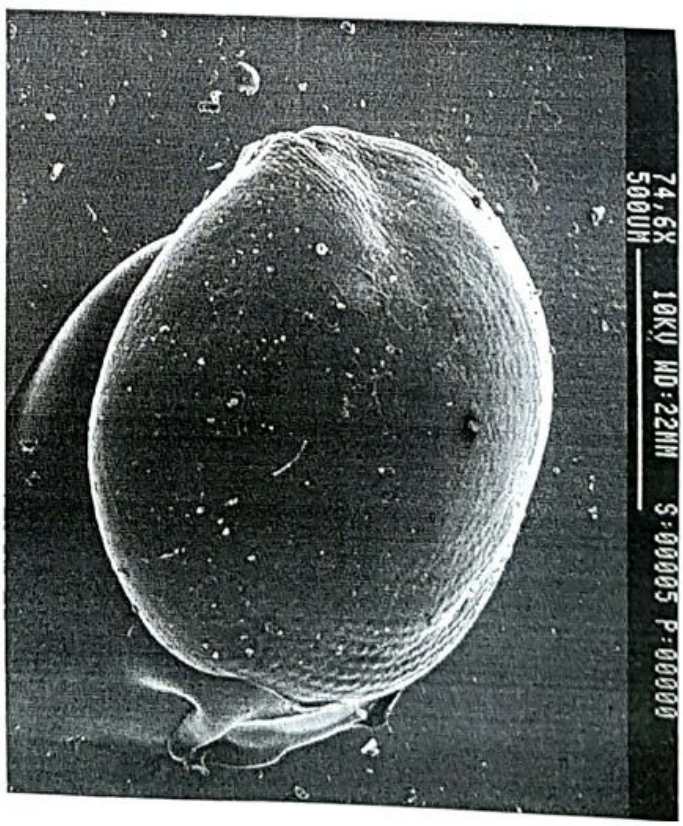

FIGURE 7.3. *Scanning electron micrograph of wild/weedy amaranth seed.*

US Southwest, additional chenopod species exist that have smaller seeds than their eastern relatives, increasing the difficulty of distinguishing between genera. However, the embryos of chenopod seeds wrap around and overlap to form a distinct beak (figure 7.4), whereas amaranth embryos meet to form liplike features, although one lip might protrude beyond the other (figure 7.3). The most common North American wild/weedy archaeological chenopod type, *C. berlandieri*, has a distinctly alveolate (pitted) seed coat, unlike any amaranth, and may retain evidence of its reticulate (netlike) pericarp (fruit coat). Amaranth seed coats tend to be smooth except at the margin, where a subtle diamondlike patterning is visible on some wild specimens, especially under high-power scanning electron microscopy. Amaranth seed coats might be slightly undulating, but they do not exhibit the distinct reticulation of *C. berlandieri* or other chenopods. Finally, amaranths lack the dorsal sulcus extending from the beak to the center of chenopods. If seed coats are entirely missing, or if specimens are otherwise in too poor shape for

FIGURE 7.4. Chenopodium *seed showing distinct beak and reticulate pericarp (fruit coat). Because this is a domesticated chenopod (*Chenopodium berlandieri *ssp.* jonesianum*) from an archaeological rockshelter in the Arkansas Ozarks, it has a truncate rather than rounded margin and a smooth rather than pitted seed coat (here hidden by pericarp).*

these features to be observed, archaeobotanists relegate them to the category of "cheno-am" (figure 7.5).

Identifying domesticated amaranths can be especially difficult because the primary change that occurred through selection was reduction in seed

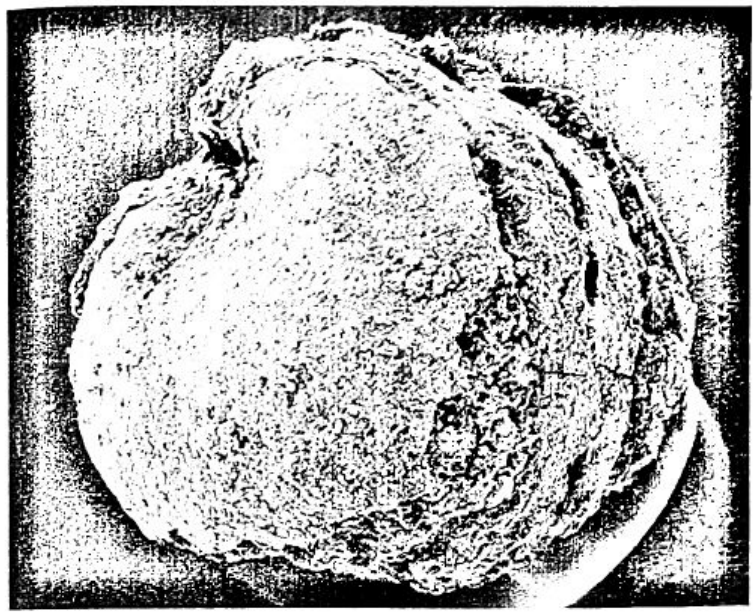

FIGURE 7.5. *"Cheno-am" perisperm with no seed coat that would enable classification to genus.*

coat thickness, resulting in pale rather than black seeds (figure 7.6), the same process that happened during domestication of Andean quinoa (*C. quinoa*) and the eastern North American cultigen, *C. berlandieri* ssp. *jonesianum* (Fritz et al. 2009; Fritz and Smith 1988; McClung de Tapia et al. 1996; Smith 1984, 1985).

The extremely thin seed coats of cultigen amaranths and chenopods are so fragile that they are poorly preserved, if present at all, after charring, and scanning electron microscopy is needed to obtain accurate seed coat measurements. Seed size increase does not seem to have accompanied testa reduction (Sauer 1993), but embryos of cultigen amaranth seeds are enlarged and oval rather than circular, giving the seeds semi-truncate margins with concentric marginal ridges, rather than being biconvex in cross-section.

