



McDONALD INSTITUTE CONVERSATIONS

Far from the Hearth

Essays in Honour of Martin K. Jones

Edited by Emma Lightfoot, Xinyi Liu & Dorian Q Fuller

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(Above) Martin Jones at West Stow, 1972 (with thanks to Ian Alister, Lucy Walker, Leonie Walker, and West Stow Environmental Archaeology Group); (Below) Martin Jones in a millet field, Inner Mongolia, 2010. (Photograph: X. Liu.)





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Published by:

McDonald Institute for Archaeological Research
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Downing Street
Cambridge CB2 3ER
UK
(0)(1223) 339327
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www.mcdonald.cam.ac.uk



McDonald Institute for Archaeological Research, 2018

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ISBN: 978-1-902937-87-8

Cover image: *Foxtail millet field near Xinglonggou, Chifeng, China, photographed by Xinyi Liu, September 2014.*

Edited for the Institute by James Barrett (*Series Editor*) and Anne Chippindale.

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Acknowledgements

The initial idea of editing this volume grew out of a conversation between Xinyi Liu and Graeme Barker at St John's College, Cambridge in June 2016. The editors subsequently discussed the provisional layout of the volume. By April of the following year, our list of agreed contributors was complete. Abstracts followed, and the chapters themselves soon after. First of all, the editors would like to pay tribute to our 36 authors, whose excellent work and timely contributions made it all possible.

For the last two-and-a-half years, the volume has been known as 'Fantastic Beasts' in order to keep it a secret from Martin. As we enter the final stage, we wish to extend our thanks to all who have ensured Martin remains blissfully unaware, including Lucy Walker, and we offer her our sincere thanks. We are extremely grateful to Harriet Hunt, Diane Lister, Cynthia Larbey and Tamsin O'Connell, who are kindly

organizing the gatherings to mark Martin's retirement and the publication of this volume.

With respect to the volume's production, we would like to thank the McDonald Institute for Archaeology Research for financial support. The McDonald Monograph Series Editor James Barrett oversaw and encouraged all aspects of this project, and we offer him sincere thanks. We would also like to acknowledge the support of Cyprian Broodbank, not least for allowing us to host the workshop at the institute, but also for his encouragement throughout all phases of the volume's implementation. Particular thanks must go to several key individuals: Anne Chippindale, Ben Plumridge, Emma Jarman, Simon Stoddart and Samantha Leggett. Finally, we are also grateful to the anonymous reviewers who recommended changes that have greatly enhanced the final version of this volume.

*Xinyi Liu, Emma Lightfoot and Dorian Fuller
August 2018*

Foreword

The 28-year term of Martin Jones as the first George Pitt-Rivers Professor of Archaeological Science witnessed, and in part created, a transformation in the fields of environmental and biomolecular archaeology. In this volume, Martin's colleagues and students explore the intellectual rewards of this transformation, in terms of methodological developments in archaeobotany, the efflorescence of biomolecular archaeology, the integration of biological and social perspectives, and the exploration of archaeobotanical themes on a global scale. These advances are worldwide, and Martin's contributions can be traced through citation trails, the scholarly diaspora of the Pitt-Rivers Laboratory and (not least) the foundations laid by the Ancient Biomolecules Initiative of the Natural Environment Research Council (1989–1993), which he chaired and helped create. As outlined in Chapter 6, Martin's subsequent role in the bioarchaeology programme of the Wellcome Trust (1996–2006) further consolidated what is now a central and increasingly rewarding component of archaeological inquiry. Subsequently, he has engaged with the European Research Council, as Principal Investigator of the Food Globalisation in Prehistory project and a Panel Chair for the Advanced Grant programme. As both practitioner and indefatigable campaigner, he has promoted the field in immeasurable ways, at critical junctures in the past and in on-going capacities as a research leader.

The accolades for Martin's achievements are many, most recently Fellowship of the British Academy. Yet it is as a congenial, supportive—and demanding—force within the Pitt-Rivers Laboratory that the foundations of his intellectual influence were laid. Here, each Friday morning, the archaeological science community would draw sticks to decide who would deliver an impromptu research report or explore a topical theme. Martin is among the most laid-back colleagues I have worked with, yet simultaneously the most incisive in his constructive criticism. As a provider of internal peer-review he was fearless without being unkind. The themed Pitt-Rivers Christmas parties were equally impactful—on one occasion Alice Cooper appeared, looking ever so slightly like our professor of archaeological science.

Martin's roles as a research leader extended to several stints as head of the Department of Archaeology, chairing the Faculty of Archaeology and Anthropology and serving as a long-term member of the Managing Committee of the McDonald Institute for Archaeological Research. Having started his professional career as an excavation-unit archaeobotanist in Oxford, he was a long-standing proponent of the highly successful Cambridge Archaeological Unit. In the wider collegiate community, he is a Fellow (and was Vice-Master) of Darwin College and was the staff treasurer of the Student Labour Club. In all roles he fought valiantly and often successfully for the interests of his constituency. His capacity to fight for deeply held priorities while recognizing the value of diverse perspectives was of utmost importance. His nostalgic enthusiasm for the debate with archaeological science that was engendered by the post-processual critique is one signal of an underlying appreciation of plurality. His active support for the recent merger of the Divisions of Archaeology and Biological Anthropology, within our new Department of Archaeology, is another. As a scientist (Martin's first degree, at Cambridge, was in Natural Sciences) he values the peer-reviewed journal article above all scholarly outputs, yet has authored as many highly regarded books as a scholar in the humanities. His *Feast: Why humans share food* has been translated into several languages and won Food Book of the Year from the Guild of Food Writers. He views academia and society as a continuum, campaigning for archaeobotanical contributions to global food security (e.g. by promoting millet as a drought-resistant crop) and working with world players such as Unilever to encourage archaeologically informed decisions regarding food products.

That Martin's achievements and influence merit celebration is clear. That his colleagues and students wish to honour him is equally so. Yet does the McDonald Conversations series publish *Festschriften*? This is a semantic question. As series editor I am delighted to introduce a collection of important papers regarding the past, present and future of archaeobotany, representing its methodological diversity and maturity. That this collection concurrently pays respect to a treasured colleague is a very pleasant serendipity.

Dr James H. Barrett

Part I
Introduction

Introduction

Far from the Hearth

Xinyi Liu, Emma Lightfoot & Dorian Q Fuller

The essays in this volume honour a man whose research over the last four decades has exemplified the potential of archaeology, archaeological science and their cognate disciplines to address central questions about food and human nature. Martin Jones was a pioneer in the fields that have come to be known as archaeobotany and archaeological science. Whether working as an on-site archaeobotanist at British Iron Age sites in the 1970s and '80s, initiating the 'Ancient Biomolecule Initiative' in the 1990s, or researching past food globalization and the use of millet in the twenty-first century, Martin has repeatedly demonstrated how archaeology can be situated within our attempts to make sense of our own experiences of the contemporary world. While some of these challenges are currently very clear, for instance in relation to food security and climate change, others may only be appreciated with the benefit of hindsight.

Martin is question-driven. As a scientist he aspires to a depersonalized methodology, towards an approach that is replicable by all; on the other hand, he sees that the methodology cannot dictate the questions we ask. He explores the territory between two interpretative traditions, those who classify humans as biological organisms and those who consider the social person. He warns that one should avoid retreating into the safety of either these traditions, as it is the interconnection between social and biological discourses that sheds most light on the past.

This volume is organized around three major themes from Martin's career, and each is derived from a title of one of his books, chapters or papers. 'A Botanical Battleground' is named after his 1988 chapter 'The arable field: a botanical battleground'. This section includes six chapters that honour Martin's central role in the development of biomolecular archaeology and archaeobotany as disciplines. The second section, 'The Stomach and the Soul', is derived from a chapter in his book *Feast: Why humans share food* (2008), and this reflects his writings on the archaeology of food from evolutionary perspectives. The final section title, 'Between Fertile Crescents', is taken from his 2004

chapter 'Between fertile crescents: minor grain crops and agricultural origins' and connects to his more recent interest in food globalization in prehistory. The name of this monograph, *Far from the Hearth*, is the title of a chapter in *Feast*, in which he contrasts the evidence for lavish consumption (feasting) in the archaeological record with the tough lives of most people much of the time, as hunger was commonplace. This contrast sets up much of the tone of Martin's intellectual aspiration.

A botanical battleground

The first section honours not only Martin's early research in the application and development of archaeological science techniques, but also his fundamental role in the development of biomolecular archaeology as a discipline and in its early funding, without which many of us would not be here today.

The section starts with two papers that are directly inspired by this research. Dorian Fuller and Chris Stevens discuss and develop Martin's concept of the 'botanical battleground', that is the conceptualization of a field as a place where weed taxa compete with each other and with the crop, and in which farmers compete with weeds. They highlight the importance of these dynamic ecosystems and the contribution that archaeobotanists can make to agricultural research by adding time depth.

In the following chapter, Chris Stevens and Dorian Fuller describe the various categories of weed seeds in terms of their seedbank ecology and how this ecology is related to and affected by agricultural practices. Using changes in weed flora through time, they show how a consideration of weed species can be used to 'paint a picture' of the history of British agriculture from the Neolithic to the present day. This analysis provides key insights into changes in intensity and location of cultivation, as well as into farming practices (e.g. tillage), harvesting strategies and processing techniques.

This is followed by two more methodological papers, starting with Victor Paz's chapter which gives

details of a determination system he has developed for macroscopic plant remains, particularly parenchyma. The paper calls for transparency in the chain of reasoning that led to an identification, allowing the reader to evaluate the determination and how secure it is. Where possible, determinations should be based on an actual reference collection, with samples matched between past and present, and based on the uniqueness of transformed archaeological remains.

The next chapter, by Carla Lancelotti and Marco Madella, discusses the historical development of phytolith studies from their 'discovery' in 1835 to the various ways they are used today. The authors then discuss how phytolith analyses add to our understanding of plant use, the origins of agriculture and agricultural techniques in the past.

Terry Brown looks back at genetic work and research on the origins of European agriculture. In retrospect, the chapter starts with a Biomolecular Palaeontology meeting in 1990 and reviews the some of the key debates around development of archaeogenetics over the past few decades. For 30 years, those multidisciplinary debates took place as conversations between geneticists and archaeologists. These dialogues have proved stimulating, challenging and enjoyable. Brown approaches this history as a participant and fellow-traveller with Martin.

The section concludes with a tribute to Martin's role in the development of biomolecular archaeology written by Terry Brown, Richard Evershed and Matthew Collins. They highlight how many scholars owe their careers to Martin, via the funding schemes that he was fundamental in initiating along with Geoff Eglinton, Gordon Curry and others. It is clear that, without Martin's sustained lobbying over many years, biomolecular archaeology would today be a much less vibrant area of research with significantly fewer archaeologists using biomolecular techniques to explore the human past.

The stomach and the soul

The second section focuses on papers emphasizing the social and cultural aspects of food, subsistence strategies and the rituals associated with food preparation and consumption. The idea that 'food is good to think with' has been central to Martin's research and thinking over many years and the papers presented in this chapter use ethnographic, archaeological and scientific evidence to explore a territory between social and biological aspects of food.

In the first chapter, Graeme Barker and colleagues explore shifting domesticatory relationships between people, plants and animals in the Kelabit

Highlands of interior Borneo. Through their proposed long landscape history, they show how the rainforest is a repository of memory of past generations and how plant translocations also 'enculture' the rainforest. They emphasize how the two local communities, the Kelabit and Penan, have very different concepts of the rainforest and a different relationship to rice farming. The Kelabit celebrate rice fields and rice cultivation and see themselves as forest domesticators. In contrast, the Penan are reluctant to separate themselves from the forest and its benevolent spirits. The authors suggest that this division has an antiquity of only a few centuries and that rice's 'need for people to grow it' was concurrent with new ways of living.

Cynthia Larbey then discusses how foraging and sharing of food became gendered. Drawing on ethnographic, primatological, archaeological and genetic data, she discusses how female foraging and subsequent sharing of plant foods increases the likelihood of children surviving to adulthood (through the birth of fatter babies, and more successful breastfeeding and weaning). This strategy can be seen today in the foraging strategies of modern hunter-gatherers and archaeological evidence suggests that it dates back to the time of early *Homo*.

In the following paper, Christine Hastorf considers the cultural and ontological perspectives that accompanied the (continued) domestication of the potato. In contrast to grain crops, potatoes reproduce asexually and in order to maintain diversity, and thus protect against disease and pests, farmers must regularly add new varieties into the farming system. Hastorf shows the importance of exchange in the robusticity of potato crops and how the need for exchange of tubers created a unique state of mind in the farmers and encouraged communication, innovation and cooperation.

We then move to the Early Natufian, with Manon Savard's paper exploring the relationship between subsistence and sedentism in non-agricultural societies. Using Hallan Çemi, Turkey, as her example, she considers the archaeobotanical remains in the light of the combined models of Optimal Foraging Theory and the Broad Spectrum Revolution, that is, the idea that when hunter-gatherers became settled they altered their subsistence strategy from one focused on hunting high-ranked animals (which required migration) to one focused on a wider range of resources, including lower-ranked ones (available locally). The archaeobotanical data show that, while a wide range of plant resources is present in the Hallan Çemi assemblage, only a few of those species are present in significant quantities. In particular, she highlights how 'underestimated plants', in this case club rush

and knotgrass, may have been the staple foods that made sedentism possible before the emergence of agriculture. Nevertheless, she also considers the possibility that permanent structures do not equate with permanent occupation and emphasizes that these sites may be important nodes in the landscape, with abundant and reliable resources worthy of the investment of time and effort required for the construction of permanent structures.

Turning to the East, the chapter by Leo Hosoya and colleagues shifts the focus from animal/plant domesticates to cooking methods. Soot/burnt marks on cooking pots from prehistoric China and Japan are analysed. Two case studies are presented—the Japanese Jomon-Yayoi-Kofun cultures and the Neolithic lower Yangtze in China—in an attempt to reconstruct the daily meals of ancient rice-eating communities.

Concluding this section, Gilly Carr, Marie Louise Stig Sørensen and Dacia Viejo Rose discuss food as heritage. They consider two examples of approaches to food as heritage today: UNESCO's recognition of intangible cultural heritage, which includes food; and the specific case of the use of food in the discussion of war and the occupation of the Channel Islands. Both cases highlight ways in which food is important beyond subsistence; how the cultural values and meanings associated with food can be used as markers of identity, togetherness and social bonds, as well as how food can contribute to conversations about history, places and ways of doing things.

Between fertile crescents

In recent years, the major focus of Martin's research has been the spread of crops across vast distances in prehistory, particularly the spread of wheat and barley from the Near East across Eurasia to China and the spread of millet species from China westwards as far as Europe. The two Fertile Crescents referred to are the well-known Near Eastern Fertile Crescent, and the 'eastern fertile crescent'—the early Neolithic sites in the Yellow River region and sites along the eastern edge of the Loess Plateau, which form 'China's Fertile Arc' (Liu *et al.* 2009). The papers in this section all address aspects of the archaeology associated with this research theme, as well as the methodologies we can use to address it.

The first chapter in this section, by Xinyi Liu, Giedre Motuzaitė Matuzevičiūtė and Harriet Hunt, returns to the question of millet origins raised in Martin's (2004) chapter 'Between fertile crescents: minor grain crops and agricultural origins'. The chapter reviews recent advances in understanding broomcorn millet origins and spread through three

kinds of evidence: genetics; the earliest archaeological evidence in China; and new finds in Central Asia and Europe. Over 10 years, the Asian millets have moved from a poorly understood peripheral resource to a well-charted core feature of Old World prehistoric agriculture and its globalization.

The contribution from Emma Lightfoot, Xinyi Liu and Penelope Jones discusses how carbon isotope analysis can be used to identify the consumption of C₄ plants in the archaeological record. Specifically, they call for greater consideration of edible C₄ plants other than the known major crops (e.g. millet, maize and so on) in isotopic studies. To illustrate the potential problem, they identify edible C₄ plants grown in three different regions (Sicily, Italy; Haryana, India; and the south coast of Peru) and consider how the proportion of edible C₄ plants growing in each of these regions could affect archaeological interpretations of stable isotope results.

We move then to archaeogenetic analyses with a chapter written by Harriet Hunt and colleagues which discusses how genetic analyses have been used to consider domestication geographies. They use a diverse range of crops to illustrate how thinking has developed from the centres of origin concept developed by Vavilov to debates over single or multiple domestications. They also consider the implications of protracted domestications and ongoing geneflow on the use of genetic data to infer the geography of domestication.

Our focus then moves to two papers discussing the archaeobotany of China. The first, by Haiming Li and Guanghui Dong, focuses on Early Bronze Age archaeobotanical remains of both wheat and barley from Lijaping in the northeastern Tibetan Plateau. The authors discuss the adoption of barley in this region around 1700 BC and compare it to the preferential adoption of wheat in the nearby Hexi corridor. They highlight the advantages that both wheat and barley had over the previous staples, foxtail and broomcorn millet, particularly in terms of cold tolerance and crop yield. They conclude that the differential adoption of wheat and barley between the northeastern Tibetan Plateau and the Hexi corridor relates to the environmental and climatic conditions of these two regions being better suited to barley and wheat, respectively.

The final paper of this monograph, by Zhijun (Jimmy) Zhao, discusses the timing and route of the introduction of wheat into China, a focus of Martin's more recent research. Zhao reviews the archaeobotanical finds of early wheat remains, providing a critical assessment of the evidence. From these data, he shows that wheat was introduced to China between 4500 and 4000 years ago, and that it was introduced

along at least two routes. The first of these is a grassland route, from West Asia through Central Asia and the Eurasian Steppe to northern China and then the middle and lower reaches of the Yellow River. The second route, the oasis route, went from West Asia through Central Asia and then to the Pamir Mountains and oases on both sides of the Tarim Basin, then to the Hexi Corridor and on to the Loess Plateau of northern China.

Concluding notes

The chapters in this volume, like much of Martin's own work, are devoted to the archaeology of food. The emphasis is not only on food itself, but also on the communities which produced and consumed it. The interdisciplinary studies presented elucidate the spatial and temporal scales of recent developments of the field. In this volume, readers will find articles discussing a wide range of time periods and environments. Many of the articles involve original thinking; they are often imaginative, and some are controversial. Some of them begin with a tentative answer, drawn from a wealth of experience and insight and guesswork, which should drive future research. Readers will also find that this book highlights some approaches that emerged in the 1990s at the time when Martin was involved in the 'Ancient Biomolecules Initiative'. These approaches have become the foundation for aspects of archaeogenetics, residue analysis and isotopic studies that are now integral features of modern archaeological science and archaeobotany. Furthermore, the book provides a number of examples that explore the territory between the biological organism and the social person, two perspectives that have ghettoized the various studies of the human condition into separate social and biological discourses that so often fail to interconnect.