Making the effort to separate amaranth seeds from chenopods and to recognize the presence of domesticates, although time-consuming, pays off in research dealing with agricultural origins and intensification in North

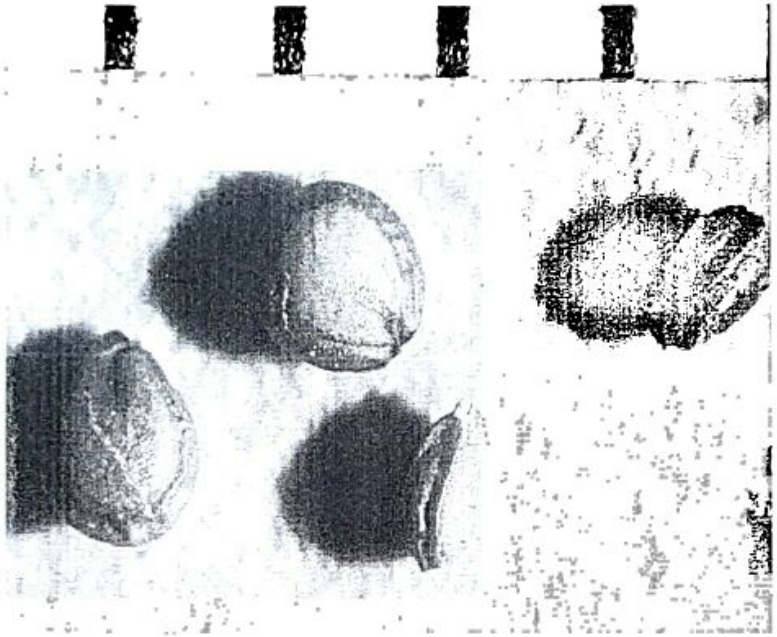

FIGURE 7.6. *Domesticated amaranth seeds. These specimens came from a 1000-year old storage pit in a dry rockshelter, the Holman Shelter, in the Arkansas Ozarks.*

America, Mesoamerica, and Andean South America (Bruno 2006; Fritz 1984; Fritz et al. 2009).

CONCLUSIONS

Archaeobotanists are continually refining traditional, decades-old practices of laboratory analysis and, at the same time, pioneering new types of research requiring technical skills and equipment not available until recently. Although our field has expanded, a protracted period of one-on-one training in the laboratory is still the ideal method of learning, followed by many years of continuing consultation with colleagues. Communication today, of course, includes options such as the capabilities to attach high-resolution images to email messages and to access websites devoted to archaeobotanical networking (see Warinner and d'Alpoim Guedes, chapter 8, this volume).

Most paleoethnobotanists today are, first and foremost, archaeologists who direct or codirect field projects or, at least, participate fully in research-design planning, excavations, laboratory work, and formulation of results. Ethnographic observations (ethnobotanical, agronomic, culinary, etc.) and experimental activities are increasingly frequent components of our studies. Still, as much as ever, identification of ancient plant remains requires expertise acquired through formal coursework, field biology, and careful scrutiny of reference specimens in comparative collections. The laboratory stage of analysis is a crucial and time-intensive link to interpretive success. This brief chapter covers philosophical and methodological points that we consider fundamental to this step in the pursuit of understanding how human and botanical spheres have intersected and coevolved through the ages.

If we were to choose three conclusions based on the examples and practices discussed in this chapter, they would be:

1. Although useful new techniques are regularly developed—for example, scanning electron microscopy, image analysis, and the extraction of DNA from seeds—none of these have replaced the intensive use of a stereomicroscope and the ability of humans to memorize and compare complex shapes as the main identification tool. The more sophisticated techniques have developed a valuable role, although preservation of DNA in charred material is often poor, limiting its use (Schlumbaum et al. 2008). Image analysis, in particular, merits further application for analyzing variation in ancient crop seeds.
2. Seed reference collections, and the associated knowledge of candidate species based on field experience of the study region, remain central to archaeobotany. Archaeobotanists must not only be archaeologists, but botanists too.
3. Identification cannot be carried out in isolation, and this generation of archaeobotanists is highly fortunate in the ease of travel and the benefits of digital communication available today. There is still scope for further standardization—on a regional basis—of identification criteria, especially for crops, and for blind identification tests. The widespread use in Europe of standardized archaeobotanical recording databases, often based on the ArboDat system developed in Germany (Kreuz and Schäfer 2002), is likely to accelerate the move to more consistent identification.

9

Ratios and Simple Statistics in Paleoethnobotanical Analysis

Data Exploration and Hypothesis Testing

John M. Marston

From its earliest days as a discipline, paleoethnobotany moved rapidly from simple descriptive lists of macroscopic plant remains from archaeological contexts to quantification of those remains. Quantification is now seen as a critical step between the recovery of archaeological plant macroremains and their interpretation, but a variety of methods for quantification exist, from simple seed counts to multivariate statistics (Pearsall 2000). Matching this diversity of methods for quantification is the diversity in their application, with some scholars using simple quantitative methods for data exploration alone, others using them for data presentation, and still others using them for hypothesis testing. A recent trend toward increasingly complex multivariate methods for data analysis and presentation has led to new insights (see A. Smith, chapter 10, this volume), but such statistics alone are unsuitable for direct integration of paleoethnobotanical reports on a regional scale.

Simple quantitative measures, in contrast, still play an important role in paleoethnobotanical inquiry and offer great potential for intersite comparison and regional interpretation. This chapter reviews simple numerical and statistical methods for quantification of paleoethnobotanical macroremains and emphasizes their utility for both preliminary data exploration and hypothesis testing. Despite the utility and explanatory potential of multivariate statistics, I argue that continued use of non-multivariate methods of analysis is

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needed and that further application of simple statistical measures to answer well-defined research questions offers an avenue for interpretive development in paleoethnobotanical method and theory.

SIMPLE STATISTICS IN PALEOETHNOBOTANY

Within the broad scope of quantitative measures used in paleoethnobotany, I consider those that rely on non-multivariate statistical methods to be *simple*, a term that refers to their degree of interpretability rather than the simplicity of calculations involved (although that is often also the case). These range from absolute taxon counts, surely the simplest quantitative measure, to standardized *Z*-scores and diversity indices, which require significant calculation. A variety of sources already describe how these measures work and provide primary bibliography on their application (Fritz 2005; Hubbard and Clapham 1992; Jones 1991; Miller 1988; Pearsall 2000; Popper 1988; Wright 2010); the aim of this chapter is not to replicate these earlier works but to review the use of simple statistics in recent paleoethnobotanical literature and to consider future development of such measures for both exploratory data analysis and hypothesis testing.

For the purposes of this discussion, I divide all simple statistics into three categories: descriptive, standardized, and relative. Descriptive methods are methods of quantification based solely on the number of seeds or plant parts observed; this category includes absolute counts, rankings, and food value estimates. Standardized methods are those that peg the absolute count to the category of remains to which a taxon belongs or to some other norming variable, such as the amount of soil floated or number of contexts analyzed, to increase comparability between samples (and sites). Such measures include density, proportions, ubiquity, and *Z*-scores. Finally, relative methods compare the absolute count value of a taxon to the value of other taxa in the same sample; this category includes a wide variety of comparative ratios as well as diversity indices.

Descriptive Methods

The most straightforward method for quantification of a paleoethnobotanical data set is the absolute count of each taxon identified. This is the raw product of laboratory investigation and has been used to describe archaeobotanical assemblages since the 1960s (Helbaek 1960, 1969; Renfrew 1973). These results may be reported on a sample-by-sample basis, as is often the case in dissertations and comprehensive monographs (e.g., Miller 2010b; Riehl 1999), as well as in some longer articles and book chapters (e.g., Klinge and Fall 2010; Schwartz et al. 2000; van Zeist and Bakker-Heeres 1982, 1984a, 1984b, 1985), or may be summarized by period or area of the site (e.g., Moore et al. 2000; Weiss and Kislev 2004). The strength of this approach, especially for sample-by-sample reporting, is that it presents the complete data set as identified by the paleoethnobotanist without any form of adjustment or data manipulation. These absolute counts can be used freely by other researchers who are interested in intersite comparison or reanalysis of the data set using new statistical techniques. For this reason, absolute counts on a sample-by-sample basis should be required as a standard part of all final site reports and excavation monographs, accompanied by a detailed description of how remains were counted. The downside to absolute counts, however, especially on a sample-by-sample basis, is that they are difficult to present graphically and may take up a massive number of pages. Electronic publication of these data thus may be preferable, despite potential limitations of that medium (Warinner et al. 2011, d'Alpoim Guedes and Warinner, chapter 8, this volume). In addition, absolute counts are dependent on the original sample size and percentage of the sample sorted, so require additional standardization before comparison with other samples or sites (Popper 1988:60).

Ranking systems and conversions to food value estimates are used to regularize the comparison of different botanical elements against one another (Pearsall 2000:206–11; Popper 1988:64–66). These measures attempt to account for differences in productivity or preservation between different plants and to improve comparability of different species across or between sites. In both cases, actual counts are abstracted to a new value, whether a rank order or a food value, based on experimental observation. This new value is still directly dependent on the original count value from each sample, so remains purely descriptive of that sample. Such an approach is useful for mapping intersite variation in plant frequencies (e.g., Jacomet 2007). The limitations of absolute counts listed above still hold for these measures, however, and the additional inferential step taken to produce food value estimates or the range for equivalent ranks introduces an additional source of variation in interpreting these results. As such, studies that make extensive use of rankings and food value estimates (e.g., Diehl and Waters 2006; Flannery 1986) are unlikely to be directly comparable with other analyses done by different researchers, potentially limiting their utility for regional synthesis and reinterpretation.

Box plots represent a powerful and intuitive graphical method for conveying differences between samples, periods, or sites (Scarry 1993a:163–67; Scarry and

Steponaitis 1997; Tukey 1977; VanDerwarker 2006:75–77; Welch and Scarry 1995; see also VanDerwarker et al., this volume, figure 11.1). They are based on simple descriptive statistics calculated from sample counts and represent sample medians, typically indicated by the center of a notch, and the dispersion of values around that median, through box edges and whiskers. Box plots do not assume normal distributions, nor do they require large sample sizes, rendering them useful for representing paleoethnobotanical assemblages. When comparing box plots representing different groups of samples, the notches that do not graphically overlap the samples can be considered significantly different at the 0.05 confidence level. Typically, data will be standardized by density, as described below, and often represented as logarithms or natural logs to enhance discrimination between samples with large and small medians (e.g., Scarry 1993a:166–67; VanDerwarker 2006:99–102); however, such standardization is not required. Box plots are especially useful in spatial or temporal comparison of multiple samples (see examples and further discussion in VanDerwarker et al., chapter 11, this volume).

Standardized Measures

One challenge with quantitative paleoethnobotanical results is that changing the size or number of samples from a given feature or area can produce completely different absolute taxon counts on a sample-by-sample basis: a 10-liter soil sample ought to produce twice as many seeds as a five-liter soil sample from the same context. Standardized measures are used to address this problem and to increase intersample comparability, both over space (within one phase of a site or between synchronic sites) and over time (between different phases of a site or between sites of different periods). The two standardization methods employed most frequently are density measures, in which seed or charcoal counts or weights are normalized by the volume (or, occasionally, weight) of soil sampled, and percentages or proportions, which compare the presence of one taxon to a larger category to which it belongs (e.g., wheat grains to total cereal grains) (Miller 1988:73–75; Pearsall 2000:196–99).