Finally, we see recent developments in Eastern Eurasia, about which little was known archaeobotanically in the earlier part of Martin's career and to which he has contributed. The recent florescence, over the last decade or so, has been an exciting time with massive strides made towards a better understanding of Asian prehistory. Martin played an important role in bringing some novel methodologies to that enterprise. The main consequence of all of these new discoveries has been to encourage us to reflect on the assumptions we have held in a western context, including our assumptions about what agriculture actually is.

Agriculture represents a dynamic ecology formed of competing crops and weeds and changing social practices. The recognition of these dynamics has been critical to Martin's thinking, from his earlier experience in West Stow Environmental Archaeology Group to his work in the Thames Valley through to the transcontinental perspective on 'minor' crops. His career has helped to make archaeobotany and biomolecular archaeology similarly dynamic fields.

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Part II
A Botanical Battleground

Chapter 1

The Making of the Botanical Battleground: Domestication and the Origins of the World's Weed Floras

Dorian Q Fuller & Chris J. Stevens

'The development of plant communities on agricultural land can thus be seen in part as a battle between weed communities and human communities, in which stakes for both parties are high'

Martin Jones (1988, 86)

Introduction

Martin Jones's work on the archaeology of British farming, pursued from the 1970s through the 1990s, combined big-picture evolutionary ecology with details of archaeobotanical evidence and individual weed ecologies. This approach considers the arable field as a habitat that is constantly evolving with changing human practice (M. Jones 1988). This was the 'botanical battleground' in which weed taxa competed with each other and the crop, and in which farmers competed with weeds. As such the arable ecosystem is defined in terms of cycles of human activity, rather than soil or climate conditions. Unlike biomes, in which shared characteristics of vegetation are determined largely by climatic constraints, the agricultural 'anthrome' (*sensu* Ellis 2011) represents something new to planet Earth from the start of the Holocene (or latest Pleistocene) created through the emergent mechanisms of culture. This has received attention in recent years as central to human niche construction or the emergence of an 'anthropocene' (e.g. Boivin *et al.* 2016; Ellis *et al.* 2013). Archaeobotany has a key role to play in documenting how these cultural ecosystems evolved and diverged. Research into the origins of agriculture has traditionally focused on social and economic transformations and the domesticated crops themselves; however, in this contribution we would like to explore the *botanical battlegrounds* that accompanied the earliest cultivation and domestication processes.

The origins of arable ecologies provide a context for the evolution of both weeds and domesticated crops from their respective wild ancestors. A weed is usually defined as a plant that grows where it is not wanted,

and as such is a human concept, as such rules do not apply in nature (Bunting 1960). Weed is a concept that arises within the history of human-plant relationships in which humans increasingly seek to control their environment. Prior to the start of cultivation weeds did not exist as such, but rather grew in their own 'natural' non-anthropogenic habitats. However, in some cases this natural habitat is a challenge to identify and Zohary (1950) classified such species as 'obligate' weeds. Nevertheless, as recognized by Harlan and de Wet (1965), there is a second definition of weed, which is a plant that thrives on disturbed ground, such as a cleared field. Such species then are pioneers and possess traits that allow for the rapid establishment of the plant and its acquisition of nutrients from the soil. This can be defined as an ecological strategy of fast resource acquisition (see Milla *et al.* 2015; Reich 2014). These ecological traits of weeds, or weediness, are shared with many domesticated cereals, suggesting parallel adaptations between crops and weeds.

As with domesticated species, some species growing in the cultivated field might be expected to evolve adaptations to this new arable ecology. Amongst such adaptations some of the key traits recognized as part of the domestication syndrome should then be considered, including changes in seed size, in germination patterns, or indeed the loss of germination. Ultimately a key distinction between weeds and crops is whether or not particular species within the cultivated field were volunteers or intentionally planted. The nature of this distinction plays an important role within the domestication syndrome; as crops evolved to be more readily harvested, so weeds utilized strategies in which they either became part of the harvest or avoided it.

Activities of the arable and the origins of fields

One of the key distinctions that makes the archaeobotanical study of domestication processes feasible is the

distinction between evidence for human practice and evidence for evolutionary changes in plants, underwritten by genetic shifts in plant populations. This is the distinction between cultivation and domestication, a distinction perhaps best clarified in the work of Harris (1989; 2012) and Hillman and Davies (1990), but essentially a division between what people do, for example *cultivate*, and what happens to plants, *domestication* (Fuller 2007; Purugganan & Fuller 2009). This creates an evolutionary process that is inherently co-evolutionary, an entangled network of feedbacks between human practices (evolving through cultural transmission) and plant morphologies (evolving through genetic adaptations). Previously, we have explored this entanglement in terms of humans getting ‘trapped’ in ever-increasing labour investment in soil maintenance, and harvesting and crop-processing technologies, which in turn are rewarded by higher returns (Fuller *et al.* 2016). A notion that was inspired by conversations with Martin Jones is to see this as shifting interactions within the food web, with human activities influencing energy flows at many levels.

Nearly three decades ago, Martin Jones (1992, 213) highlighted the need to move beyond ‘oversimplified correlates of a “domestication event” to examining’ the wider influences of humans on the nutritional status and the species they consume, such as the soil conditions in which food plants grew. This view highlights the importance of the small details of the nature of cultivated fields, the species in them and how these competed and adapted over time. Rather than framing a singular shift from foraging to farming, we need to explore the evolving ecosystem of cultivated fields alongside the various ‘intermediate economies’ (*sensu* Harris 2012) through the two to three millennia of the protracted domestication processes (Fuller *et al.* 2014). By considering the arable system as a *botanical battleground* we can usefully frame the key variables in this transition process, in which plants favoured by people (crops) and those not (weeds) compete for resources, and in which humans strategically alter the conditions of soil, water and light resources; and through this framework we can perhaps see more clearly some of the commonalities and differences between crops and weeds in the making of agriculture.

Cultivation involved a number of transformations of the soil which established the parameters of competition. First, pre-existing vegetation was largely cleared from the small plots of cultivation. It is conceivable that small woody perennials were left in place. Seed-dispersal studies of recruitment in natural grasslands suggest that existing perennials can limit seed establishment, especially of species not already established, whereas in annual ecosystems there is

greater competition between seeds (Peart 1989). The act of cultivation creates a new type of habitat in which annual disturbance is both uniform and highly predictable, with the removal of the existing plant canopy providing repeated opportunities for seeds present in the soil seed-bank to participate. Field clearance tends to mean that sunlight is widely available for growth and germination, but faster-growing plants in the field may quickly shade out their neighbours. Tillage also creates deeper cracks, which may bury seeds more deeply than if they had fallen on natural soil surfaces. Certain human cultivation practices may counteract some of these factors. For example, planting in rows or well-spaced crops will reduce overshadowing and competition between the roots of different plants. People can also add both nutrients (manuring) and water (irrigating) to the soil, and one of the key questions asked of archaeobotanists is when such practices came about? And what methods, for example inferences from weed seed ecology or stable isotopes, can provide evidence for such practices (Bogaard *et al.* 2007; G. Jones *et al.* 2010; Madella *et al.* 2009)? Evidence from elevated $\delta^{15}\text{N}$ in cereal grains from Greece suggests small intensively managed and manured fields (Vaiglova *et al.* 2014), something that may have been the norm for early arable systems (Bogaard 2005), with declining $\delta^{15}\text{N}$ levels in cereal grains over the course of the Holocene suggesting a movement towards less intensive, more extensive systems (Araus *et al.* 2014; Styring *et al.* 2017). In China, early fields were also small-scale (<10 sq. m), allowing close management of water and soil, including manuring with household waste and drying out to increase rice yields and control weeds (Fuller & Qin 2009; Weisskopf *et al.* 2014; 2015).

From the point of view of plant competition, these fields appear generally nutrient-rich and therefore potentially favoured plant traits that fit a nutrient acquisitive strategy, as opposed to a conservation, or nutrient-allocation, strategy, as defined by Reich (2014) and Milla and colleagues (2015).

Many adaptations of cereal spikelets serve to facilitate the position of seeds for germination. For example, grass awns, as well as aiding animal and water dispersal, can move in daily cycles in response to ambient temperature. This action drives the spikelet along the soil surface until a suitable crack or depression is found, and in some cases enables the burial of spikelets (Kulić *et al.* 2009; Peart 1979). In wild wheats the two awns open and close on a daily cycle, serving to ratchet the spikelet into soil (Elbaum *et al.* 2007). In weedy species of oats (*Avena* sp.) the bent awn plays a key role in drilling spikelets into the soil, enabling survival through winter for spring germination (Somody



Figure 1.1. Wild barley spikelets (*Hordeum spontaneum*), hand-picked (left) and that have dehisced overnight and are projecting into cleared soil in the morning (right). (Photograph: D. Fuller, Iraqi Kurdistan, May 2012.)

et al. 1985). Experiments with the awned dicot *Erodium* indicated that seed burial was more effective in soils with plant litter than barren or compacted soil, a useful adaptation within grassland environments (Stamp 1989). While long awn morphology may be excellent for dispersal (Fig. 1.1), and it may play some role in deterring herbivory, the metabolic investment in creating awns will detract from the potential investment in seed nutrients that power the early seedling. Human harvesting and sowing, along with the development of non-shattering types, removes the need for dispersal mechanisms, hence reduced metabolic expenditure upon these structures is expected during domestication leading to a reduction in awns and barbs (Fuller 2007).

The evolution of seed size: automatic escalation

The new competition created by the tilled and sown field accounts for one of the key recurrent domestication traits, namely larger seed size. Increased seed size during domestication was attributed by Harlan and colleagues (1973) to selection relating to seedling vigour and competition, and to deeper planting; however, the latter explanation has often been emphasized at the expense of the former (cf. Zohary 2004). This seemingly forgotten explanation of Harlan and colleagues (1973) was that larger seed sizes in crops are expected to evolve in relation to the highly disturbed soils of early cultivation. Larger seeds have a series of competitive advantages, including being correlated with larger seedlings in many grasses and legumes

(Baskin & Baskin 2001, 214). Larger seedlings will have a head-start in competition for light and space in what, after competing vegetation is removed, is effectively a level playing field, as sown grain or grain from the seed-bank germinates. Hence larger grains have a selective advantage, while conversely, the competitive advantage of smaller grain sizes that might aid dispersal and burial though reduced seed mass is lost.

Fuller (2007) emphasized depth of burial as a possible cause of increased grain size, but while supported experimentally in some taxa it was not in others (Kluyver *et al.* 2013). Larger seeds had advantages in seedling emergence in lentil (*Lens culinaris*), mung-bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), lima bean (*Phaseolus lunatus*) and more weakly in pea, but no significant correlation was recorded for soybean, peanut or common bean. A further difference, among the pulses tested, was between species processing hypogeal germination, in which cotyledons remain in the soil providing food for the seedling, and those with epigeal germination, in which cotyledons are raised above the soil, where they become photosynthetic. As might be expected species processing hypogeal germination were better at emerging from depth generally, and it may be that selection for larger seeds in epigeal species might increase the photosynthetic area, providing more resources for initial growth (Kluyver *et al.* 2013).

That seed size increase predominantly correlates with domestication, not just in cereals and pulses grown for their seeds, but in numerous vegetables grown for their leaves and tubers, such as lettuce,

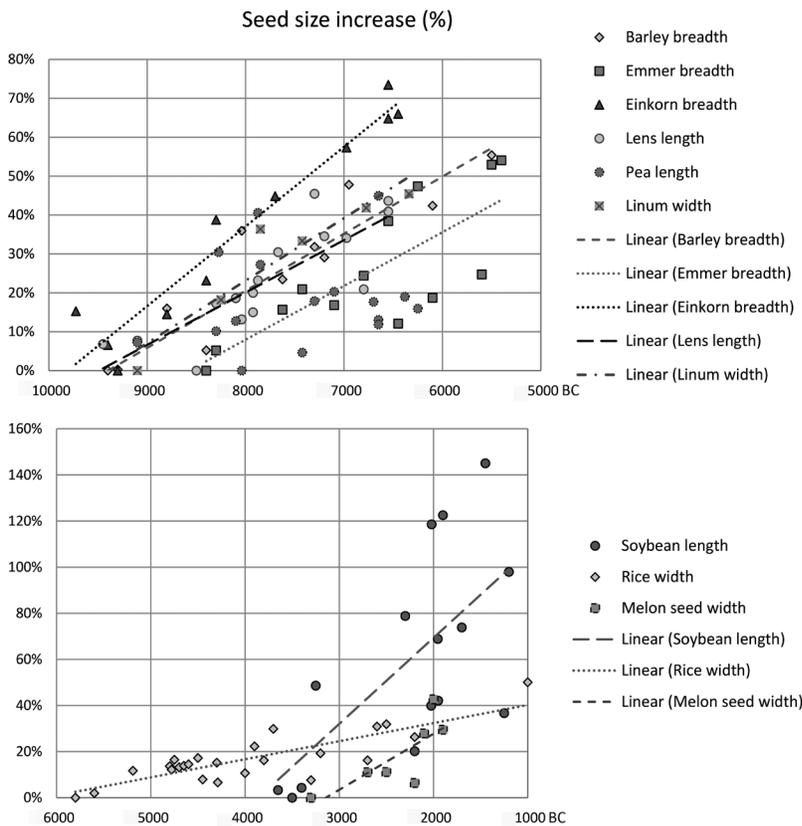


Figure 1.2. Seed size increase over time standardized to percentage change, comparing Southwest Asia (10,000–5000 BC) and China (6000–1000 BC) for selected crops. Linear regressions indicated for some taxa to illustrate trends. (Raw data from Fuller et al. 2014, except melon, from Fuller 2012.)

potato, beet, carrot and parsnip, indicates that seed-size increase was an evolutionary outcome arising from the cultivated environment (Kluyver *et al.* 2017). It is possible that this trait may be linked to other correlated traits, such as overall biomass of other organs that are linked in development to seed size, that is the effect of allometry or pleiotropy. Such changes, however, took millennia (Fuller *et al.* 2014; 2017), hence differences between generations within average seed size occurred on a minute scale that would be difficult to measure even with modern scientific techniques, let alone apparent to the naked eye. As such it is implausible that seed-size increase with initial domestication could be a target of conscious human manipulation. Instead, seed-size increase took place as part of the crops becoming incorporated into new arable ecologies, calling for more application of toolkits of comparative functional ecology to understanding domestication (Milla *et al.* 2015).

Archaeobotanical evidence allows us to put the timing and extent of changes in seed size into their cultural and geographical context and to explore comparisons across crops. Despite the effects of charring that may reduce seed sizes variably, charred archaeological seeds still document chronological trends during episodes of domestication (Fuller 2018; Fuller *et al.* 2014; 2017). Previous work has compiled

time series data for a range of annual crops, including Near Eastern cereals and pulses, North American composites, sumpweed (*Iva annua*) and sunflower (*Helianthus annuus*), Chinese (japonica) rice (*Oryza sativa*) and soybean (*Glycine max*) and Indian (indica) rice (*Oryza sativa*) and mungbean (*Vigna radiata*) (Fuller *et al.* 2012; 2014; Purugganan & Fuller 2011). One observation of Kluyver and colleagues (2017) is that the total size increase in cereals and pulses, grown for their seeds, is generally greater than that in vegetable crops. Indeed, when archaeobotanical data for size increase are plotted together, by standardizing these in terms of percentage change from the original (earliest/smallest size), some comparisons are striking (Fig. 1.2). First, it can be seen that in the Near Eastern cereals and representative pulses (lentil and pea, *Pisum sativum*) the trends of seed-size change are similar, with similar rates and total amount of change (average maximum being 45–65 per cent larger over 4000 years), with emmer wheat showing the slowest trend (although pea has a less clear trend). For China, rice showed a total increase towards the lower end of this spectrum at *c.* 50 per cent, while much more rapid and greater increase was evident in the soybean (>100 per cent increase) and in melons (*Cucumis melo*). Melon-seed size may be selected in part by simple allometry, as selection for larger fruits would developmentally

increase seed size, but selection from increased competitiveness in the botanical battleground of the cultivated field may have played a fundamental role, particularly in the early stages of domestication. Conscious selection of traits, such as fruit size or seed size, would be expected to increase the speed of change, and on this point it is worth noting that seed size in Chinese melons is relatively rapid in comparison with changes in cereal grain size (Fuller *et al.* 2014). Tree fruit seeds may also increase in size somewhat more rapidly (Fuller 2018).

Domestication of crops represents convergent evolution, involving similar adaptations. In this sense, crops emerged through domestication as tested warriors on the botanical battleground, with highly acquisitive ecological strategies. Indeed, crops appear to have been selected from wild ancestors that lay on the more acquisitive end of the annual herbs within a flora, processing characteristics that made them more adaptable to increased competition and disturbance (Cunniff *et al.* 2014). Sometimes, however, crops combine traits that are at odds with competitive adaptation within the ecological setting of their wild progenitors. For example, seed number and seed size can be regarded as trade-offs (e.g. Sadras 2007) in which plants may gain a competitive advantage through producing a greater number of seeds or by producing fewer, larger seeds (Harlan *et al.* 1973). However, both grain size and number have tended to increase with domestication. As crops come to lack the fall-back strategies of a seed-bank or perennating organs, this high investment and consumption habit can make them vulnerable to invaders that are less needy, the weeds, against which human cultural practices must evolve and adapt.

The sources of weeds in early Western Asia

Archaeobotanical evidence tells us that weeds have been persistent within crops throughout the Old World for many millennia. So where did these weeds come from? And how did some come to be such strong actors in the arable theatre?

The list of plant species reported as weeds of cultivation worldwide is staggering, in the tens of thousands (Randall 2002), covering a diverse range of plant families and genera. However, it is unlikely they evolved *de novo* with the creation of the first arable fields, so in answer to where weeds came from, we might rather ask: what was the original geography and habitat of the 'wild progenitors' of weeds?

Just as crops have evolved from wild relatives, we should perhaps think of weeds as also deriving from wild weed progenitors. It may be the case that populations of the same taxonomic species can still

be found in less anthropogenic 'natural' habitats, the so-called 'facultative weeds' (Harlan & de Wet 1965; Hartmann-Shenkman *et al.* 2015; Zohary 1950). Other weeds, however, have been termed 'homeless' or 'obligatory' (Harlan & de Wet 1965; Hartmann-Shenkman *et al.* 2015; Willcox 2012; Zohary 1950), indicating taxa that are unknown outside their arable and highly anthropogenic habitats. In other words, the original habitat of their ancestors, pre-dating cultivation, either no longer exists in its original form, or the ancestral forms of these species have since become extinct.

The presence of these 'obligatory weeds' on early sites in the Levant, alongside early domesticated crops, or morphologically wild cereals, has emerged as a key argument for recognizing the beginnings of cultivation (Colledge 2002; Hartmann-Shenkman *et al.* 2015; Willcox 2012). At Epipaleolithic Abu Hureyra (11,200–10,100 BC), Hillman (2000) argued for emergence of an arable ecology based on increases in potential weed taxa alongside morphologically wild rye and einkorn wheat. While this is a suggestive pattern, its statistical robustness has been questioned and the data reinterpreted as broadening of plant diet and a shift in foraging across a wider range of environments; in other words, cultivation was not required as an explanation for the changes seen (Colledge & Conolly 2010).

The few large-sized grains of rye and einkorn from Abu Hureyra could suggest some cultivation, as their size falls near the upper end of the range in late Early PPNB sites (see Fuller 2012, fig 5.3), but occasional transient cultivation, alongside a predominant strategy of collecting from wild stands, is both more plausible and likely. Nevertheless, the taxa at Abu Hureyra, mainly rye and some einkorn wheat, were not the key founder crops of more widespread cereal agriculture, that is barley and emmer wheat. So the notion that there was a single centre of agricultural origins has passed into intellectual history.

In the early Holocene, evidence for a more extensive weed flora is found alongside morphologically wild and evolving cereals that were increasingly acquiring a domesticated character. Willcox (2012) compiled a list of 19 indicator weeds, drawn from obligatory and facultative weed lists, from which he excluded taxa with edible seeds and ruderals that might have grown upon human settlements. The facultative weeds mainly have their alternative habitat in the steppe through to the desert margins (Zohary 1950; 1962). In this regard many facultative weeds originate on the drier end of the spectrum from cereals that are regarded as native to the transition zone from steppe to open woodland (Hillman 2000). Only in some cases can these weeds be definitely identi-

Table 1.1. Presence/absence of a select roster of founder weeds, expanded from Willcox (2012) to include some taxa discussed by Hartmann-Shenkman et al. (2015), and other key weedy grasses. Note that not all wild seed taxa are included, as some hard-seeded taxa or minute taxa may survive from animal dung or be processed as food in their own right (e.g. *Chenopodiaceae*, *Cyperaceae*, *Polygonaceae*, *Juncaceae*). Primary archaeobotanical primary sources, cereal proportions and median ages are those reviewed in Maeda et al. (2016, supplementary materials), with additions from Arranz-Otaegui et al. (2016). These data are drawn from all types of contexts, but the presence of charred cereal grains suggests that crop/food processing is a major input to these assemblages.

		Northern sites																		
Age: 1000s BC		10.6	11	9.9	9.6	9.5	9.1	9.1	8.6	8.4	7.7	7.5	7.4	7.4	7.1	6.9	6.8	6.7	6.6	6.2
sites	Obligate/Facultative	Abu Hureyra 1	Dederiyeh	Qaramel	Mureybit-II	Hallan Cemi	Mureybit-III	Jerf al Ahmar	Djade	Çayönü (bp/oh)	Asikli Höyük	Halula	Abu Hureyra 2	Cater Huyok IV-1	Ras Shamra (V/c)	Bouqras	Nebi Mend	El Kowm	Çatal Höyük	Sabi Abyad II
% Cereals		3.9	1.5	23	0.6	1.4	75	46.4	15.5	50.2	19.5	31.8	46.4	25.9	8.6	25	71.5	22.4	44	58.8
<i>Adonis</i>	O		X	X		X		X	X	X		X	X		X		X		X	X
<i>Bellevalia</i>	O	X		X	X	X	X	X	X		X	X			X			X	X	X
<i>Bupleurum</i>	O			X																
<i>Centaurea</i>	O		X		X	X	X	X	X			X	X			X			X	X
<i>Fumaria</i>	O		X		X	X		X	X	X		X	X							
<i>Galium</i>	O	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
<i>Glaucium</i>	O	X		X				X	X			X	X						X	X
<i>Heliotropium</i>	O	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X	X
<i>Lolium temulentum</i>	O														X					
<i>Ornithogalum</i>	O	X		X				X	X				X		X					
<i>Papaver</i>	O			X				X				X	X				X	X		
<i>Phalaris</i>	O			X				X		X		X			X				X	X
<i>Silene/Gysposila</i>	O/F	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
<i>Teucrium</i>	O					X			X		X	X	X						X	
<i>Vaccaria</i>	O					X			X	X		X							X	
<i>Valerianella</i>	O								X		X	X			X				X	X
<i>Aegilops</i>	F			X				X	X					X	X	X		X		X
<i>Avena</i>	F	X										X			X					
<i>Coronilla</i>	F			X				X	X			X								
<i>Crucianella</i>	F		X	X				X			X	X			X			X	X	
<i>Erodium</i>	F	X	X					X					X						X	X
<i>Lolium cf. remotum</i>	F																			
<i>Lolium sp./perenne/rigidum</i>	F	X		X				X	X	X		X		X	X	X	X	X	X	X
<i>Onobrychis</i>	F	X	X					X	X			X	X	X				X		
<i>Thymelaea</i>	F					X	X	X	X	X	X				X	X			X	
<i>Trifolieae</i>	F	X		X	X	X	X	X	X	X	X	X	X			X	X		X	X
<i>Trigonella astroites</i>	F				X		X	X	X	X	X				X					X
Total weed taxa		11	9	15	8	11	8	20	19	9	10	20	13	6	11	9	6	9	15	14

fied to species level in archaeological material. For example, Hartmann-Shenkman and colleagues (2015) were able to identify to species level 5 obligate weeds, as well as a longer list of 39 facultative weeds, from Atlit-Yam, dating to c. 6900 BC. Nevertheless, the long

list of these taxa and their recurrence across sites with both early domesticated and pre-domesticated (or intermediate) cereal finds suggests that the emergence of a weed flora was part and parcel of agricultural origins.

Table 1.1. (Continued).

		Southern sites															
Age: 1000s BC		9.9	9.4	9.3	9.1	9	8.6	8.6	8.5	7.9	7.7	7.6	7.5	7.4	7.2	7	6.9
sites	Obligate/Facultative	Geshet	Gilgal	Iraq ed-Dubb	Neiv Hagdud	Zahrat Adh-Dhra 2	el-Hemmeh	Aswad	Tell Qarassa	Beidha	Wadi Jilat 7	Aswad-2	Nahal Hemar	Ghorafé	Basta	Ramad	Aitit Yam
% Cereals		0.5	?	16	28.8	36.3	52.6	71.2	47.2	0.5	8.3	74.9	4.9	51.9	29.6	82.3	20.5
<i>Adonis</i>	O				X			X	X		X	X		X		X	X
<i>Bellevalia</i>	O				X			X				X	X	X		X	
<i>Bupleurum</i>	O					X										X	X
<i>Centaurea</i>	O	X			X		X		X		X	X	X			X	X
<i>Fumaria</i>	O	X	X		X		X		X		X	X				X	X
<i>Galium</i>	O	X		X	X		X	X	X		X	X		X	X	X	
<i>Glaucium</i>	O			X												X	
<i>Heliotropium</i>	O				X	X			X							X	X
<i>Lolium temulentum</i>	O																X
<i>Ornithogalum</i>	O							X	X			X		X		X	
<i>Papaver</i>	O																
<i>Phalaris</i>	O	X			X		X		X				X	X		X	X
<i>Silene/Gysposila</i>	O/F			X	X		X	X	X			X		X	X	X	
<i>Teucrium</i>	O															X	
<i>Vaccaria</i>	O							X	X			X		X		X	
<i>Valerianella</i>	O								X								
<i>Aegilops</i>	F	X	X	X	X	X	X			X		X				X	
<i>Avena</i>	F		X		X	X		X	X		X	X	X	X	X	X	X
<i>Coronilla</i>	F															X	
<i>Crucianella</i>	F											X				X	
<i>Erodium</i>	F	X	X		X		X										
<i>Lolium cf. remotum</i>	F															X	
<i>Lolium sp./perenne/ rigidum</i>	F							X	X	X		X		X		X	X
<i>Onobrychis</i>	F				X	X		X	X				X			X	
<i>Thymelaea</i>	F					X		X	X			X		X			X
<i>Trifolieae</i>	F	X					X	X	X		X	X	X	X	X	X	
<i>Trigonella astroites</i>	F				X		X	X	X			X		X		X	
Total weed taxa		7	4	4	13	6	9	12	16	2	6	15	6	12	4	22	10

A broader analysis of these data suggests the diversity of weed species increases during the pre-pottery Neolithic with greater cereal use (Table 1.1; Fig. 1.3). Thus, as cereal consumption increases, so does the evidence for a greater range of key weed taxa, implying that weed seeds were preserved through charring of crop-processing waste. For the southern Levant, the strength of this relationship is stronger

in the PPNB ($r^2=0.769$ for the Late PPNB) than in the PPNA ($r^2=0.169$ for PPNA), suggesting that over the era of domestication the arable ecological niche and its associated flora became increasingly entangled. Part of this can be attributed to the evolution and adaptation of key weed species shifting from their previous ecological strategies into emergent arable ecosystems. Additional factors, like the adoption of domesticated

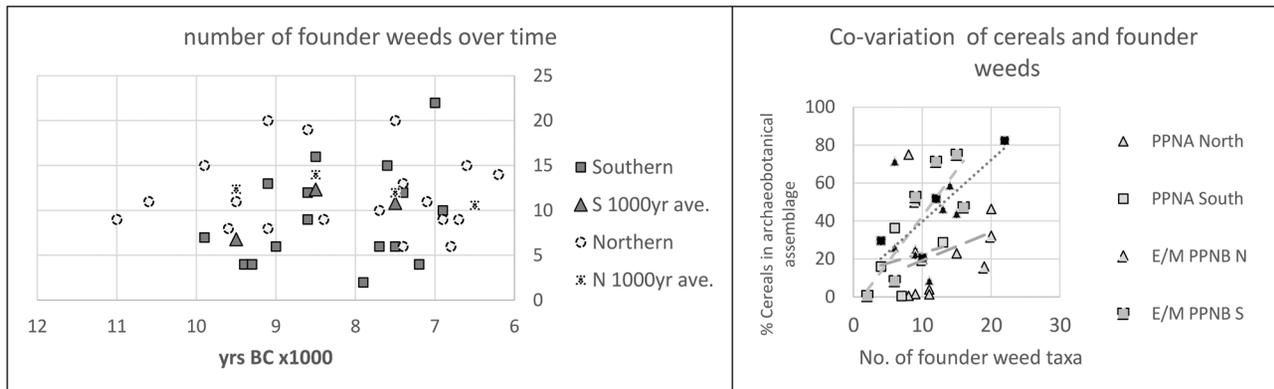


Figure 1.3. (Left) Chart showing the number of founder weed taxa over time (from the select list in Table 1.1), plotted by site against median age; averages for northern and southern regions calculated for each millennium; (right) Chart showing correlation between number of founder weed taxa and total proportion of cereals in the plant assemblage, suggesting a positive correlation between weed presence and cereal dependency, especially in the southern Levant.

animals and the use of their dung as fuel, might also contribute to greater wild seed diversity, but taxa that are well known to survive dung, for example Chenopodiaceae, Cyperaceae and Polygonaceae (Filipović 2014; Spengler 2018), are not included amongst our founder-weed roster. A few minute-seeded grasses are also associated with surviving in dung (Filipović 2014), but are not included in our list. Small seeded legumes (e.g. *Trifolium* spp., *Trigonella* spp., *Onobrychis* spp. etc.) are ambiguous, however, and could be derived from dung; but we have left them on our weeds list following that of Willcox (2012). In addition, the predominance of cereal grains, alongside other larger grasses, which are normally digested and not included in dung (Wallace & Charles 2013), highlights major inputs from agriculture/food into the archaeobotanical record.

In a few cases we can point to potential morphological evolution in weeds that likely accompanied adaptation to cultivation, human harvesting and sowing. Large weed seeds accompanying cereal grains into storage are likely to get dispersed with sowing, thus creating selection for seed characteristics that mimic the crop, including potentially changes in size and the loss of dormancy mechanisms. An interesting case is provided by *Bupleurum*. Like most Apiaceae, *Bupleurum* spp. typically disperse as individual separated mericarps. In the obligate weed *B. subovatum*, however, mericarps remain fused in pairs, which make them closer in size to grains and spikelets, and this trait likely evolved as an adaptation to dispersal with seed-corn prior to 6900 BC (Hartmann-Shenkman *et al.* 2015).

Lolium temulentum (darnel) is another obligate weed, a large-grained grass close in length to barley. Available genetic data indicate that it is phylogenetically close to *L. remotum*, a flax weed primarily distributed across northern Eurasia, with which it

is interfertile, although both are predominantly self-fertilizing, much like wheat/barley (Charmet *et al.* 1996). Likewise it is also interfertile with *L. persicum*, which has a broadly Middle Eastern distribution from Baluchistan to Anatolia (Davis 1985). *L. temulentum* appeared only towards the end of the Pre-Pottery Neolithic, with examples from Atlit Yam (c. 6900 BC) and Ras Shamra VC (c. 7100 BC) (Hartmann-Shenkman *et al.* 2015; van Zeist & Bakker-Heeres 1986). The *Lolium* from Ramad (c. 7300 BC) was shorter, like *L. remotum* (see van Zeist & Bakker-Heeres 1985, 511), or perhaps *L. persicum*. *L. rigidum/perenne* types were widespread in the Neolithic Near East, making precise identifications a continuing challenge. It is plausible that once *L. persicum* invaded early cultivated fields, it differentiated into *L. remotum* and *L. temulentum*. *L. temulentum* evolving longer grains that mimic harvested barley or wheat grains that would be hard to remove during processing (Harlan & de Wet 1965). Subsequently *L. temulentum* was to spread as a frequent cereal weed through both Pakistan and Europe.

Secondary domestications: weeds as sources of crops

In some cases, weeds became so well adapted to cultivation that they could even out-compete crops. Some of these 'weeds' themselves then became valued as resources that ultimately became domesticated. A farmer observing a weed-infested field (Fig. 1.4) might dismay at the reduced harvest of the favoured crop, but in times of need might decide that gathering the grains of these weeds would also provide an alternative source of calories, as recorded for *Bromus secalinus* (bromegrass) in Europe (M. Jones 1988), eventually cultivating the weed itself, turning it into



Figure 1.4. A field of wheat (*Triticum aestivum*) in which weedy oats (*Avena fatua*) and wild barley (*Hordeum spontaneum*) appear to be rather better than the crop. (Photograph: D. Fuller, Iraqi Kurdistan, May 2012.)

a crop. These are what botanists have referred to as secondary domesticates (e.g. Vavilov 1992). One way to explain these domestications is that they represent a case of conscious selection by farmers, who decided to transform a weed using the model of existing crops, thereby rapidly breeding it into a domesticate. But it is also possible that this began through inadvertent outcomes of the co-evolutionary battles of arable field, between weeds and farmers.

Europe's cultivated oat is a classic example of a secondary domesticate. *Avena sativa* (oat) was itself domesticated from a weed (*Avena ludoviciana* or the *A. sterilis* complex) that in all likelihood was evolving for millennia as a weed of cultivation. Today *A. ludoviciana* is found on fallow fields and field edges, and river banks and oak scrub (Davis 1985), where one suspects it has been invasive from arable fields. Its ancestor has been shown to be *Avena sterilis* (Loskutov 2008), a native to Mediterranean and steppic habits of the Near East, growing upon limestone slopes and calcareous coastal soils, and is a recurrent weed on many early sites (Table 1.1). The widespread weedy oat today, *Avena fatua*, has

no native habitat, and represents a probable parallel derivation from *A. sterilis* (Loskutov 2008). The genus *Avena* as a whole is largely circum-Mediterranean (Baum 1977), and while there is evidence for short-lived early cultivation of *A. sterilis* during the PPNA in Israel (Weiss *et al.* 2006), there is no evidence for a lasting tradition of cultivation or oat domestication in the Near East. Instead, the oat crops we know today appear to have been domesticated in central or eastern Europe around the Late Bronze Age to Early Iron Age and by the first millennium AD were widespread as a cultivated domesticate. They came into their own in the more marginal environments of northern Europe, Ireland and Scotland from around 2000 years ago, and possibly earlier in Scandinavia (Grabowski 2011). An unanswered question is whether or not the naked oat, widely cultivated in cooler and higher elevation parts of China, Tibet and the Himalayas, is derived from the same domestication. More likely, it represents a further secondary domestication of weedy *A. sterilis/ludoviciana* that dispersed eastwards with wheat and barley during the later Neolithic or Early Bronze Age (Stevens *et al.* 2016). The naked, free-threshing grains

of east Asian cultivated oats (*Avena nuda*) fit alongside other winter cereals in this zone, naked barley and free-threshing bread wheat; whereas European oat retained its hull, joining an agricultural milieu already dominated by hulled cereals, spelt wheat and hulled barley. This highlights how secondary domesticates were selected in each region for features paralleled within existing domesticates.

Oat domestication and secondary cereal domestications have been little studied. Like other cereals, oats have spikelets that do not dehisce from the panicle, and this can be diagnosed in preserved spikelet bases. It is conceivable this trait was unconsciously selected initially within weedy oats where it evolved as a mechanism by which they were more likely harvested and sown with seed corn. This appears the case for the semi-domesticated *A. abyssinica* in Ethiopia, probably derived from the wild shattering oats, *A. barbata*, and variant *A. vavilovii*, all weeds of highland wheat and barley (Baum 1977; Ladizinsky 1975). In contrast to *A. barbata* and *A. vavilovii*, *A. abyssinica* is shorter, blending into wheat and barley fields, has grains similar in size to barley and non-shattering spikelets. These spikelets are readily harvested by sickle, then threshed and processed and consumed with the main cereal crop, and in some cases it is cultivated on its own.

This example provides a model for the evolutionary trajectory for cultivated oats (*A. sativa*), in which domestication traits, probably greater grain size, then non-shattering, evolved through adaptations resulting from escalating co-evolutionary feedbacks through which weedy oats became an ever better mimic of the main crop, probably barley, in which at first it was tolerated as an edible weed, through to cultivation in its own right. In this scenario the evolution of secondary domesticates is just as unconscious as primary domestications (Fuller *et al.* 2010) and might be similarly protracted.