Density measures are one of the most useful measures available to paleoethnobotanists because they control for differences between sample sizes. Although an arbitrary 10- or 20-liter sample may be a target sample size for flotation, real-world conditions often necessitate taking smaller samples from contexts of particular interest (e.g., hearth or vessel contents). Calculating density values for taxa of specific interest (e.g., all wild seeds, maize kernels or cupules, oak charcoal) is a necessary starting place for all intersample analyses. Proportions or percentage measures are another invaluable tool for standardizing the count of one taxon of interest against larger categories of botanical remains; these measures can be used to identify diachronic or contextual differences in the use of a particular plant across a site or between sites (Kreuz et al. 2005; Miller 1988; Miller and Smart 1984; van der Veen 2007a; VanDerwarker and Idol 2008; VanDerwarker and Kruger 2012; VanDerwarker et al. 2013).

Standard scores, also termed *Z-scores*, are values transformed to increments of standard deviations around a population mean (Drennan 2009; Shennan 1997). To be more accurate, these measures are based on computation of a sample mean and sample standard deviation, so are properly Student's *t*-statistics, but I retain the term *Z-score* (or standard score) as it is exclusively used in the paleoethnobotanical literature. The advantage of *Z*-scores is that they standardize each taxon by its relative abundance in a sample, so that taxa that produce large numbers of seeds per plant (e.g., *Chenopodium quinoa*) can be more meaningfully compared to taxa with low counts in archaeological contexts (e.g., maize cupules) (Pearsall 2000:199, 204).

One final type of standardized measure that has been used widely is ubiquity, which calculates the percentage of samples in which a given taxon appears (Pearsall 2000:212–16; Popper 1988:60–64). This is distinct from the other standardization methods detailed above because it standardizes presence/absence values across all samples, rather than actual count data. The utility of ubiquity has been debated (Kadane 1988:210; Pearsall 2000:214; Popper 1988:63–64; VanDerwarker 2010b:66; Wright 2010:51–52) but it remains in common use because it is easy to calculate and may be more informative than standardized count data when taxon counts in each sample are very low. Ubiquity works best when all samples are taken from similar types of contexts under similar depositional conditions and sampling measures, and can be paired with proportions or density measures to track changes in the use of taxa over time (Hastorf 1990). If samples are variable, however, ubiquity may be more misleading than helpful in identifying meaningful patterns of deposition among plant remains because a simple ubiquity measure will conflate and obscure intrasite variation (Pearsall 2000:214).

The limitations of standardized measures are most evident when counts for each taxon are low, as differences of one or two seeds between samples are magnified into seemingly substantial intersample differences in proportion or percentage. Although ubiquity does not suffer from this limitation, it reduces count data to presence/absence and thus treats samples with large quantities of

a taxon the same as those with isolated finds of that taxon (Hubbard 1980:52; Kadane 1988:210). In addition, ubiquity is sensitive to sample number and thus different sampling strategies can produce substantively different results and conclusions (Popper 1988:61).

Relative Measures

In contrast with descriptive measures, which are based solely on absolute counts, and standardized measures, which are based on absolute counts as parts of a whole (i.e., taxon, sample, or category of remains), relative measures relate the count of one taxon to that of another. This includes a wide variety of ratios in which the numerator is exclusive of the denominator (termed *comparisons* by Miller [1988:75]) and diversity indices, which indicate the homogeneity or heterogeneity of a sample or group of samples and are calculated based on the relative values of multiple taxa (Pearsall 2000:210–11; Popper 1988; Shannon and Weaver 1949; Simpson 1949). The unique strength of relative values lies in this comparative aspect, which allows straightforward visualization and interpretation of changes in multiple taxa over time or space.

Diversity indices are less commonly used in paleoethnobotany than in other archaeological fields, including zooarchaeology (Peres 2010; Reitz and Wing 2008; VanDerwarker 2010b). This is partially due to inherent issues of equifinality, in that one diversity index value represents both the evenness and species richness of a sample, so samples with few taxa but high evenness may have diversity values similar to those with many taxa and low evenness (Popper 1988). The two most common diversity indices used in archaeology are the Shannon-Weaver index (Shannon and Weaver 1949) and Simpson's diversity index (Simpson 1949), both of which incorporate measures of species evenness and richness to calculate diversity between samples. The Shannon-Weaver index calculates sample diversity on a scale of 0 (only one taxon present, no diversity) to a maximum relative to the number of taxa present (multiple taxa, evenly distributed), whereas the Simpson's diversity index uses the same input variables but produces a value of diversity that ranges from 0 (no diversity) to 1 (infinite diversity). The notable difference between the Shannon-Weaver and Simpson's indices is that the latter is less sensitive to the presence of few rare taxa than the former, so may be more appropriate for the analysis of paleoethnobotanical assemblages that are numerically dominated by a few ubiquitous taxa. In addition, the value of the Simpson's index is bounded between 0 and 1, allowing for a ready comparison with the maximum theoretical diversity measure (i.e., the maximum is independent of the number of taxa present), which aids in comparison of values between sites. A related, though rarely used, measure is niche width, which measures the evenness of resource utilization (Christenson 1980; Wymer 1993).