Mimicry of crops by weeds during their vegetative growth phase is a further common outcome of the botanical battleground. It is likely that all traditions of cultivation involve some degree of field weeding or roguing to remove competition to increase crop productivity, potentially selecting for weeds that look increasingly like the crop. The case of *A. abyssinica* is one case in point, being shorter in stature, whereas many wild oats stand tall above cereals. Others include *Camelina sativa* ssp. *linicola* N. Zing. that mimics flax in vegetative characters, has synchronous flowering with the crop and non-dehiscent capsules (Barrett 1983). Another form, *C. sativa* var. *crepitans* Sinskaya, has dehiscent capsules and co-occurs with rare dehiscent flax forms (*Linum usitatissimum* ssp. *crepitans* Elladi).

Another well-documented mimic is *Echinochloa crus-galli* (barnyard millet: Barrett 1983). The wild form, barnyard grass, is widespread in wetlands across Eurasia, commonly occurring as a weed of rice. In Japan, a subspecies of Japanese barnyard millet, *E. crus-galli* var. *utilis* (Ohwi & Yabuno) Kit. was cultivated and domesticated, during the Middle Jomon period long before the arrival of domesticated rice from China (Crawford 2011; Yabuno 1987). However, another weedy subspecies of this grass, *E. crus-galli* var. *oryzicola* (Vasinger) Ohwi, is well adapted to flooded paddy fields, mimicking rice in appearance from its seedling stage throughout its vegetative growth, making weeding near impossible (Barrett 1983), but usually flowering and setting seed before the rice harvest (de Wet *et al.* 1983a). In parts of the Caucasus in Russia a non-shattering form of *E. crus-galli* var. *oryzicola* has evolved in rice fields (also called *E. macrocarpa* Vasinger), in which spikelets remain on the panicle. These are reportedly cultivated sometimes in their own right and made into beer and flat breads (de Wet *et al.* 1983a), thus providing a parallel spectrum of adaptations to those of weedy and domesticated oats.

Rice fields have provided a potentially rich habitat for the evolution of other secondary domesticates. Kimata and colleagues (2000) proposed that all the native species of millets in India originated as weeds of rice, as their wild forms commonly occur in rice fields. However, this appears incorrect, as some native millets form primary staple foods within regional Neolithic traditions, for example *Panicum sumatrense* (little millet) in northwest India (Fuller 2006; Weber & Kashyap 2016) and *Brachiaria ramosa* (browntop millet) in southern India (Fuller 2006; Kingwell-Banham & Fuller 2014), before the arrival of rice. But it is likely true for Kodo millet (*Paspalum scrobiculatum*), the wild form being a widespread weed of rice, especially in dry (rainfed) fields (de Wet *et al.* 1983b; Moody 1989; Weisskopf *et al.* 2014). Early archaeobotanical finds comprise occasional grains associated with assemblages dominated by other millets or rice, but during the Iron Age on the Indian Peninsula it occurs with very high frequency and ubiquity, often out-numbering all other crops (Cooke & Fuller 2015), with plumper-grained, domesticated type forms occurring alongside narrower grain (wild types) (e.g. Kajale 1984). As the main form of early rice cultivation in India was likely rain fed (Fuller & Qin 2009; Weisskopf *et al.* 2014), the potential for poor yields due to low rainfall or drought and competition from weeds would have been high. In this context the more prolific grain-producing weeds, such as *Paspalum scrobiculatum*, could have been increasingly

attractive as fall-back foods, eventually evolving into domesticated crops.

Losing the battle, winning the war?

In conceptualizing the arable field as a battleground between crops and their human allies and weeds, Martin Jones provided a framework that recognized a dynamic history in agriculture. Overall, secondary domesticates have received less attention than primary crops, but are key representatives of the botanical battleground, helping to adapt agriculture to a wider range of environmental conditions as humans took traditional crops beyond their native ranges, and hedging against crop failures through diversification.

Over the long history of agriculture, not only have weed assemblages changed, but the species that constitute weeds have evolved, and in this sense the arable ecosystems of the world represent a dynamic and changing anthropogenic ecology. Archaeobotanists have a unique vantage point, and a duty, to reveal more about this battleground. For one thing, agriculture has had and continues to have an unparalleled impact on global ecosystems, cultural stability and human population dynamics. Yet most scientific agricultural research draws on a shallow time depth of experiments and historical knowledge, whereas archaeobotany offers an approach to a holistic history of agricultural ecosystems.

Acknowledgements

This paper was supported by a European Research Council grant 'Comparative Pathways to Agriculture' (CompPAG, no. 323842).

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Chapter 2

The Fighting Flora: An Examination of the Origins and Changing Composition of the Weed Flora of the British Isles

Chris J. Stevens & Dorian Q Fuller

The nature of charred assemblages

With the application of flotation to archaeological sites across much of Europe and the Near East, it quickly became apparent that charred assemblages appeared to be remarkably uniform, comprising wood charcoal along with charred grains, cereal chaff and seeds of species often commonly associated with arable fields (Jones 1985; Knörzner 1971). It was these wild species' seeds, the charred seeds of agricultural plants which were to form a large part of Martin Jones' work, that we explore further here, drawing on changes within the weed flora, and the picture it paints of the history of agriculture within the British Isles.

The nature of competition

One of the major contributions of Martin Jones was the discussion of the reproductive strategies of weeds, in particular those associated with dormancy, germination and the formation of seed-banks and how they related to past agricultural practice (Jones 1981; 1984; 1988a,b; 2009).

Agriculture by its very nature produces disturbed environments through tillage, by spade, ard, plough, hoe and/or harrow. For perennial species, unless they are able to reproduce seed within a single season, survival in the arable field relies on seasonal reproduction through vegetative means or simply through avoidance within low disturbance tillage regimes, for example by ard. In contrast, annual species had already evolved a number of strategies to colonize disturbed habitats, by which they were eventually able to dominate arable fields. For annuals and perennials one strategy to colonize disturbed soils was through appendages attached to the seed, dispersal mechanisms that facilitated the finding of recently vacated suitable microsites for germination. The other strategy was through the formation of seed-

banks comprising seeds buried within the soil. These buried seeds often require certain conditions before they will germinate, known as dormancy mechanisms. These mechanisms delay germination, allowing the plant to disperse their seed temporally. In this way seeds buried in the seed-bank can seek out suitable moments when conditions are favourable for germination to establish a new plant.

On the basis of seed persistence and dormancy breaking mechanisms four seed-bank types have been defined (Grime *et al.* 1988; Thompson & Grime 1979).

Transient seed-banks

Type I: Seeds lack dormancy mechanisms, germinating shortly after shedding. Often no light requirement. Seeds have little longevity in the soil.

Type II: Seeds possess dormancy breaking mechanisms, for example chilling, after which there is often no light requirement. Usually germinating in early spring, but can be in winter. Seeds have little longevity in the soil.

Persistent seed-banks

Type III: Most seeds germinate shortly after shedding, but some enter dormancy, forming a persistent seed-bank.

Type IV: Most seeds are dormant and few germinate directly after shedding. Colonization is from a large maintained seed-bank with little seasonal fluctuation in its size.

Type I seed-banks predominate within large-seeded grasses, for example *Bromus* sp. (see Table 2.1; Thompson & Grime 1979), and are associated with dry-grassland ecologies, with predictable seasonal disturbance, where vegetation dies off in the dry summer. Dispersal via awns and germination with the next rains are essential to the plant's survival to the next generation. Such habitats are found within

the grassland steppe of the Near East and the natural grasslands of central Europe. Seeds of Type I species are shed prior to and during harvest, and would germinate either prior to autumn tillage, or potentially after sowing (Fig. 2.1). As such they can potentially survive within the arable field under autumn sowing. However, such species would more likely be removed by tillage, hoeing or weeding prior to spring sowing (Fig. 2.2) and hence, if not harvested then reintroduced with seedcorn, would be absent within spring-sown fields.

Type II seed-banks are associated with species inhabiting northern temperate and continental zones, evolving in situations where seasonal annual disturbance, perhaps relating to water-erosion, solifluction or frost-heaving, can lead to vegetation openings during winter and spring (Thompson & Grime 1979). Examples include *Galium tricornerutum* (corn cleavers) and *Agrostemma githago* (corncockle), probably native to the mountains of the Near East and Mediterranean regions, respectively (cf. Ehrendorfer & Schönbeck-Temesy 1980, 607–8; Greuter 1995). For both species, seed germination increases after ‘chilling’ at lower temperatures *c.* 4–6°C (Chauhan *et al.* 2006; de Klerk & Smulders 1984; Steinbauer & Grigsby 1957), as occurs in their natural habitats during winter. This same requirement was also seen for the British native *Galium aparine* (cleavers). In the arable field such mechanisms allow seeds shed in summer potentially to avoid autumn ploughing (Fig. 2.1), but they are likely to be destroyed by spring ploughing (Fig. 2.2) and hence are potentially good indicators of autumn sowing (see Jones 1981). *Agrostemma githago*, however, can appear after spring sowing, possibly due to an after-ripening period that removes the need for chilling within dry storage (cf. de Klerk & Smulders 1984), something that might occur if it was stored with, then resown as, a contaminant of the seedcorn.

By the nature of their lack of longevity, seeds of species with Type I and II seed-banks tend not to become buried, and are often larger in size. Within the agricultural field, such species might germinate before tillage, hence they are often reliant on being harvested and resown with the crop, characterized by being of similar height and possessing grain-sized seeds.

Species displaying Type III seed-banks might be thought of as evolving within environments characterized by regular, but more sporadic, catastrophic disturbance, for example flooding or fire, which destroys much of the vegetation before it can set seed. This strategy allows them to germinate quickly and continue to dominate such environments without the need to recolonize from adjacent habitats. Seeds of such species can be variable in size, for example *Poa*

as opposed to *Lithospermum arvense* (field gromwell). It is also notable that while after-ripening is required, 90 per cent of *Lithospermum arvense* seed germinates within the first year, suggesting recruitment to the arable field is predominantly through continued production of seed rather than the seed-bank (Chantre *et al.* 2009). Within the arable field, Type III species, given their tendency to germinate after shedding, as with Type I species, might well be expected to be more greatly diminished under spring sowing regimes (Fig. 2.2) than autumn.

Type IV species usually produce high numbers of small seeds, for example, *Chenopodium* spp., *Juncus* sp., *Stellaria media*, although others such as *Fallopia convolvulus* (wild buckwheat) have much larger seeds. They are adapted to environments where disturbance regularly occurs, but is unpredictable both in its seasonal timing and that such disturbance may not occur every year.

To summarize, species with transient seed-banks are more likely to persist where they are harvested with the crop then resown with the seedcorn through broadcast sowing, a method of sowing that dominates ethnographic and historical accounts (e.g. D’Andrea & Haile 2002; Hillman 1984; Murray 2000). Type I species are generally associated with autumn germination (Fig. 2.1) and Type II with spring, although as seen above this is not always the case (Fig. 2.2). Species with semi-persistent seed-banks (Type III) will potentially be able to survive periods of grazing and tillage. However, where fields are left fallow but still tilled and harrowed, or planted in rows and regularly weeded, they will be much reduced, unless by virtue of having large seeds they are able to be resown as contaminants of the seedcorn. Species with persistent seed-banks (Type IV) might be expected to be lower where cultivation regularly shifts to new plots, or with the use of the ard, which unlike asymmetrical shares neither cuts deep nor turns the soil burying the seed (Figs. 2.3, 2.4). However, with the use of the plough they are much more likely to increase as the plough buries newly shed seed and brings those buried, but which have lost their dormancy, to the surface (Fig. 2.4; Fay & Olsen 1979).

The second aspect is the relation of perennials and annuals to tillage and rotation with pasture (Figs. 2.3, 2.4). The situation is complex, not least because of incomplete knowledge about the ability of perennial species to produce seed in their first year and so escape cultivation by behaving more like an annual than perennial. For example, *Plantago major* (broadleaf plantain or white man’s foot) may produce seed within six weeks of germinating from a persistent seed-bank (Holm *et al.* 1977). However, where perennial plants

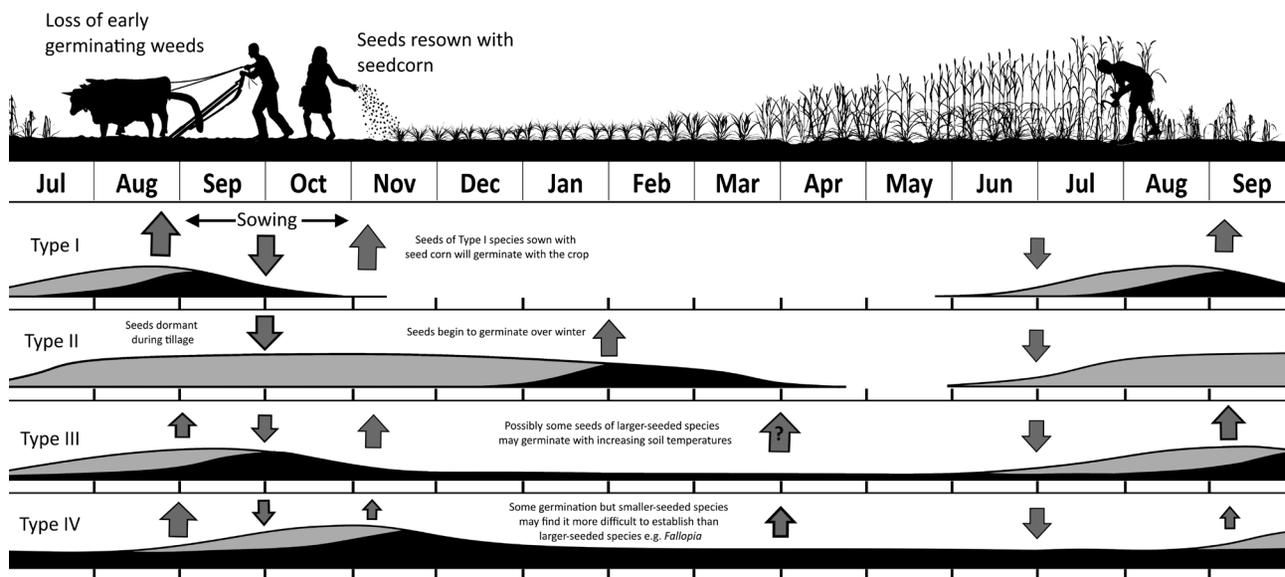


Figure 2.1. Diagrammatic representation of seed-bank types (includes annual and perennials) from Thompson and Grime (1979) denoting additions (down arrows) and losses (up arrows) from the seed-bank within an autumn sowing-tillage cycle. Black areas denote seeds capable of immediate germination with suitable stimuli, grey areas viable seeds that are dormant and not capable of immediate germination.

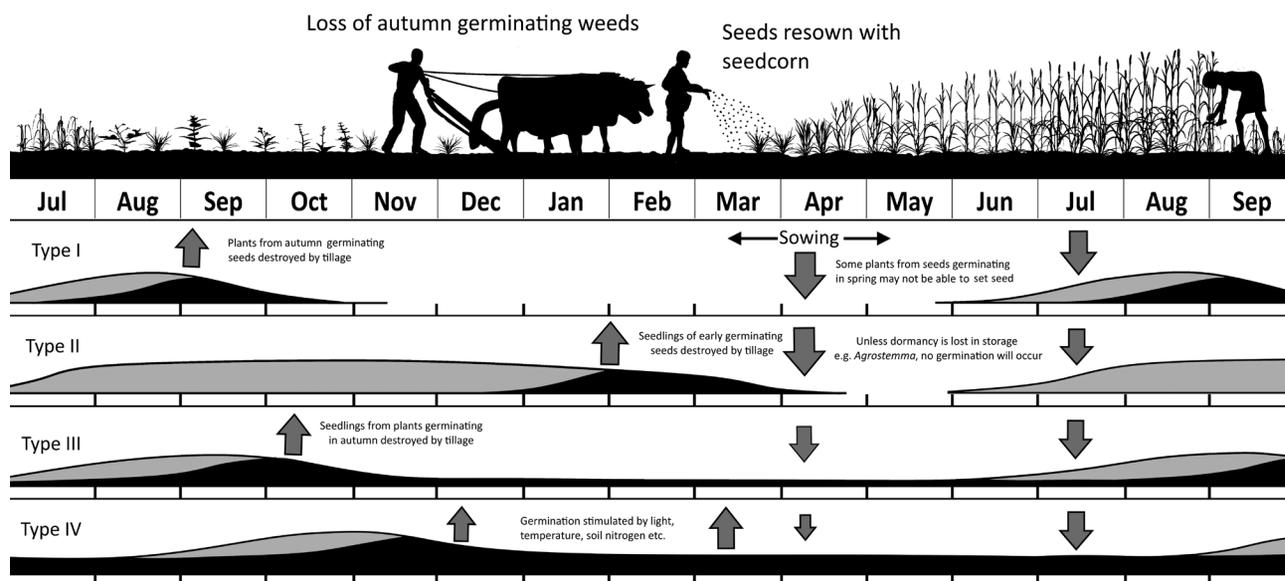


Figure 2.2. Diagrammatic representation of seed-bank types (includes annual and perennials) from Thompson and Grime (1979) denoting additions (down arrows) and losses (up arrows) from the seed-bank within a spring sowing-tillage cycle. Black areas denote seeds capable of immediate germination with suitable stimuli, grey areas viable seeds that are dormant and not capable of immediate germination.

are untouched by minimal tillage regimes, for example ard tillage, they will have less reliance upon survival by regeneration from seed or be able to persist to set seed in subsequent years. Conversely, asymmetrical ploughs will 'lift' such plants and turn them over,

exposing their roots to drying. Therefore we might expect perennials to decline in the arable field where soil disturbance is deeper, and for longer durations. For this reason perennials have often been seen as indicators of ard cultivation or ley farming, while

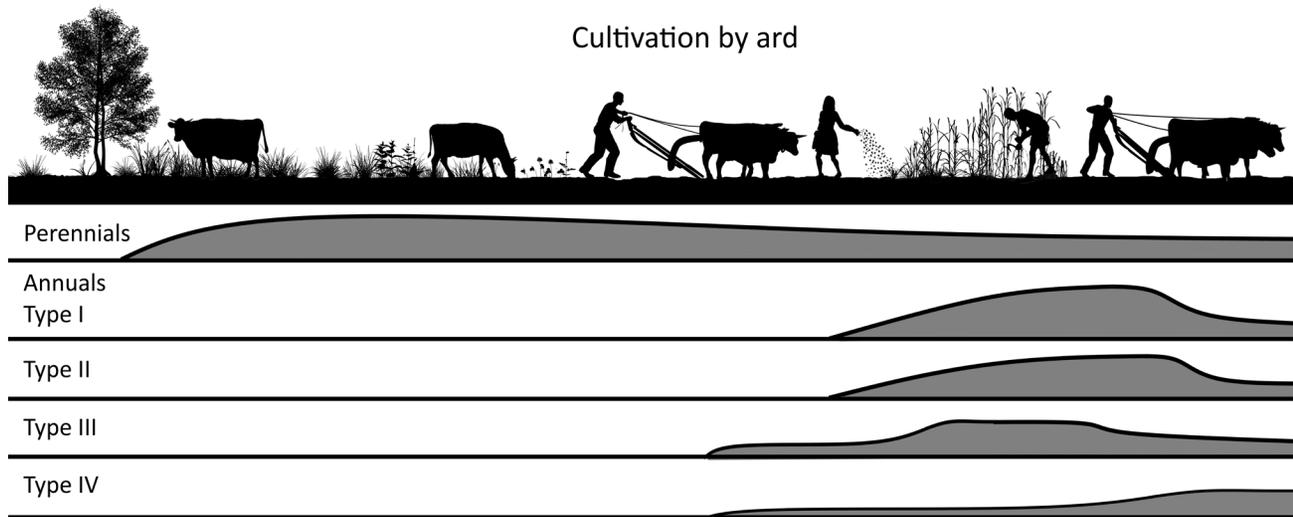


Figure 2.3. Relative presence and persistence of perennial species and annual species of seed-banks Types I–IV in the field, following a period of pasture under successive seasons of ard cultivation.