Comparison ratios, in which the numerator and denominator represent different taxa, are powerful tools for identifying patterns in paleoethnobotanical data, visualizing those patterns, and testing hypotheses. Given appropriate attention to how such ratios can address the specific research question of the analyst (Miller 1988; Wright 2010), it is possible to design ratios that measure specific relationships that might change across time or over space. Such ratios might be indicative of changes in fuel use (Klinge and Fall 2010; Miller 1996, 1997; Miller and Marston 2012; Miller and Smart 1984), crop processing (Scarry 2003; Stevens 2003b; VanDerwarker 2005, 2006; VanDerwarker and Stanyard 2009; Welch and Scarry 1995), agricultural risk management (Marston 2011), or environmental disturbance and degradation (Gremillion et al. 2008; Marston 2012a; Miller and Marston 2012). Comparative ratios are the most versatile simple statistic available to paleoethnobotanical researchers; recent scholarship demonstrates the utility of these ratios and other simple statistics in addressing a broad variety of research questions for both preliminary data exploration and hypothesis testing.

APPLICATIONS FOR DATA EXPLORATION

Simple statistics are well suited to data exploration, as they reduce complex tabular quantitative data into single numerical values that allow comparison between samples over space and time (Tukey 1977). Such "pattern searching" approaches (Jones 1991:70) allow for inductive interpretation of possibly meaningful spatial and temporal trends in the distribution of paleoethnobotanical remains, and are compatible with exploratory uses of multivariate statistics (VanDerwarker 2010a; A. Smith, chapter 10, this volume). Data exploration using simple statistics is thus a recommended first step in the quantitative analysis of paleoethnobotanical samples (Pearsall 2000:246).

In this section, I describe the use of simple statistics for exploring data and identifying patterns across space (within and between sites) and over time, with an emphasis on recent literature in the field. See earlier reviews for additional references from the 1960s through the 1990s (Hastorf 1999; Jones 1991; Miller 1988; Pearsall 2000; Popper 1988), as well as other chapters in this volume for additional approaches to intra- (VanDerwarker et al., chapter 11, this volume) and intersite analysis (Stevens, chapter 12, this volume).

Across Space

Identifying spatial patterning among paleoethnobotanical macroremains within single sites remains a challenge in reconstruction of the past (VanDerwarker et al., chapter 11, this volume). One limitation when interpreting intrasite variation is sample size, which often precludes applying statistical tests to individual samples and results in samples being grouped by area or (more frequently) by phase, eliminating potential interpretation of spatial variation (Jones 1991).

Simple measures, such as percentage composition of samples, are well suited to this type of intrasite spatial analysis. In one notable study, Hastorf (1991) investigated the spatial distribution of domestic food plants among the pre-Hispanic Sausa of Peru using spatially referenced pie charts that indicate the relative proportion of different domesticates in each sample (figure 9.1). These maps convey patterns of behavior, indicating that certain structures were used for food storage and processing, whereas others were used as dumps or compost areas, and open patios were preferred for maize processing (Hastorf 1991:142–43). This pie chart approach to visualizing relative percentages of taxa within a site or between sites has since been applied to investigate spatial distribution of food plants in other paleoethnobotanical studies in both the Old World (Allen 2005; Alonso et al. 2008; Borojevic 2011; Grabowski 2011; Hald 2010; Hald and Charles 2008) and New World (Lennstrom and Hastorf 1992, 1995). Alternately, density plots overlaid on maps of archaeological sites can illustrate the spatial distribution of botanical remains, perhaps more effectively than pie charts (Bogaard et al. 2009; Hally 1981; Weiss et al. 2008; see especially figures in VanDerwarker et al., chapter 11, this volume).

Intersite variation in paleoethnobotanical remains can show patterns of plant processing that indicate status differences or specialization of labor within a society. Trinary graphs (or triangular scatter plots) are an effective way to depict the relative proportions of three classes of data on one graph and can be used to identify differences in agricultural practices or plant disposal within or between sites (Alonso et al. 2008; Jones and Rowley-Conwy 2007; Stevens 2003b; van der Veen 1992a; figure 9.2). Welch and Scarry (1995) used box plots of logarithmically transformed standardized measures to compare diet and food processing between isolated farmsteads and higher-status residential centers in the Moundville polity. They found significant differences in nutshell and maize processing between farmsteads and population centers, with much higher levels of food processing at farmsteads but similar levels of maize consumption between the two types of sites (Welch and Scarry 1995).

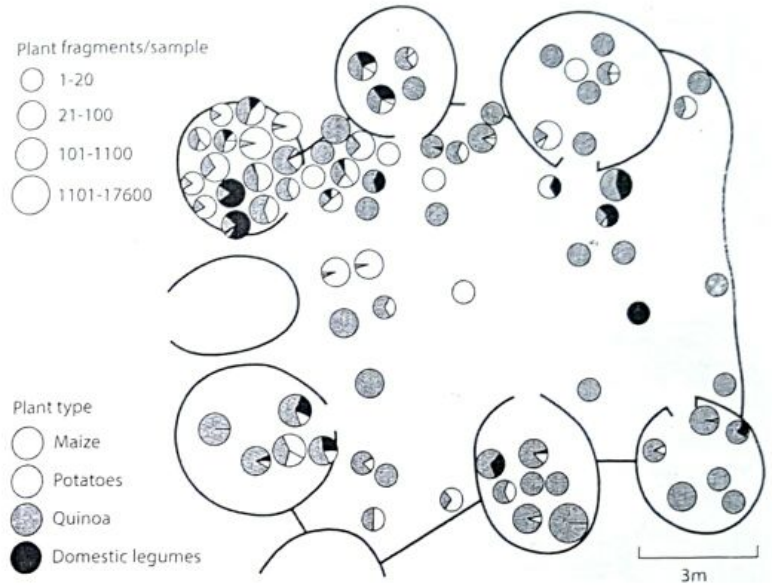

FIGURE 9.1. *Sample pie chart map showing differential use of plants over space within a household compound. Although this image is overly complex, some basic patterning (i.e., maize processed outside, potatoes primarily in upper left structure) can be discerned. After Hastorf 1991:figure 5.1.*