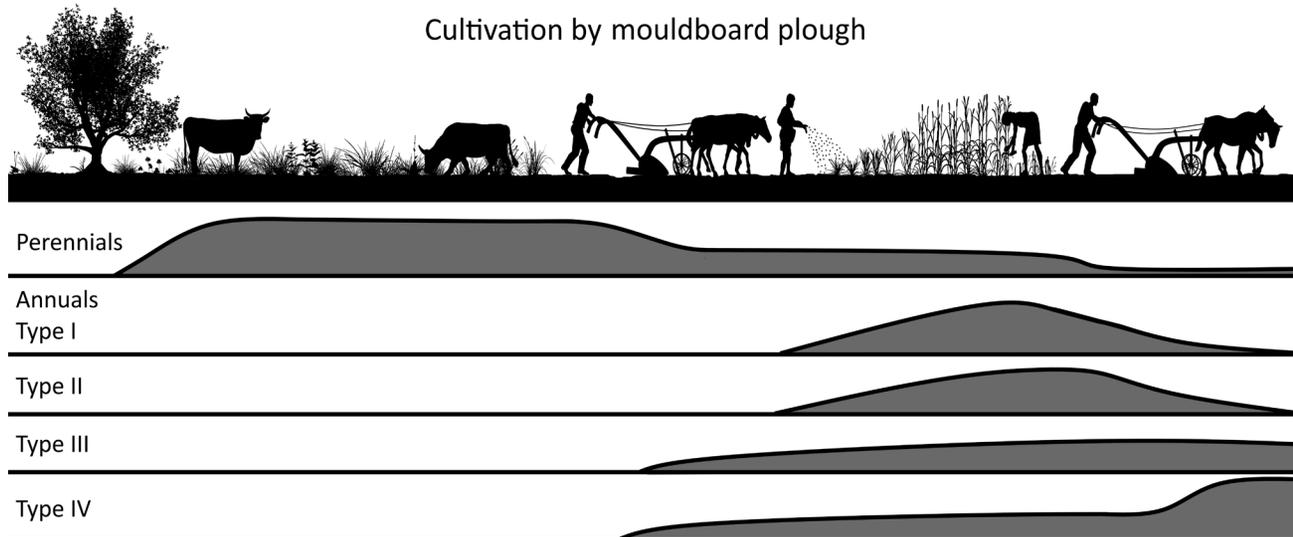


Figure 2.4. Relative presence and persistence of perennial species and annual species of seed-banks Types I–IV in the field, following a period of pasture under successive seasons of cultivation with a mouldboard plough.

high percentages of annual species are interpreted as indicators of mouldboard ploughing (Hillman 1981).

Identifying archaeophytes

In terms of prospective pathways towards the formation of the British arable weed flora, we may delineate two components; indigenous species found in natural habitats that adapted to arable fields, and introduced species spread as contaminants of cereal grain or commensals of habitation. Prior to the formation of the English Channel some 8000 years ago, the main means

by which new species could reach the shores of Britain and Ireland was through people or with the animals they brought with them. The species that arrived before AD 1500, the beginning of the modern era, have traditionally been termed archaeophytes. The first serious consideration of archaeophytes within the British Isles was conducted within the nineteenth century (Henslow 1835; Watson 1847–59). This was later revisited by Godwin (1975) and more recently by Preston and colleagues (2004), using the growing body of work available on pollen and macro-remains in order to disentangle the native from the introduced.

We have compiled a list of common weeds recovered from archaeological sites within the British Isles (Table 2.1), together with ecological information pertinent to how they spread into the first arable fields and ecological and physiological information pertaining to how they maintained a viable population and were affected by subsequent cultivation regimes.

Several factors come to light in examining this record. The first is that many potential archaeophytes have a distinctly southeastern (Salisbury 1961; Webb 1985), or uneven distribution, especially with regard to Scotland, Wales and Ireland. The second is that within Europe many have a distinctly southern temperate to Mediterranean-Atlantic distribution. The final point is that many of these potential archaeophytes, as might be expected, lack 'natural' non-anthropogenic habitats within the British Isles. In terms of local recruitment, it has long been noted by Martin Jones that many of the weeds species found associated within prehistoric fields are naturally associated with coastal, riverine and/or woodland habitats. Finally, the majority of the species listed within Table 2.1 as possible aliens are generally also not considered native within other European floras (Preston *et al.* 2004; Webb 1985).

One difficulty with the use of waterlogged and pollen records in identifying native flora is the absence of species that are uncommon in wetlands. Further, seeds of the Poaceae and Fabaceae are difficult to identify and rarely survive in waterlogged deposits; hence the native status of species within these families remains particularly problematic.

Further as to the routes by which these species might have arrived in the British Isles we must also consider the following points:

Number and nature of likely incursions (migration, trade, redistribution and transport of grain through taxation)

Probability of weed seeds being transported within seedcorn (affected by harvesting methods, species height and processing, e.g. grain size and dispersal mechanisms, if sieved or shaken in baskets)

The probability of an individual species, including native species, by virtue of their ecological parameters becoming permanently established within the local arable weed flora.

Given the focus on trade, taxation, migrations and agricultural practice the incursions of weed flora as such can be seen to be reflective of the greater political and economic landscape of Europe.

The first wave of weeds

Unlike Neolithic assemblages on the continent which can be relatively rich in the number of seeds and taxa

(Kreuz & Schäfer 2011), the number of weeds recorded for the Neolithic in the British Isles is extremely low. Dismissing possible intrusive elements (see Pelling *et al.* 2015; Stevens & Fuller 2012) the more certain introduced weeds include *Fallopia convolvulus* and *Avena fatua* (common wild oat). *Bromus* is also common but rarely identified to species, although it seems probable that both *Bromus secalinus* (rye brome) and *Anisantha sterilis* (bromegrass) were introduced at this time. *Bromus hordeaceus* (soft brome) is considered native to Britain on the basis of coastal subspecies (cf. Preston *et al.* 2004), but its ecology and reproductive strategies are similar to those of *Bromus secalinus*. A similar situation also exists for Neolithic finds of *Vicia* and/or *Lathyrus*, in part because of difficulties in identifying charred material to species—for example, *Vicia sativa* (common vetch) like *Bromus hordeaceus* has a coastal sub-species, *Vicia sativa* subsp. *nigra* (L.) Ehrh.—but also because of the difficulty of recovering identifiable macrofossils, which for both grasses and leguminous species rarely survive in waterlogged deposits. The last example concerns *Galium*, which presents a similar, but slightly different set of problems. Most macrofossils are assumed to be of *Galium aparine*, a likely native species of coastal regions and woodland edge; however distinguishing this species from *Galium tricornerutum* or *Galium spurium* (false cleavers) is problematic. *Galium tricornerutum* is thought to be a Roman to Medieval introduction, while *Galium spurium* is thought to be introduced after AD 1500 (see Hill *et al.* 2004); a curious situation, given that *Galium spurium* is relatively common in charred assemblages from Greece all the way to northern France (Bakels 1999; Coward *et al.* 2008; Knörzer 1971). Finally, there arises the question of whether the genetic lineages of those plants that occupy anthropogenic environments are in fact closer to once existing native species, or if rather they comprise new lineages containing arable adapted phenotypes which evolved on the continent.

What is noticeable is that many of the weed species recovered from British Neolithic sites, including native species, are large-seeded and reach similar heights to the crop. Some, such as *Persicaria maculosa* (lady's thumb), can be slightly shorter, while others, for example *Chenopodium album* (goosefoot), and possibly *Atriplex*, grow to similar height, but have small seeds. However, these are generally less common, as are those of other low-growing native species, *Polygonum aviculare* (knotgrass), *Stellaria media* (chickweed), *Plantago lanceolata* (English plantain) and the archaeophyte *Urtica urens* (annual nettle)—the last, recovered from southeast England (Hunter 2012), represents the first record for this species.

Table 2.1. Common weeds within British archaeobotanical assemblages.

Species	Seed size mm	Life cycle	Height cm	Native status, Earliest date	Main distribution (K value)	Naturalized habitat
<i>Adonis annua</i>	L	A, 2/3	40	Ar, LIA/RB	SE Eng (9)	0
<i>Agrostemma githago</i>	G(H)	A, 2	100	Ar, LIA/RB	Eng (-)	0
<i>Anisantha sterilis</i>	G (A)	A, 1	80	Ar, Neo	Eng, W Ir (8)	0, 6
<i>Anthemis cotula</i>	S (H)	A, 3/4	60	Ar, LIA/RB-	C, E, SE Eng (8)	0
<i>Atriplex patula</i>	S(A)	A, 2/4	87	N, [?Neo] MLBA	Widespread (6)	(1), 6
<i>Avena factua</i>	G (A)	A, 1/3	150	Ar, Neo	Eng, W Ir (-)	0
<i>Bromus hordeaceus</i>	G (A)	A, 1	80	?N ?Ar, ?Neo	Widespread (8)	3 (ssp. 1)
<i>Bromus secalinus</i>	G (A)	A, 1	90	Ar, ?Neo	S, C, E Eng (-)	0
<i>Centaurea cyanus</i>	G (H)	A, 2	80	Ar, RB	Eng, E Sc (7)	0, 6
<i>Centaurea nigra</i>	G (H)	A, 2	80	?Ar, RB	Widespread (7)	3
<i>Chenopodium album.</i>	S	A, 4	100	N, Neo	Widespread (6)	(1), 6
<i>Chrysanthemum segetum</i>	G	A, 3	60	Ar, ?IA/RB	Widespread but patchy (8)	0
<i>Cirsium arvense</i>	I (H)	P, V 3	120	N, Neo	Widespread (7)	3, 6
<i>Cirsium vulgare</i>	I (H)	P, 1	150	N, Neo	Widespread (7)	3
<i>Eleocharis palustris</i>	S (A)	P, V, 3/4?	60	N, [Neo]/MLBA	Widespread (6)	2
<i>Fallopia convolvulus</i>	G	A, 4	100 T	Ar, Neo	Eng, Wa, E Sc, W Ir (6)	0, 6
<i>Fumaria muralis</i>	G	A, 4	100	?Ar, MLBA	Wa, S Eng, W Ir, NE Eng, E Sc (8)	-
<i>Fumaria officinalis</i>	G	A, 4	52	Ar, MLBA	Eng, Wa, E Sc, W Ir (8)	0, 6
<i>Galium aparine</i>	G (A)	A, 2	150 T	N, Neo	Widespread (7)	1, (4), 6
<i>Galium spurium</i>	G (A)	A, 2	100 (T)	Ar, ?LBA/RB	Rare, SE Eng (7)	0
<i>Galium tricornatum</i>	L/G (A)	A, 2	50 (T)	Ar, Sax?	SE Eng (8)	0
<i>Lapsana communis</i>	G (H)	A, 3	95	?N, [Neo] RB/Sax	Widespread (7)	0, 6, (2, 4)
<i>Lithospermum arvense</i>	G	A, 3	50	Ar, LBA/IA	SE, C, E Eng (8)	0
<i>Lolium perenne</i>	I/G (A)	P, 1	50	?N, BA	Widespread (8)	(2), 3, 6
<i>Lolium temulentum</i>	G (A)	A, 1	90	Ar, med	Rare, C Eng (-)	0
<i>Malva sylvestris</i>	I	P, 3	150	Ar, MLBA	Eng, Wa, SW Ir (8)	0, (4), 6
<i>Montia fontana</i>	S	P, 4	20	N, [Neo] MLBA	Wa, SW, SE, NE Eng, NE Sc (5)	2
<i>Odontites verna</i>	S	A, 3	50	N, IA	Widespread (7)	1, 3
<i>Papaver dubium/rhoeas</i>	S (H)	A, 4	60	Ar, ?MLBA	Eng, E Sc, SW Ir (8)	0, 6
<i>Persicaria maculosa</i>	I/G	A, 4	80	N, Neo	Widespread (7)	(2), 6

The predominance of tall, large-seeded species might then suggest that crops were harvested relatively high on the culm, as Knörzer (1971) originally suggested for *Bandkeramik* sites. Likewise the predominance of large weed seeds might also indicate that small weed seeds were removed after harvest, perhaps through the use of winnowing baskets, as such seeds fall through the holes between the weave. An absence of chaff generally in the Neolithic has led to the suggestion that crops were stored in a highly cleaned state (Stevens & Fuller 2012). It might also be that harvesting high on the culm brings in fewer weed seeds. More recently a difference noted between LBK I and LBK II sites was attributed to a change in harvesting strategies (Kreuz & Schäfer 2011); for example,

numerous seeds of *Veronica arvensis* (wall speedwell), a small-seeded, low-growing weed, from LBK II sites suggest harvesting low on the culm. Curiously, this species is regarded as native in the British Isles despite the first record not being until the Iron Age (van der Veen 1992), but is seen as a Neolithic introduction on the continent (cf. Preston *et al.* 2004).

A perhaps more pertinent question is to what extent species that entered the British Isles during the Neolithic were able to gain a foothold within what was still a greatly wooded, and spatially and temporally discontinuous, fragmented arable environment. As Jones (1988b) states, cultivated plots appear highly dispersed, forming 'a harlequin environment'. Further, between 3500 and 2800 BC environmental

Table 2.1. (Continued.)

Species	Seed size mm	Life cycle	Height cm	Native status, Earliest date	Main distribution (K value)	Naturalized habitat
<i>Plantago lanceolata</i>	I/G	P, Vs 3	15	N, ?Neo	Widespread (8)	1, 3, 6
<i>Poa annua</i>	S	P, V 3	20	?N, IA	Widespread (6)	1, 3, 6
<i>Polygonum aviculare</i>	I/G	A, 4	30	N, Neo	Widespread (6)	1, 6
<i>Prunella vulgaris</i>	S	P, Vs 3	30	N, [Neo] MLBA	Widespread (6)	3, (4)
<i>Ranunculus acris</i>	G	P, V 3	75	N, MLBA	Widespread (3)	(1, 2), 3
<i>Ranunculus repens</i>	G	P, Vs 3	60	N, MLBA	Widespread (5)	(1, 2, 4), 3, 6
<i>Rumex conglomeratus</i>	S/I (A)	P, ?4	60	N, [Neo] MLBA	Widespread (8)	2, 3
<i>Rumex crispus</i>	S/I (A)	P, ?4	100	N, [Neo] MLBA	Widespread (8)	1, 2, 3, 6
<i>Sherardia arvensis</i>	I (A)	A, ?2	40	?N, MLBA	Wa, Eng, SW Ir (8)	(1), 3, 5
<i>Stellaria media</i>	S	A, 4	50	N, Neo	Widespread (6)	1, 6
<i>Trifolium repens.</i>	S	P, Vs 4	20	N, MLBA	Widespread (5)	3, (6)
<i>Trifolium pratense</i>	S	P, 3	45	N, MLBA	Widespread (7)	3
<i>Tripleurospermum inodorum</i>	S	A, 3 Vs	60	Ar, MLBA	Widespread (7)	0, 6, (5)
<i>Urtica dioica</i>	S	A, 4	150	N, Neo	Widespread (5)	2, (3,4), 6
<i>Urtica urens</i>	S	A, 4	60	Ar, ?Neo	Eng, less Ire, Wa, Sc (8)	0, 6
<i>Veronica arvensis</i>	S (H)	A, 3	25	?N, IA	Widespread (8)	0, 6
<i>Valerianella dentata</i>	S/I	A, ?2	15	Ar, MLB	SE, C, NE Eng (7)	0
<i>Vicia sativa</i>	G (H)	A, ?4	90 T	?N, Neo	Widespread (8)	1, 5, 6
<i>Vicia tetrasperma</i>	I/G (H)	A, ?4	60 (T)	Ar, ?Neo/IA	S Eng, Wa (7)	(1), 3, (4), 6

Average seed size: L=Large/spikelet-sized >4–5 mm; G=Grain-sized >2.5 mm; S=Small <2.5 mm; I=intermediate 2–2.5mm; A=Appendages (awns, bracteoles, bristles, etc.) that might increase seed size, or H=headed or seeds released in pods/capsule resulting in grain contamination (Grime *et al.* 1988; Stace 2010).

Life cycle: A=Annual; P=Perennial; Seed-bank type (1 & 2 transient; 3 & 4 persistent); V=Vegetative reproduction; Vs=Seasonal vegetative reproduction.

Height: Maximum height in cm; T=twining, climbing, scrambling habit; (T)=less pronounced habit.

Native status: Ar=Archaeophyte; N=Native. **Earliest date:** Neo=Neolithic; MLBA=Middle–Late Bronze Age; IA=Iron Age; RB=Romano-British; Sax=Saxon; med=medieval; [Neo]=within waterlogged deposits/charred deposits not associated with cereals (Godwin 1975; Hill *et al.* 2004; Stace 2010; Thomlinson & Hall 1996; Preston *et al.* 2014).

Main distribution: Eng=England; Ir=Ireland; Wa=Wales; Sc=Scotland. **K Value:** 3=Wide boreal; 4=Boreal-montaine; 5=Boreo-temperate; 6=Wide temperate; 7=Temperate; 8=Southern temperate; 9=Mediterranean Atlantic (from Hill *et al.* 2004).

Naturalized habitat (other than arable fields, waysides, urban areas): 0=No main non-anthropogenic habitats; 1=Coastal; 2=Riverine, Fen, Marsh; 3=Grassland; 4=Woodland; 5=Heath/scree; 6=Recorded as disturbed anthropogenic environment: hedges, waste ground, disturbed soils; (n)=peripheral to habitat (Hill *et al.* 2004; Grime *et al.* 1988; Stace 2010; BRC 2017).

proxies, archaeobotanical records and radiocarbon evidence combined indicate that cereal cultivation was abandoned over much of the British Isles with the onset of rapidly deteriorating climatic conditions, with possible small enclaves of agriculture surviving in Scotland, particularly within the island communities (Fig. 2.5; Stevens & Fuller 2012; 2015). It is possible that some weeds survived within disturbed anthropogenic environments, but quite probable that many were reintroduced within the Bronze Age, and that the genetic lineages of these early introductions were no more prevalent in the succeeding Bronze Age than those of the peoples who brought them (cf. Olalde *et al.* 2017).

Even if only short-lived, the nature of Neolithic agriculture and probably the eco-systems it produced

appears unique when compared to later periods. While small-seeded annual species with Type IV seed-banks are present, it appears unlikely that they were able to build up the large persistent seed-banks that characterized later agricultural fields. Likewise, the low presence of perennial species might also reflect regimes in which cultivation was relatively small-scale and intense (as per Bogaard 2005; Bogaard *et al.* 2013); although equally it may be that the grazed grassland floras, that when cultivated gave rise to high numbers of perennials within arable fields, were also not well established at this time (see Fig. 2.5). Further, the high presence of species with transient seed-banks would seem contrary to highly intensive systems in which grains are suggested to have been planted individually in rows (see Kluyver *et al.* 2013; Krez & Schäfer

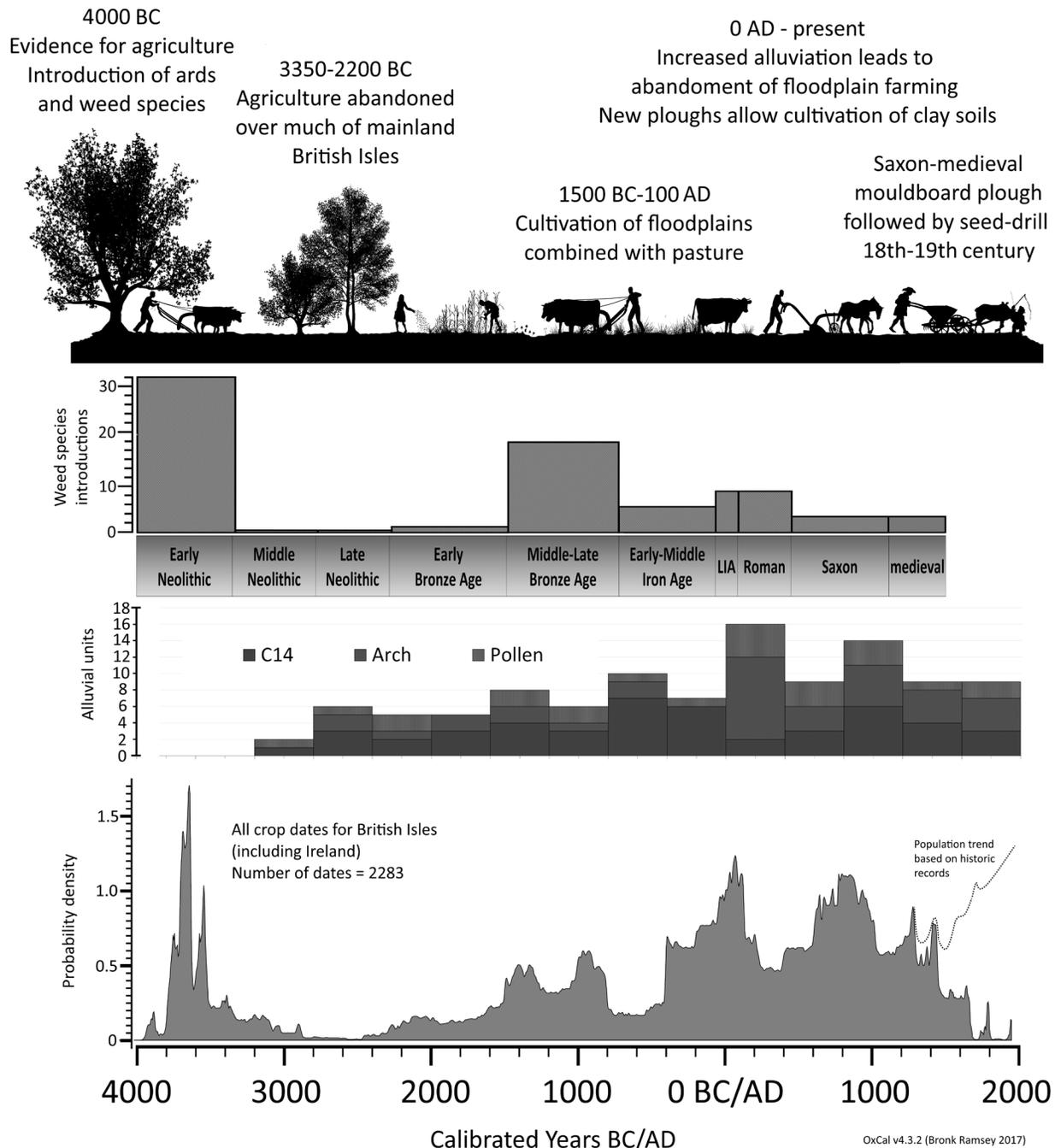


Figure 2.5. A timeline of agricultural changes discussed in the text and number of introduced/reintroduced weed flora (from Table 2.1) plotted against evidence for increased alluviation (from Macklin & Lewin 1993) and summed probability for direct AMS radiocarbon dates on crop species ($n=2283$) for the British Isles, including Ireland (data taken from Bevan et al. 2017), indicating fluctuations in both agricultural activity and human population.

2011). Given the predominance of broadcast sowing in ethnographic accounts, historical texts and pictorial evidence, the existence of intensive systems of this nature in the past without further evidence should be questioned.

Farming the floodplains: the age of the perennial weeds

The upsurge in agriculture that accompanied the Early Bronze Age, as the Beaker peoples expanded across

Europe and into the British Isles, left little archaeobotanical record in terms of the existing weed flora of this time. Rather, as Jones (1988b) writes, it is the Middle Bronze Age that marks the birth of agricultural ecosystems within the British Isles, something that has been increasingly substantiated within recent years (Fig. 2.5; Bevan *et al.* 2017; Stevens & Fuller 2012; 2015).

Godwin (1975) saw the Romano-British period as that of the greatest increase in archaeophytes, but as more archaeobotanical data was added the emergent picture began to resemble one of more gradual change (Jones 1984). However, in the past 20 years the impression is again shifting, and now the later Bronze Age can perhaps begin to rival the Romano-British in terms of both archaeophytes and the expanding native weed flora.

The most notable foreign additions were *Lithospermum arvense*, whose rock-hard seeds could not have gone unnoticed during grinding, *Papaver rhoeas/dubium* (long-headed poppy), *Tripleurospermum inodorum* (scentless mayweed), *Malva sylvestris* (common mallow) and *Valerianella dentata*, along with possibly *Sherardia arvensis* (field madder), *Lolium perenne* (English ryegrass) and *Fumaria* sp. We might also add *Silene latifolia* (white campion), *Chenopodium polyspermum*, *Chenopodium ficifolium*, potentially small nettle (*Urtica urens*) (cf. Preston *et al.* 2004) and possibly *Vicia tetrasperma* (smooth vetch), although the first records for the latter currently appear in the Iron Age. It is notable that many of these species, including *Chenopodium polyspermum*, are low growing, and it may be that a change to bronze sickles facilitated lower harvesting on the culm, assisting their spread.

The case for the native status of *Sherardia arvensis* is still unclear. Like *Fallopia convolvulus*, there appear to be pre-Holocene records for the British Isles, and it might also be regarded as having been re-introduced (Godwin 1975). The origins of *Lithospermum arvense* probably lie in southeast Europe, and it appears in charred assemblages there by the later seventh millennium BC (Colledge & Conolly 2007; Zohary *et al.* 2012, 177–9), and later southwest Bulgaria, along with *Sherardia arvensis*, and *Valerianella dentata* at 6000–5650 BC (Marinova 2007).

Of some interest is the lack of Early Neolithic European and Near Eastern records for several of these species (Coward *et al.* 2008), most notably *Tripleurospermum inodorum*, *Sherardia arvensis* and *Papaver rhoeas/dubium*. It might be noted that *Tripleurospermum inodorum* is recorded from Neolithic Ireland (McClatchie *et al.* 2014), but this would seem out of keeping with the record for Europe. Its origins are also difficult to pinpoint, but between the Baltic coast of Europe and the Caucasus region seems most probable.

However, it is the first significant appearance of native wet ground species, such as *Ranunculus acris* (meadow buttercup), *R. repens* (creeping buttercup) and *Montia fontana* subsp. *chondrosperma* (Fenzl) Walters (blinks), commonly accompanying *Eleocharis palustris* (common spike-rush), that really distinguish the later Bronze Age and Iron Age weed flora. Bronze Age ard marks have been excavated from numerous locations, including the Upper and Lower Thames Valley (Yates 1999; 2001, table 7.3) and East Anglia (Evans *et al.* 2009), indicating an expansion of the agricultural landscape that incorporated river floodplains (Fig. 2.5).

It is with this evidence that the early work of Martin Jones on *Eleocharis palustris* should be considered (Jones 1981; 1984; 1988a,b). *Eleocharis palustris* is a native British species, occupying wetland habitats on the margins of water bodies such as rivers, streams and ponds. Today, floodplains are not seen as conducive to arable agriculture, and the case for *Eleocharis* being a past arable weed rested upon its unequivocal association with cereal remains, seen through its presence within storage contexts associated with charred grain, as well as the stomach contents of bog-bodies (Jones 1988a,b). As Jones writes, *Eleocharis*, while not associated with wheat crops today, is found within dry-sown rice paddies, demonstrating that it can survive a fair degree of disturbance and drying out of the soil, as might have existed within poorly drained prehistoric fields (Jones 1988a).

The presence of *Eleocharis* as a weed of arable fields is likely down to three important factors. The first is the nature of its reproduction. It can survive a drop in water-table during summer below soil level, but most importantly, while little reproduction through seed takes place, reproduction by rhizome within the second year of growth occurs when old rhizomes break away from the adult plant (Walters 1949), as might occur under arding. It also frequently co-occurs today in wet-marshy rough pastures alongside *Lolium perenne*, *Poa*, *Trifolium*, *Cirsium*, *Ranunculus acris* and *Rumex* sp., whose charred seeds are commonly encountered in archaeobotanical samples of this date, making their first real appearance in the arable weed flora (see Table 2.1).

This brings us to our second point, that the high numbers of predominantly grassland perennials which dominate later Bronze Age and Iron Age samples might indicate a changing attitude to land use. While high numbers of perennials can be associated with low-disturbance tillage by ard, they are also correlated with the cultivation of fields previously under pasture (Chancellor 1985; 1986). The use of Bronze Age fields for arable can be seen from ard-marks, but it seems probable that a pattern of land use emerged

within this period in which such fields regularly alternated between animal pasture and arable (Figs. 2.3, 2.5).

The third point is the changing nature of the floodplain itself. Today, floodplains are heavily alluviated, but the onset of such anthropogenic alluviation is generally only dated to the start of the Bronze Age, increasing in later periods (cf. Fig. 2.5; Macklin *et al.* 2014). In the Upper and Lower Thames Basin, around a metre of alluvium was deposited within the Romano-British period alone, with increasing amounts in the Late Saxon and medieval period (Robinson 1992; Stevens *et al.* 2012, 404–7). This led to the poorly draining alluvial soils of today, which rendered the floodplain largely uncultivable. But in the Bronze Age and Iron Age, while fields might be inundated with autumn and winter floodwaters, it is likely they had sufficiently drained away by spring to enable roots to breathe.

Such evidence is by no means unique to the British Isles and is also seen in the Netherlands from the Early Bronze Age onwards (Arnoldussen 2008, 257–9). Further similar weed assemblages, including *Eleocharis palustris*, have been recovered as far away as the Carpathians in Hungary during the Late Neolithic, 4700–4300 BC (Gyulai 2007), as well as Iron Age Europe (Kreuz & Schäfer 2011).

New invasions, new innovations

The Roman invasions of England from Caesar's campaigns of 55 and 54 BC to Claudius' conquest in AD 43, and the shifting nature of Europe within the closing centuries of the first millennium BC, brought about many changes within the agricultural landscape of England, not to mention a whole new suite of weeds previously unknown to the farmers of Albion.

Such changes appear to have manifested themselves in one of two ways: the first through the increased geographical movement of peoples, and crops and weeds, through trade, taxes and migration; the second through a shift in agricultural innovations, particularly tillage technology, and an expansion onto new soils.

Among the new debutants is corncockle (*Agrostemma githago*) which, as noted above, probably originates in the mountains of Greece, where it is present from the earliest Neolithic (Coward *et al.* 2008). The earliest records for this species in the British Isles come from the Late Iron Age (Evans & Jones 1979; Lodwick 2014), but it becomes increasingly recurrent during this period. The association of both *Agrostemma githago* and probably *Centaurea cyanus* (cornflower) with Roman expansion is seen within

northern France, where it is attributed to the importation of grain (Derreumaux & Lepetz 2008). Also included is *Lithospermum arvense*, a species hitherto absent in northern France (cf. Bakels 1999), yet present in Britain since the later Bronze Age.

Of greater importance is the occurrence of *Anthemis cotula* (stinking chamomile), a noxious species associated particularly with the cultivation of heavier clay soils. Seeds of this species, together with *Agrostemma githago*, have been recorded from earlier contexts (cf. Preston *et al.* 2004); however, experience tells us that such finds often occur from sites with overlying medieval components (see Stevens & Fuller 2012) and hence are probably intrusive. Indeed, where direct radiocarbon dating has been carried out this has proved to be the case (Pelling *et al.* 2015). Seeds of *Chrysanthemum segetum* (corn daisy) are also known from Iron Age contexts, but that they appear more commonly in Romano-British contexts suggests a Late Iron Age to Romano-British introduction. This species, in contrast to *Anthemis cotula*, is characteristic of lighter, sandier, acidic soils, and taken together they indicate an expansion of arable practice during this period.

The interpretation of the changes within the Iron Age through the Romano-British period by Jones (1981; 1984; 1988a,b) drew together several key elements: the appearance of free-threshing wheat, improvements in ploughing technology, the decline of *Eleocharis palustris*, *Carex* spp. and *Montia fontana* subsp. *chondrosperma*, and the rise of *Anthemis cotula*, a noxious species associated particularly with the cultivation of heavier clay soils. The logical inference chain presented the argument that improved ploughing technologies allowed the cultivation of heavier soils, such as on alluvial plains. On these ploughed heavier soils, free-threshing wheats were increasingly grown. Consequently, the improved drainage of the floodplains eventually led on to the decline in wetland species.

We would now suggest that some modification of this argument is necessary. While Jones very much saw a continuum of change beginning in the Middle to Late Iron Age and continuing through the Romano-British period, he took into account no likely problems of intrusive material. On recent reconsideration of these problems, a different picture emerges. While bread-wheat has been shown to be present within Iron Age Britain, many finds have proved intrusive, as is likely with some of the weeds that accompany them (Pelling *et al.* 2015; Stevens & Fuller 2012). It now appears that bread-wheat played a substantial role in neither Iron Age nor Roman agriculture within the British Isles. The rise in *Anthemis*

cotula undoubtedly can be related to the expansion of agriculture onto clay soils, and the introduction of asymmetrical shares, seen through finds of iron coulter, the cutting implement that cuts the sod before the wooden share, which lifts and turns it. But it is likely such practices were at first restricted to more Romanized settlements within the first century AD, only becoming more commonplace within the third and fourth centuries AD.

This expansion onto clay soils no doubt contributed to the rise of clay alluvium on the floodplains, with increased run-off from clay soils under cultivation taking it into the river catchment areas where it accumulated (Stevens *et al.* 2012, 405–7). The decline of both *Eleocharis* and *Montia* might then be in part due to the eventual abandonment of such areas for cultivation during the later Roman period (Fig. 2.5; cf. Robinson 1992). It might also be noted that both species are commoner on lighter soils that allow their roots to breathe and would be diminished by clay alluviation.

The battle won and lost

Many of the associations made by Jones (1981; 1984; 1988a,b) for the Late Iron Age to the Romano-British period gain more prominence within the Saxon and Medieval periods. The weeds that made their first appearance in the Romano-British period, *Anthemis cotula*, *Agrostemma githago*, *Centaurea cyanus*, *Chrysanthemum segetum*, become mainstays of charred assemblages within the Medieval and Saxon period (cf. Jones 1988b). There is also a notable transition to a much greater dominance of annual weed seeds with persistent seed-banks and away from perennial species (Fig. 2.4) that has been linked to the appearance and spread of mouldboard ploughs from the seventh to eighth centuries AD (cf. Stevens & Robinson 2004; Thomas *et al.* 2016).

The Saxon to Medieval period in many ways sees the changes discussed by Jones (1981; 1988a,b; 2009) that were occurring in the weed flora over the Romano-British period come to fruition. Spelt wheat is replaced by bread-wheat and, gradually over much of Saxon England, the ard by the mouldboard plough (Fig. 2.5).

One curious phenomenon is the increased appearance of *Lapsana communis* (common nipplewort) in charred assemblages from the Saxon to medieval period. The species is one of the key defining weeds of the Neolithic *Bandkeramik* of Europe (Bakels 1999; Knörzer 1971) and present in waterlogged assemblages from the Neolithic onwards (e.g. Nye & Scaife 1998; Robinson 1989; Tomlinson & Hall 1996),

but regarded as doubtfully native (see Preston *et al.* 2004). Yet in Britain its first occurrence charred is in the Late Romano-British to Saxon period (Greig 1990; Stevens & Robinson 2004). Why this species appears to have taken so long to become established as a weed in the British Isles is unknown, but in part, may be its greater tolerance to heavier clay soils (Salisbury 1961, 294).