Across Time

The investigation of diachronic change at multiperiod sites is best approached through simple statistics. Any type of standardized or relative measure can be easily tracked over time as a way to identify meaningful patterns of change resulting from environmental or cultural change within a society. Among standardized measures, change in density measures and proportions of certain food or fuel taxa over time is typically grounds for further investigation of why certain plants, or classes of plants, became more or less common during different periods (Crawford 1997; Hastorf 1990; Miller 2010b; Mrozowski et al. 2008; Pearsall 1983). Proportions are especially useful in tracking changes in wood charcoal assemblages between periods, a proxy measure of changes in wood use and forest structure over time. Work in the Mediterranean and Near East has identified declines in slow-growing trees and their replacement by scrub vegetation as an effect of human population expansion throughout

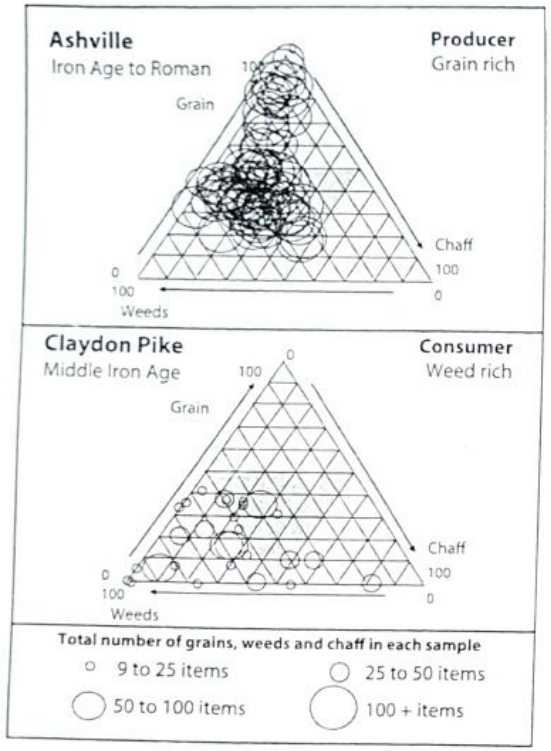

FIGURE 9.2. *Sample trinary graphs distinguishing relative proportions of cereal grain, cereal chaff, and weed seeds in samples from two sites in England, designated as producer and consumer sites. After Stevens 2003:figure 3.*

the region (Eastwood et al. 1998; Marston 2009, 2010; Miller 1999; Rubiales et al. 2011; Willcox 1974); anthropogenic changes in forest succession also have been identified in the area surrounding the Mississippian site of Cahokia in the American Bottom (Lopinot and Woods 1993).

Diversity measures are also well suited to exploratory data analysis. Changes in diversity measures over time at multiphase sites may illustrate chronological trends in the diversity of food remains and human-affected plant communities. Scarry (1993a) found that diversity in maize type declines over time in two different valleys of the Moundville polity, indicating that farmers were increasingly standardized in their production (figure 9.3).

Wymer (1993) found a similar result during the Middle Woodland to Late Woodland transition in the central Ohio River valley, which, combined with declining niche width, indicates agricultural intensification. VanDerwarker and colleagues (VanDerwarker et al. 2013) associated declines in maize

production and increases in wild plant food diversity with increasing uncertainty and risk among contact-era Cherokee. I used this statistic to identify diachronic change in steppe grassland health, presumably as a result of different grazing regimens, between periods of occupation at Gordion, in central Anatolia (Marston 2010). Comparison ratios can also be used to identify similar diachronic trends in diet, agriculture, and land use, but are perhaps better suited to hypothesis testing, as detailed below.

APPLICATIONS FOR HYPOTHESIS TESTING

Hypothesis testing has been one primary aim of paleoethnobotanical analysis since the first widespread publication of quantitative data from systematic flotation samples. Although some hypotheses, especially those related to the chronology of certain morphological characteristics related to domestication processes, can be addressed through presence/absence (e.g., Boivin and Fuller 2009; Denham 2005; Diehl 2005; Fuller 2006, 2007b) or categorical data (e.g., Asouti and Fuller 2013), most hypotheses about agricultural production and land use require the use of quantitative data. Simple statistics are well suited to test implications of hypothetical models derived from broader bodies of theory and from previous archaeological exploration in a region.

Several robust bodies of ecological theory give rise to models that can be tested using paleoethnobotanical data and recent efforts in the field have focused on testing models derived from niche construction theory (Smith 2007a, 2009b; B. Smith, chapter 18, this volume) and behavioral ecology (Gremillion 1996a, 1998, 2002b; Gremillion and Piperno 2009a; Kennett and Winterhalder 2006; Marston 2009, 2011; Piperno and Pearsall 1998a; Winterhalder and Goland 1997; Gremillion, chapter 17, this volume). In addition, prior archaeological research in a region may lead to specific hypotheses about diet, land use, and agricultural practices that can be answered through paleoethnobotanical investigation (e.g., Fuller and Stevens 2009; Hillman 1984a; Marston 2012a; Miller 1999; Miller and Marston 2012; Miller et al. 2009; van der Veen 2007a; VanDerwarker 2006). Spatial or diachronic change in standardized measures or relative measures applied to specific taxa provides an especially effective method to test implications of such hypotheses.