By the sixteenth century, darnel (*Lolium temulentum*) had gained a reputation as one of the worst weeds within England, and shared a similar status, according to Virgil, within Mediterranean fields some millennium and a half before (Salisbury 1961, 30). Yet there are few records for the British Isles prior to the Medieval period. The species appears to have originated through evolution in early cultivated fields of the Levant by c. 7000 BC, based on divergence of *L. remotum*/*L. persicum* (see Fuller & Stevens, this volume).

While the angled shares of the mouldboard plough did much to eliminate many of the perennials that once plagued prehistoric farmers' fields, other developments since the start of the British agricultural revolution, spanning the last four centuries, served to reshape the composition of the arable weed flora. Such inventions, including improved harrows, first depicted in the Bayeux Tapestry (c. AD 1070), would have further diminished many perennial species and those of seed-bank Types I–III. The Mesopotamian seed-ard apart (Hillman 1984), the history of the dibbler to plant seeds in a row dates back to the fifteenth century in Italy. The advantage of such methods was first that grains were individually 'hand-loaded', usually in batches of four to five, eliminating many grain-sized weed seeds with Type I seed banks. Also, planting within rows allowed more efficient weeding to be conducted within the early growing stages, a development that, although improved upon by the invention of the seed drill by Jethro Tull in 1701, was not widely adopted until the nineteenth century (Fig. 2.5). The adoption of these planting methods, accompanied by the use of mechanical screens to remove grain-sized contaminants from the crop, gradually eliminated many of the grain-sized weed seeds including those of seed-bank Types II and III. It was these practices that did much to remove many common weeds, such as darnel, corn marigold, cornflower, corncockle, pheasant's eye and cleavers. However, as Salisbury (1961) writes, it was not until the 1950s with the use of herbicides that the battle was at last decided. What the agriculturalist won, the botanists lost, and today's cornfields are no longer the picture of colours which once adorned the landscape every summer for the past four millennia.

Acknowledgements

This paper was supported by a European Research Council grant 'Comparative Pathways to Agriculture' (ComPAg, no. 323842). Thanks to Peter Schauer at UCL for help with the construction of the SPD curve in Figure 2.5 and to the three anonymous reviewers for their helpful comments.

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Chapter 3

A System for Determining Plant Macro Archaeological Remains

Victor Paz

An explanation of the methodology

In the study of plant macro archaeobotanical remains, an *identification system* refers to the procedure used to recognize plant remains from a sediment matrix sample. Specifically for macro remains, it comes mainly from water flotation processing of sediments, which are then sorted and identified based on general categorizations, for example seeds, parenchyma, wood, and so on. A *determination system*, on the other hand, is the procedure that attempts further to recognize identified materials to taxon. Determination is what we aspire to do with most of our archaeobotanical materials in order to make interesting inferences concerning the human past; the more transparent the determination system, the more informed interested parties could be. This is even more relevant when the plant remains play a central role in a wider archaeological discourse, such as on questions surrounding the complexities of people–plant and people–landscape relationships or interactions.

Just send them to a botanist?

Commonly a botanist is not readily equipped to work on charred archaeobotanical materials, which is the nature of most plant macro remains that survive in an archaeological site. They are not used to determining taxa from seeds, let alone transformed fragments of seeds and vegetative organs. Botanical identifications as organized in ‘keys’ almost always start from identifying flowers, fruits and leaves (e.g. Calumpong & Menez 1997; Clapham *et al.* 1987; Cullen 1997; King & Robinson 1987; Stace 1997), and seldom through a key based on seeds or vegetative organs (e.g. Rose 1981). Most of the time, from a botanist’s point of view, identification through the flowers and fruits is more than enough to determine species successfully (cf. ESF 1989, 7); plant parts that very seldom survive in pristine condition.

With this fundamental difference in approach, and not particularly keen on knowing the answers

to problems set by the archaeologists, it is not hard to expect a botanist to be unenthusiastic about the task of identifying the macro remains in an archaeobotanical assemblage. Sadly, what regularly happens is the non-conversion of samples to data. In my own experience, when project directors prefer to send their archaeobotanical flot samples to a botanist, rather than to an archaeobotanist, they end up disappointed. It is very rare to come across results of such collaboration in our part of the world. Trained botanists such as Jon Hather (1992; 1994) and Douglas Yen (1977; 1988), who worked on Asian and Pacific materials, and were deeply interested in archaeological questions, are rare to find. The responsibility therefore falls on the shoulders of the archaeologist specializing in archaeobotany. The archaeobotanist fills the gaps of knowledge and know-how between archaeology and botany.

A focus on macros

Plant macro assemblages have a high level of determination success. Unfortunately, even after two decades of methodological progress, we have not been uniformly straightforward with the way we determine the plant remains, and in many parts of the world archaeobotanical studies remain an afterthought in archaeological projects. There may or may not be a correlation between the two above-mentioned woes, but we could at least try to address the latter in this chapter.

There really is a need to clarify further the methodology for the determination of macro plant remains. The intention is to achieve through practice an accepted convention that is not chiefly based on the authority of the specialists. We must clarify all the variables in the process, including the proper place of an individual’s authority in the system. The chain of reasoning which led to a determination must be explained. Anyone who bothers to read an archaeobotanical report may then judge how much value they would give to the findings, and how far they are will-

ing to take it. The determinations an archaeobotanist provides define the inferences we make as archaeologists. When plant remains are identified with precision to species, it is mostly taken at face value and the significance of its presence in the archaeology is lined up to support large-scale narratives. This is especially relevant in narratives involving plant domestication, origins and spread of agriculture, human subsistence strategies and, to a lesser extent, inferring rituals and well-being practices (see Barton & Paz 2007; Paz 2005; 2012).

A reflection on determinations

I believe that the aim of archaeobotanical determination is to demonstrate how the botanical remains we recover were indeed part of a specific plant. We use the botanical taxonomy as a baseline, with the binomial taxa convention indicating genus-species as a target of our determination attempts. As archaeologists, specifically as archaeobotanists, we start with the premise that, given the right samples and sufficient reference collection, we can determine identifiable plant remains to the level of species. I think this premise is where the problem starts.

Walton Green (1999, 18–21) argued in his work, and mainly through several discussions at the George Pitt-Rivers Laboratory at Cambridge, an intriguing recommendation for archaeobotanical determination. It is epistemological and forces the archaeobotanist to reflect on how one determines plant remains. In his proposal, non-prefix binomial taxon identification may only be used if:

There are no ordinal or binary characters differing between identified and reference samples, and all quantitative characteristics are closely matched—within two standard deviations

Specimens of all taxa in the local Floras of equivalent rank in the same taxon of immediately superior rank have been examined and eliminated, for example identification of all members of the genus that are in the local Flora

Multiple modern reference specimens were examined from more than one population. The accession number and location of the reference material should be cited; at least one population should be from the same geographical area as the archaeological specimen; identification of the reference material should be based on full-plant identification

Green proposed to use the prefix ‘prob.’ for all identification of which the archaeobotanist is convinced, but which do not fulfil the conditions for un-prefixed identification. This category includes identifications done with photographs and images, after which all closely related taxa of equivalent rank

have been eliminated. He uses a prefix ‘cf.’ when the specimen being identified merely shows similarities to, and could be a member of, the stated taxon. A prefix ‘elim.’ is used as a discretionary prefix to show that the identification was only done through a process of elimination (as opposed to examination of morphological characteristics). In other words, when the ideal condition for determination is not met, the authority of the investigator is brought into play and prefixes are added in the taxonomic determination.

While I have full praise for the recommendations of Green, and was inspired by his reasoning, I differ at some fundamental level. As a starting point, I think Green’s proposal, as stated in his first point, is unnecessarily strict and paralysing for the investigator. While it is correct to suggest consulting all the Flora of a region and, from this reference, seek for actual taxon matches, many regions in the world do not have a complete Flora—let alone a localized one. The amount of effort and time that will have to be allocated in order to look at all equivalent rank and immediate superior rank queries will be initially daunting. I have to say, however, that once done successfully, a taxon will then be easily determined next time around. But that is if one finds the references that will satisfy the demand for a complete documentation of a taxon.

In many places in the world, regional Floras are far from complete. There are no complete compendiums for most tropical regions, and there is a scarcity of sub-regional Floras to refer to. The scale of building a complete Flora is monumental. The British Isles is a good example for a region having a confidently comprehensive flora record. The Flora project was begun in the late nineteenth century, to be completed only in 1934 (Stace 1997). The project was completed thanks to a large population of botanists undertaking systematics, recording a temperate-based climate flora.

Looking at tropical regions, such as Southeast Asia, or even just Island Southeast Asia, what we have is a much larger land area and a broader range of tropical climates and flora. The attempt to complete a tropical Flora has shown difficulties from the outset (Mabberley 1992, 9). The regional Flora—*Flora Malesiana*—started only in the late 1940s (van Steenis-Kruseman 1950) and has not been completed to date, with very erratic additions through the years (Ashton 1982; Laubenfels 1988). As of its latest addition in 2013, it has published 21 volumes under Series 1 (seed plants) and four volumes of Series 2 (Pteridophytes); most of the more recent volumes contain revisions/additions of taxa already covered in earlier volumes. To think that this was done with better technology, with about a hundred international collaborators working on the project globally (see Floramalesiana.org), it may be unlikely that an

almost complete record of the flora of a tropical region can be produced in the next few decades. In addition, if the direction of botanical systematics becomes more reliant on genomics (Soltis *et al.* 2013; Sytsma & Pires 2001), the physical traits of the plant will likely become secondary in defining taxon; it seems less promising for the purposes of macro archaeobotany.

The central issue, I believe, is whether it is possible to construct a complete record of a region's current and past flora. Unfortunately, this is highly improbable, especially in regions with very rich and diverse plant life, such as the tropics. It is also worth asking if we can truly gather absolute knowledge on the flora of a region, on top of totally knowing its past plant population history. It is a fundamental question to ask; are we confident that science has actually recorded every plant taxon formed in nature and living at the present? What about the countless species of plants that were selected against and are long extinct, or have reverted back from being cultivars/domesticates to a new 'wild form' at any given time in the past? I propose that, rather than basing our determination attempts on perceived absolute knowledge of current and past flora, we admit that we are making best-fit determinations and that we explain this with clarity. The archaeologist who plans to use the archaeobotanical data shall then be properly guided as to what extent the data may be of use for supporting their research problem, and gauge its useful value for generating inferences.

Contribution of this system

There are two intertwined elements in this system; one is for determining transformed seeds, fruits and nuts, and the other focuses on charred parenchyma tissues, with further determination of wood not fully addressed. The main focus of this system is the determination of parenchyma remains. The corpus established by Hather is the foundation of this approach and mainly applied to Southeast Asian and Pacific archaeobotanical assemblages. It confirmed beyond doubt that charred parenchyma can be identified and separated from other plant charcoal remains. It has further confirmed patterns observed by Hather—specifically on the relevance of the difference between tissues charred fresh and charred dry (Paz 2001). A third confirmation is the survival of surface and sub-surface features of vegetative organs, such as the periderm structure. Hather (1988, 146) already pointed out that its survival is significant to the exercise of identification.

My own ethnoarchaeological work with a Negrito community in the Sierra Madre of Luzon demonstrated that a common way of processing taro corms is by roasting on an open fire. It was observed that the

scraping and cutting-out of charred portions of the corm leads to a concentration of charred parenchyma tissue coming from the surface and near-surface of the vegetative organ. They have a better likelihood of survival because they get charred and integrated into the ashy matrix of a hearth with minimal time lapse (see Paz 1999). Observations done on the periderm of root crops reference samples such as yam (*Dioscorea alata* L.), taro (*Colocasia esculenta* [L.] Schott), sweet potato (*Ipomoea batatas* [L.] Lam) and cassava (*Manihot utilissima* Pohl) did not reveal possible diagnostic quantitative features. Most of the fragments observed, though, had parenchyma cells attached to phellogen-associated tissues beneath the periderm. When they survive together, and can be quantifiably observed, it will allow the possibility of identification beyond saying that the material is a periderm fragment.

A clear contribution of this work to the study of charred parenchymatous tissues is the further quantification of species-specific determination. In Hather's work, this was not necessarily done, because his concern then was more to see the general patterns, and observations that may help guide early attempts to identify charred remains in the archaeology. In our system we have created two distinct steps to add rigour to the determination process; an internal and external step. This will be further explained below.

Determination procedure

The archaeobotanical reports and presentations of archaeobotanical results in publications often do not provide the necessary details as to how a determination was reached. In areas where there is a deep tradition of archaeobotanical work, the need to go through the justification of an identification of every plant remain may be extremely redundant and tedious. In regions like Southeast Asia there are a few exceptions where the publication of results is extensively discussed (see Castillo & Fuller 2010): examples are the terminal publications of the Khok Phanom Di project in Thailand (Thompson 1996) and the Niah Cave Project in Sarawak (Barton *et al.* 2016a,b). I take the position that the exception can be made the rule, wherein we shift the reliance of the system towards the scrutiny of the plant remains themselves based on access to reference resources while defining the role of the investigator's authority. It is clear to me that the need for a more organized and transparent system is not a pedant's exercise.

The system for determination

Discussing the ideal and the actual practice of identifying transformed plant remains is important. I attempt

Table 3.1. Classifications of seeds based on preservation conditions (after Hubbard & al Azm 1990). Regrettably this system was adopted by only a few others. In my own work its use is limited to Preservation class 6 and Distortion classes 2–7. With the exception of waterlogged material, I consider Preservation 1 and Distortion 8 to be contamination, but they still can/must be described.

Class	Preservation
1	Perfect
2	Epidermis virtually intact; rachillae observable so as other external elements
3	Epidermis incomplete; rachillae, hairs etc. occasionally preserved
4	Fragments of epidermis remaining; other features virtually unobservable
5	Identified by gross morphology only
6	'Clinkered' ('see-through' with the shape of the seed preserved in the outline of the mass of the bubbles, but with a clear view from one side to the other through the holes)
Class	Distortion
1	No noticeable distortion
2	Slight puffing of seeds noticeable
3	Clearly distorted
4	Gross distortion
5	Seeds fused together in a solid lump, faceted when free
6	Carbonised tarry material exuded from distal ends of caryopses
7	Sides of the seed longitudinally wrinkled, partially collapsed and concave
8	Sprouting: as (7), but with the radical greatly elongated

Table 3.2. Table indicating variables relevant in establishing the level of confidence of determination: (Y) good match; (?) questionable match; (X) not present; (prob.) probably; (elim.) eliminated.

Variable	No prefix	prob.	cf.	elim.	suffix 'type'	Form/shape description
Reference collection	Y/?	Y/?	?	X	X	X
Image	Y	Y/?	?	X	X	X
Illustration	Y/?	Y/?	?	X	X	X
Flora	Y	Y	Y	Y	Y/?	X
Taxonomic details	Y	Y	Y	Y	Y/?	X
Geographic area	Y	Y	Y	Y	Y	X

to reason that identifying and determining macro archaeological remains follows these premises:

- 1) No specialist/expert knows everything, and therefore cannot simply leave identifications unexplained. A system must therefore be verifiable and allow for explanation as to how determinations were made. The practice to be followed in this work will adopt the spirit of versions of scales of confidence already applied in Asia and the Pacific by Douglas Yen (Bodner 1986; Glover 1976; 1981) and Gary Crawford (1983; 1986), but limits and situates the role of the specialist in the determination process.
- 2) The focus of the identification/determination system is not to pursue a theoretical absolute correspondence between the archaeological material and a species of plant living in the distant past; rather it is on achieving a best-fit identification/

determination, and the manner of how the investigator can convince interested individuals of the merits of the results presented.

- 3) A composite of methods and references must be used. When reported, images of the material and what it was compared to should be included to support the determination. In turn, work done this way contributes to an improvement of archaeological referencing—improving the reference base for others to use.
- 4) There are certain identifications/determinations of macro remains that, while they may not pass the rigid prerequisites for the highest level of confidence (no prefix), may be stated as such based on the experience and knowledge of the archaeobotanist.

There is no need to go into detail regarding the methods applied to collect macro archaeological

samples (Barton *et al.* 2016b; Fuller 2008; Paz 2001). We start with a sample collected by hand or through flotation. The contents of the sample are sorted into plant remains and other materials, for example animal and insect remains, non-organic artefact, and so on. The botanical remains are further divided between the identifiable and the non-identifiable pieces.

The identifiable plant remains are further sorted into pieces that can be further determined and those, especially seeds and nut fragments, that are so badly charred that no further determination can be done. This sub-set can, however, still be further classified, following the preservation/distortion nomenclature proposed by Hubbard and al Azm (1990; Table 3.1). The determinable remains that cannot be identified at the moment, due to a failure of matching, can be further described by their general shape (after transformation) using a system proposed by Martin and Barkley (1961) or a similar/modified approach. When images are shared of these remains in reports or publications, other practitioners may be able to identify/determine, or make suggestions, which may be pursued later.

Specific to the assemblage of seeds, fruits and nuts that were identified, I proposed the following determination arranged by descending scale of confidence.

Non-prefixed: A binomial taxon determination may be made without any prefixes whenever it fits all determination variables (see Table 3.2); it fits taxonomic diagnostics, geographical distribution, and the species citation in a Flora. These are firm prerequisites for a non-prefix determination. It must also fit clear photographic/image reference(s) of the plant parts, for example seed, nut, etc., and/or line illustration reference(s), or both. The use of a reference collection is still important, but not essential.

Prefixed 'prob.': Matches Flora citations, geographical area and fits taxonomic details; the existence of image, illustration or reference collection, but not all. It differs from the 'non-prefixed' determination in that only one out of three—image, illustration and reference collection—matches or is a good fit, with the other two variables weak or questionably matching.

Prefixed 'cf.': All the determination variables may or may not exist (see Table 3.2). The archaeological material resembles an image/illustration/reference sample or a previous identification by an archaeobotanist/authority, but there is no exact morphological fit. Three out of the five other categories match the archaeological material, but the investigator has

doubts about the exact fit of these categories with the material.

Prefixed 'elim.': A low confidence determination. It indicates that the material may perhaps be the taxon proposed, but the determination was derived without any images, illustrations or reference collection sample. The specialist/archaeobotanist makes an authority/experience call.