In this section, I detail recent approaches to hypothesis testing through the use of simple statistics, with a particular focus on the use of spatial and diachronic change in specially constructed ratios to identify human behavior in the paleoethnobotanical record. Other methods of hypothesis testing using multivariate statistics complement this approach and have additional

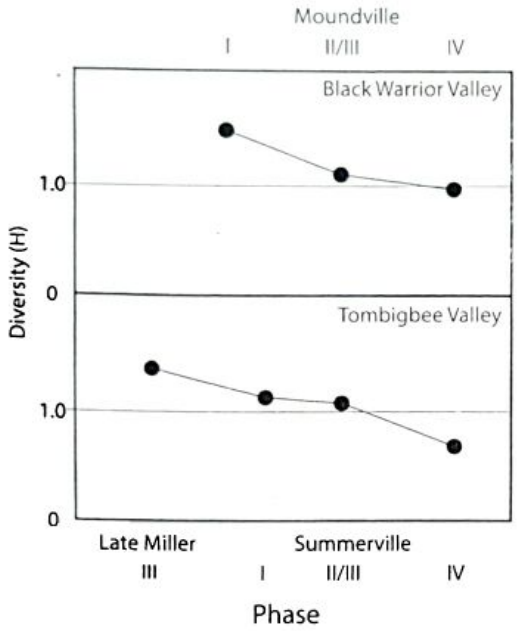

FIGURE 9.3. *Sample Shannon-Weaver diversity graph comparing maize cob row number diversity between two regions over time. After Scarry 1993:figure 11–17.*

benefits for uniting the analysis of animal and plant remains quantitatively (Colledge et al. 2004; Smith and Munro 2009; VanDerwarker 2010a; VanDerwarker and Peres 2010; A. Smith, chapter 10, this volume). Simple statistics, and especially comparative ratios, however, incorporate a smaller set of taxa and can be more specifically tailored to hypothetical test implications, providing greater clarity during analysis and interpretation, and better comparability between sites and regions.

Across Space

Both inter- and intrasite variation can be interpreted through the application of comparative ratios that have been designed to test specific hypothetical implications based on the research questions being addressed. One such research question is related to the location of crop processing among sites within a cultural zone. In the New World, a maize kernel-to-cupule ratio (figure 9.4) indicates the relative proportion of cleaned maize kernels to crop processing debris (maize cupules) and can be compared on a regional scale

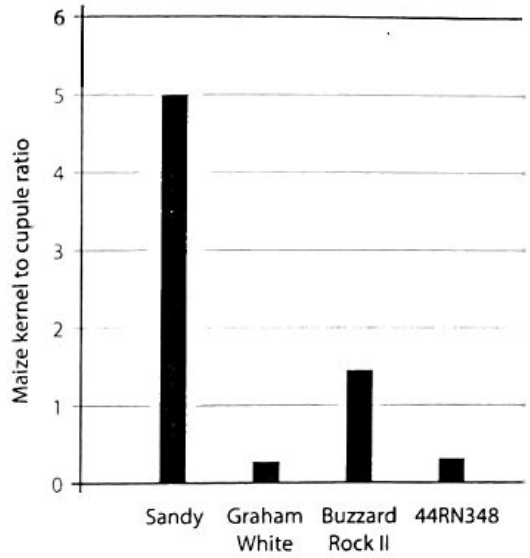

FIGURE 9.4. *Sample comparative ratio: the maize kernel-to-cupule ratio across four Late Woodland sites in the Roanoke valley. After VanDerwarker and Stanyard 2009:figure 3.*

(Peres 2010; Scarry 2003; VanDerwarker 2005, 2006, 2010b; VanDerwarker and Stanyard 2009). Scarry (1993a, 2003; Scarry and Scarry 2005; Scarry and Steponaitis 1997; Welch and Scarry 1995) identified distinct spatial patterns of these remains as evidence for variable locations of crop processing and food preparation in the Southeastern United States.

Similarly, VanDerwarker applied this ratio to Olmec sites on the Gulf Coast of Mexico and Late Woodland sites in Virginia (VanDerwarker 2005, 2006; VanDerwarker and Stanyard 2009). These studies identified differences in the kernel:cupule ratio as evidence for local processing of maize at some settlements (such as the Olmec site of Bezuapan and most Late Woodland sites of the Roanoke valley) but for importation of processed grain to other settlements (the Olmec site of La Joya and the Late Woodland Sandy site). At sites in Europe, regional patterns of labor mobilization can be identified through comparison across several sites of two different measures of crop processing, as measured by the ratio of weeds to cereals combined with the ratio of large to small weed seeds or the ratio of cereal grains to glume bases (Fuller and Stevens 2011; Stevens 2003b).

Alternately, comparative ratios can test the expectations of ecological models relating to the location of cultivation in an ecologically variable environment.

Gremillion and colleagues tested hypothetical upland and lowland cultivation systems in the Cumberland Plateau of eastern Kentucky by comparing the percentages of seeds from lowland, upland, and intermediate plant communities among nine sites in the region; they found that most sites used lowland or intermediate zones for agricultural production (Gremillion et al. 2008). Similar models derived from ecological theory offer potential avenues for quantitative analysis of paleoethnobotanical remains (Kennett et al. 2006; Piperno 2006a; Piperno and Pearsall 1998a; Zeanah 2004).

Naomi F. Miller has applied a seed-to-charcoal ratio (figure 9.5) to multiple prehistoric and early historic sites in the Near East to identify differential patterns of fuel use between sites located in arid steppe environments and wooded areas (Miller 1996, 1997; Miller and Smart 1984). In a recent paper, Miller and I broadened this analysis to six sites on the upper Euphrates, where annual rainfall varies from 500 mm to 200 mm over a few hundred kilometers (Miller and Marston 2012). We tested the hypothesis that reduced rainfall would necessitate increased use of animal dung for fuel across this region through the use of a seed-to-charcoal ratio and identified a general trend in which median seed-to-charcoal ratios are higher at more arid sites, as predicted. We also used a wild-seed-to-cereal ratio as a measure of foddering animals with agricultural products and identified a similar geographic trend, with increased foddering in wetter areas, where crop yields are higher and more consistent (Miller and Marston 2012). This same geographic comparative approach has been applied to Bronze Age sites in Cyprus, Jordan, and Syria, where the authors found similar trends relating forest cover, dung fuel use, and animal foddering across vegetation and rainfall clines (Klinge and Fall 2010).

Across Time

Comparative ratios can be used to identify why different agricultural practices may have been adopted over time at a single site. Research at Gordion, in Central Anatolia, shows substantial variation in agricultural strategies over nearly 3,000 years of occupation (Marston 2010, 2011, 2012a; Miller 2011b; Miller et al. 2009).

I devised a proxy measure of steppe health (figure 9.6) using charred seeds from animal dung burned as fuel; this ratio compares plants that are indicators of healthy, protected steppe to those that resist predation, either through physical (i.e., spines) or chemical defenses, and are often the last plants left in severely overgrazed areas (Marston 2011, 2012a). This ratio is strongly correlated with regional population levels: evidently, high regional population led

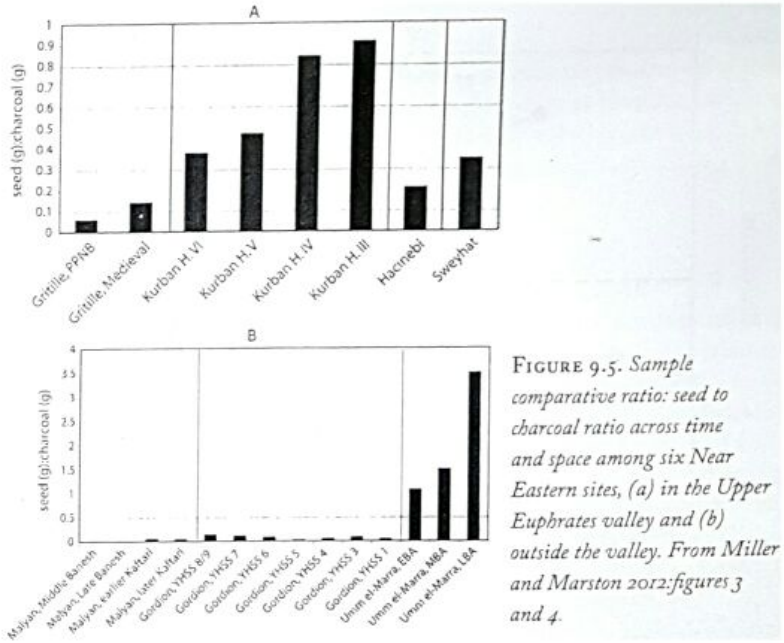

Figure 9.5. *Sample comparative ratio: seed to charcoal ratio across time and space among six Near Eastern sites, (a) in the Upper Euphrates valley and (b) outside the valley. From Miller and Marston 2012:figures 3 and 4.*

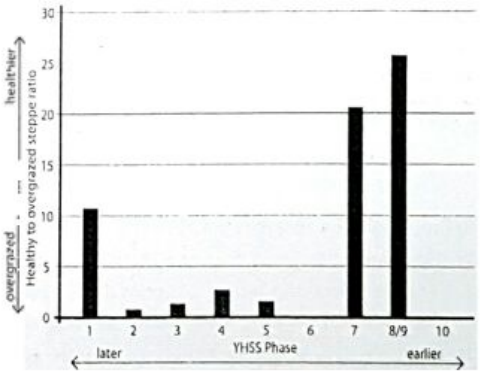

Figure 9.6. *Sample comparative ratio: changes in steppe health over time at Gordion, Turkey, measured by a ratio of plants indicative of healthy steppe (mainly perennial grasses) to those present in overgrazed areas (here,* Alhagi *and* Peganum*). YHSS 1 is the latest phase (Medieval) and YHSS 10 the earliest (Middle Bronze Age). From Marston 2012:figure 8.*

to overgrazing. Similar trends are evident in wood use at Gordion and at the site of Malyan in Iran, with increasing regional population leading to forest succession and deforestation (Marston 2010, 2012a; Miller 1985, 1999, 2010b; Miller and Marston 2012).

Wild-seed-to-cereal ratios can be used to identify diachronic change in animal foddering (Marston 2011; Miller 1997; Miller and Marston 2012; Miller et al. 2009) but also changes in cereal cultivation practices resulting from shifts between primary cultivars (Fuller and Stevens 2011). Gremillion and colleagues identified significant increases in the weed-to-canopy-seed and lowland-to-upland-seed ratios over time from a number of sites in the Cumberland Plateau, concluding that human agricultural activities led to increasing disturbance in plant communities over time (Gremillion et al. 2008:400).

CONCLUSIONS AND FUTURE DIRECTIONS

Quantitative reporting of paleoethnobotanical remains, especially on a sample-by-sample basis, permits numerical analysis of trends over space and over time using both simple and multivariate statistics. Simple statistics include descriptive statistics, which are useful for presenting data, and standardized and comparative statistics, which are powerful tools for data exploration and hypothesis testing. Recent scholarship has focused on the use of simple statistics primarily during the data exploration stage of paleoethnobotanical analysis, but comparative ratios in particular offer an avenue for hypothesis testing both within and between sites and regions.

One current trend in paleoethnobotanical analysis is the increased use of multivariate statistics, which have a long history in Europe but have only been widely applied in North America during the last decade (Jones 1991; Pearsall 2000; VanDerwarker 2010a; A. Smith, chapter 10, this volume; VanDerwarker et al., chapter 11, this volume). These methods of analysis are well suited to simplify massive data tables and can produce unique insights into the use of plants in the past (e.g., Colledge et al. 2004; Peres 2010; Smith and Munro 2009; van der Veen 2007a). In contrast, simple statistics rely on selective use of specific taxa from the paleoethnobotanical assemblage, and for this reason can be easily targeted to test hypotheses with clear paleoethnobotanical implications. Simple statistics have the potential to test implications of ecological and behavior models that predict certain dietary or agricultural responses to environmental and cultural change, and should be considered more often for hypothesis testing as well as data exploration.

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