Suffix 'type': This is applied when the level of confidence is very low or lacks most determination variables. It means that the shape of the specimen fits a previously well determined plant familiar to the investigator. The candidate plant comes from the same geographical area, and has some of the morphological characteristics of this plant's seed, nut or fruit. It must only be used to determine remains, at most, up to genus level.

Form shape description: None of the six determination variables exist, but the archaeological specimen is distinctly a seed, a nut fragment or any other plant part. The material may then be described by its preservation/distortion condition and general shape, for example Spheroid, Angular, Triangular, and so on. A number is attached to the shape description based on a chronological sequence with other specimens from the same site that were only given shape descriptions, for example 'Angular 3', 'Spheroid 2' and so on. Sometimes under this categorization a very tentative identification may be added, mostly at the family level (with prefix 'cf'). This is to facilitate future researchers, who may have a better stock of references and experience, to verify the hunch (see Fig. 3.1).

Charred parenchymatous tissue identification and determination

A parenchymatous tissue fragment is a specific kind of charred plant remain. Archaeobotanically it is almost always in the form of plant charcoal that looks amorphous to the naked eye; devoid of clear structures, such as the remains of wood rays. Further analysis may determine if indeed the charred material is parenchyma. Untransformed parenchyma cells are more or less shaped as isodiametric polyhedrals with thin non-lignified cellulose walls. The tissues formed by parenchyma are usually ground tissues in which other tissues are embedded. Parenchyma cells are concerned with photosynthesis, storage of various materials, wound healing, secondary thickenings and the origin of adventitious structures (see Esau 1965, 8; Tootill 1984). There are specific plant organs that are mostly composed of parenchyma tissues. These are the

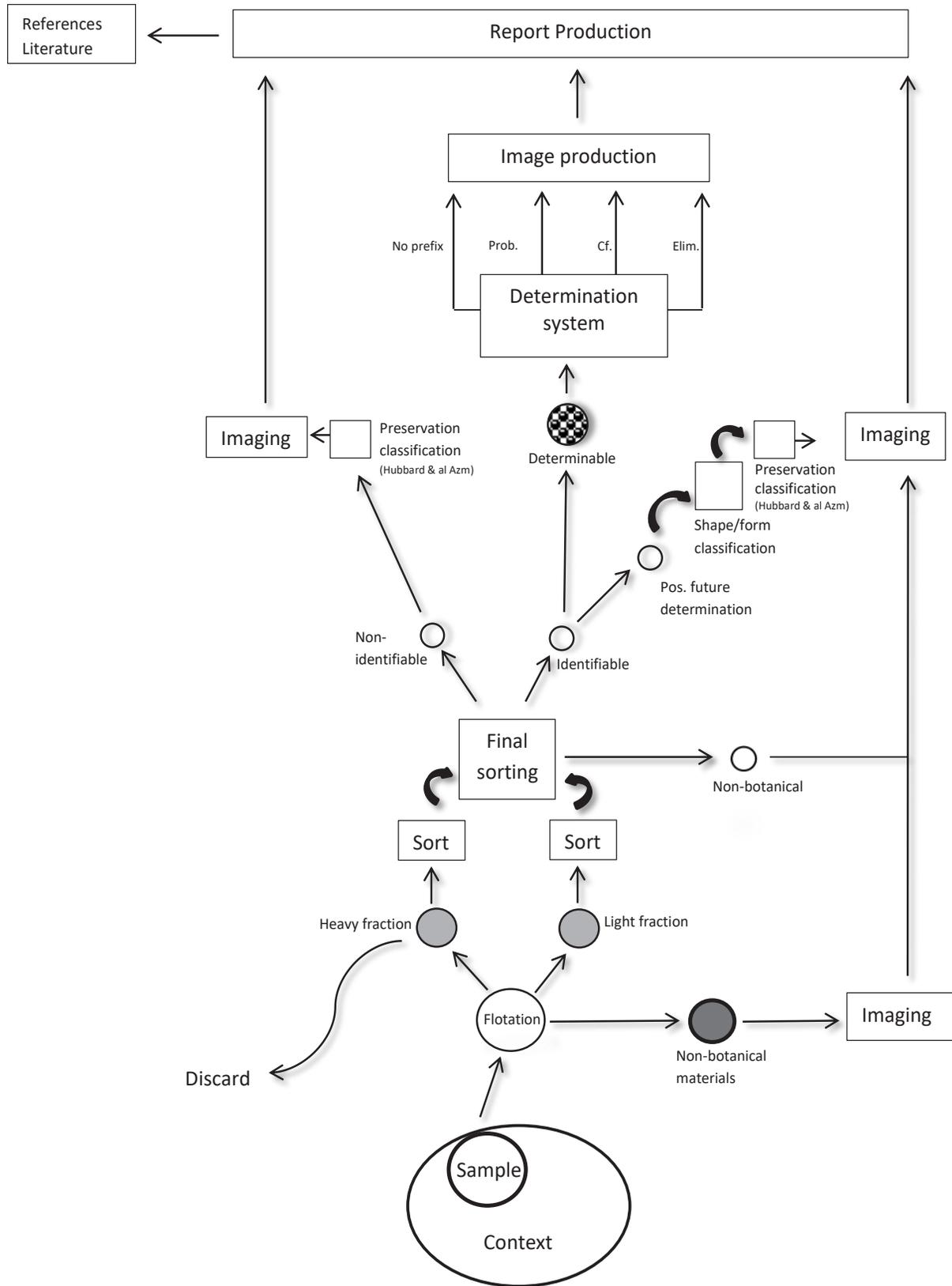


Figure 3.1. General schema showing the process of identification and determination of plant macro remains.

vegetative organs which humans have made a habit of exploiting, such as tubers, corms and rhizomes.

The identification system for charred parenchyma tissues was developed only in the last two decades of the twentieth century. However, the identification of remains of root/stem tubers in archaeology has a longer history. Early identification of arrowroot (*Canna edulis* Ker Gawl.) and cassava was possible in South American sites in the late 1950s because they were recovered almost whole and desiccated (see Hather 1988; Towle 1961). In charred form, pioneering archaeological identification of remains of root/stem tubers were on whole or large fragments of vegetative organs, for example potato, sweet potato and cassava (see Hather 1988; Rosendahl & Yen 1971). Until the 1970s it was only possible to identify remains of vegetative organs when they survived in large pieces, with their external morphology mostly intact. The challenge was to develop a method of identification that would allow analysis of smaller fragments, up to pieces that are not larger than 10 mm, which is the common condition of preservation in an archaeological context.

The Hather methodology

The challenge of developing the methodology for identifying seemingly nondescript charred vegetative organs was taken up by J.G. Hather (1988) in the mid 1980s, and since then has become the key approach followed (see Holden *et al.* 1995; Oliveira 2008; Paz 1997; Pearsall 2000; Perry 1999; Ussher 2015). Hather's training was in botany before he developed his interest in archaeology. He worked on a fundamental archaeological problem, which was how to identify root crops in charcoal form (Hather 1988; 1991). He was the first to characterize clearly the difference between charred vegetative and charred non-vegetative parenchyma tissues. Hather also pioneered developing a vegetative organ reference collection comprised of thin-sectioned tissues and charred whole vegetative organs from various taxa mainly for archaeobotanical purposes. In the process he demonstrated that 'charred plant tissues may be recognized as having characteristics of the anatomy of organs of a family or related groups within a family' (Hather 1988, 341). Hather was also the first to recognize the significance of taphonomic processes in any attempt at studying charred vegetative plant remains, which led him to develop a system of identification based on a combination of morphological features, anatomical features and artefactual characteristics of charred tissues—concluding that all identification of charred organs, even with the remains of tissue components identifiable, has to be wholly artificial in nature (Hather 1988, 346).

Hather also recognized the patterns connected to the condition of a tissue upon charring (fresh or dry). He observed patterns in the nature of vesicle disintegration and tension fracturing, which allows inference of the size of the organ, and the orientation of the fragment analysed in relation to the larger organ to which it belonged. The work of Hather, at the minimum, highlighted a better sorting method for charred remains in an archaeological sample. Practitioners in the past mostly identified everything as wood charcoal. After Hather's study, we could now further sort the charred materials to possible fruit tissues and vegetative organ tissues from the actual wood charcoal remains.

The system that we have been using for determining parenchymatous charcoal directly follows Hather's work (1988; 2000). It also follows the determination system that we presented for seeds and nuts. Determination is done through reference collections of contemporary plant parts. Comparisons are made on the morphology of a specimen against the reference collections for charred plant tissues. At best this is dictated by the extent of transformation of tissues after burning; especially in the formation of charring features, such as where cavities form, the collapse/fusing of cell walls and the preservation of elements within the remains of vascular bundles. Together with the artefactual features, the transformed anatomical features may be measurably compared, that is cell size, cell shape, cell-wall characters, cell contents, presence of aerenchyma and idioblastic cells (see Paz 2001).

Procedure for identification

The process of identifying charred vegetative parenchymatous tissues is as follows.

Sample sorted with the naked eye or low-power microscopy; wood-like charcoal from other plant remains, and other artefactual materials. The sorted wood-like charcoal examined for parenchymatous remains is often rounded, cells are spherical, or more or less isodiametric, tissues are made up of cells without a distinct organization; charred parenchymatous tissues often contain regular/irregular patterns of cavities; sometimes there are dense reflective regions surrounded by larger dull textured regions. All the vegetative tissue parenchyma scrutinized under a microscope, with a minimum of 10× magnification. The exposed surface must be scrutinized for other diagnostic features. When possible, further fracturing of the sample should be done to expose un-weathered or less distorted surfaces.

The best samples undergo Scanning Electron Microscopy (SEM). This involves grabbing images

of the best surfaces containing the most diagnostic features, that is cell shape, cell size, cell-wall thickness and patterning, vascular organs, vesicles and tension fractions, idioblastic cells, crystals and remains of starch grains.

The images are further analysed using an image-processing programme capable of measuring diagnostic features. All observable cells should be measured by their 'long' and 'short' axis, circumference, as well as the thickness of the cell walls. Vascular organs must be measured by the general area, 'short' and 'long' axis, and the localized cell-wall thickening pattern of xylem remains documented. If there are remains of starch grains, they should also be measured in the same manner as the other quantifiable features (see Fig. 3.1).

Comparison with reference collections and other resources

The exponential growth of comparative resources in cyberspace has become incredibly useful. Plant lists, Flora, images and other relevant research work that may strengthen variables we indicated useful for determination are now more accessible. This was not the case until at least the 1990s. Still, at the heart of our determination system is an actual reference collection of plant parts; our matching approach between past and present plant forms, and the uniqueness of the transformed archaeological remains dictates this.

There are now several dedicated archaeobotanical reference collections maintained in various research centres across the globe. One such collection is being maintained and developed at the University of the Philippines, Archaeological Studies Program (UP-ASP) in Diliman. At the core of the reference collection are plants known to be utilized by people. Specific to vegetative organs, the collection started with the most ethnographically important root crops and some samples of known famine food tubers (informed through ethnography). The premise was that these same root crops and famine tubers were significantly exploited in the region in the past. Moreover, they may serve as proxy evidence for biogeographic inferences, and past human population-movement arguments. With our approach in mind, a relatively small-sized reference collection can still be effective in arguing for a high confidence level of determination. If we are transparent, a discerning reader may make better informed decisions as to how much to accept and use the information we provide. A weak reference collection may be augmented by other collections/references and resources through the internet, and the skill/experience of other specialists—provided that specialist and reports present/share at least an image of the pertinent material.

At the core of the reference collection at the UP-ASP is the parenchyma collection; currently with eight species from four of the most important genera humans exploit for their vegetative organs, namely, *Dioscorea*, *Manihot*, *Colocasia* and *Ipomoea*, with more samples actively being added. Within the species represented in the collection are several individuals coming from several population stands—relevant, we realized, in providing a better range of measurements of diagnostic features. There is also a basic fruit pericarp collection which includes bananas (*Musa* spp.) and jack fruit (*Artocarpus* spp.) samples. In addition to the charred reference collection of parenchymatous material, a wood reference collection was developed, which now holds 100 species from 38 families. Added to these are 78 species of woody vines from 28 families. Our running count of plant seeds and nuts in the collection is 381 species from 62 families.

While the reference collection will never be a complete representation of the current tropical flora in our region, and there are many more species that must be included in the future, I am confident that the species currently represented are sufficient to make effective archaeological macro remains determinations.

Measuring

Measurements of parenchyma tissue diagnostic elements are made by opening digitally stored SEM micrographs on image-analysis software. The cells, vascular organs, crystals and starch grain remains must all be measured by their long axis, short axis and area. It is appropriate to label the measurements 'long axis' and 'short axis' to avoid unnecessary difficulty in orienting exposed tissue surfaces—knowing that parenchyma cells in tissues are not consistently oriented. Added to this, the charring process transforms the features of the tissue and often skews the shape and true orientation of the cells. The cells must be measured from the inner surface of cell walls. When cell walls are composite (two cell walls fused after charring), they must be measured whole and the measurement divided into two. All measurements may be encoded and analysed on spreadsheet software, and the cluster of measurements compared with the values from known species in a reference collection—the more overlap there is in the range of measurements between the archaeological and a known species, the higher the level of match per variable.

Determination scale

As already mentioned, we determine by using categories arranged in a scale of confidence. At the highest level of confidence, the parenchyma tissue may be

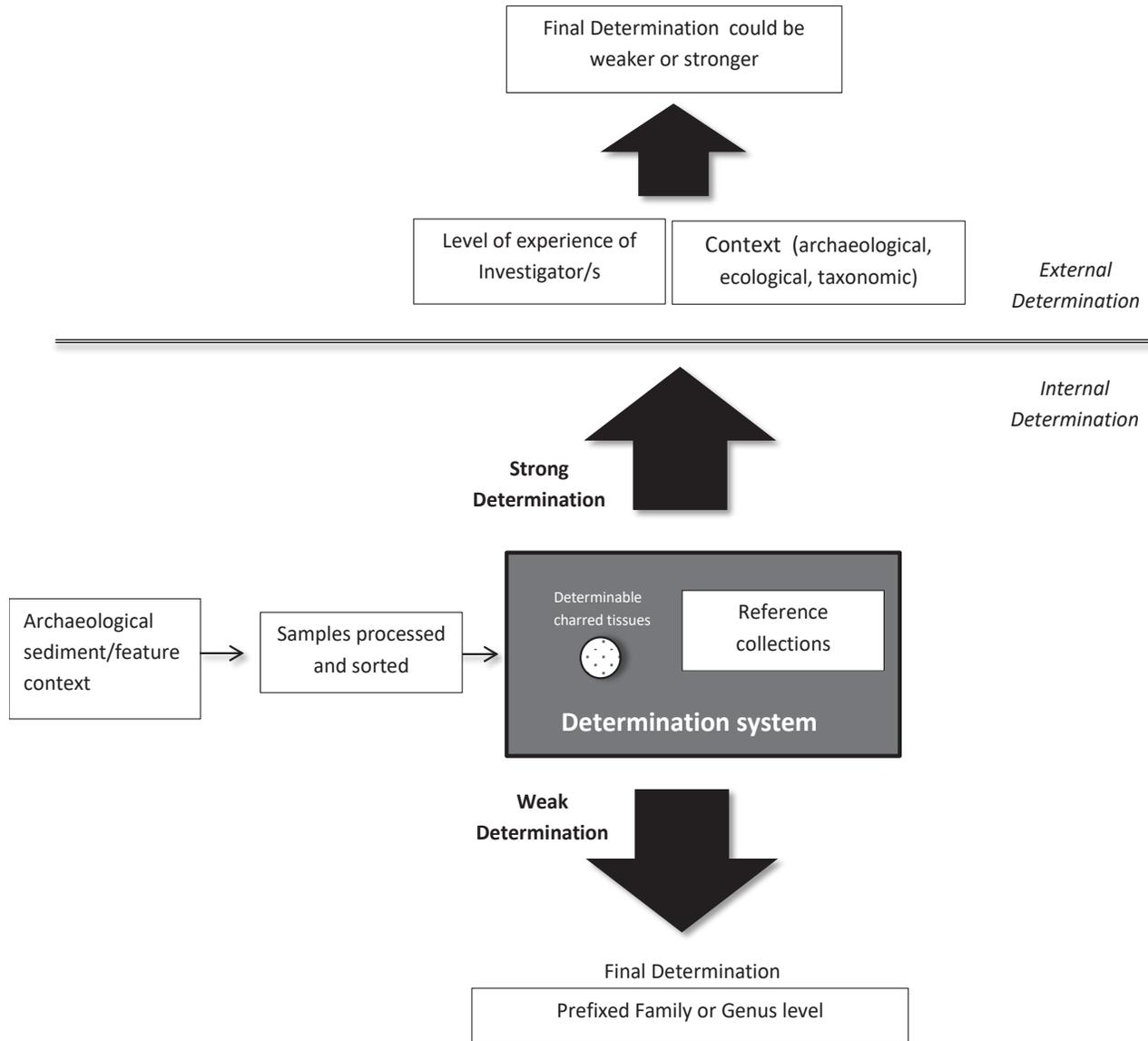


Figure 3.2. Diagram of determination process, which shows the two-step process (internal and external steps).

determined to species. Any further precision is not acceptable in our methodology. At the lowest level of confidence, the material may be identified simply as parenchyma tissue (see Fig. 3.2). Applying the two-step approach in determination, we start from an internal determination step, which means that the sample was studied purely on the presence of diagnostic elements internal to the charred remains. If there are few observable diagnostic elements, then the determination is weak. At best it will have a prefixed taxon determination to genus level. At worst, we can say that we looked at the sample and could only define that it is definitely charred parenchyma tissue.

The internal variables we seek in samples are the biological structures and taphonomic artefactual

features found on the actual archaeological charred tissue. Depending on the number of diagnostic elements—which dictates the determination—the external determination elements, composed of archaeological context, ethnoarchaeological data, ethnobotanical data and temporal data, may or may not be used to improve on the internally derived determination. External context must not go beyond the limits defined by the internal determination step.

If the determination is strong (that is, diagnostic features beyond cell size/shape and wall thickness were observed, the collective measurements of the features fits a reference collection taxon, cellwall thickening patterns of xylem were observed, there were druse formation or idioblastic cells observed), it

can be further improved by considering external determination variables, such as archaeological, ecological or taxonomic context and the experience-derived insights of the investigator. It may also be possible that, after considering external determination variables, an initially strong confidence determination may be weakened by contradictions beyond the physical context of the sample. This may happen especially when the internal determination conclusion is strong, but did not have enough diagnostic variables and there is inconsistency in fit when compared with samples of taxon from the reference collection, the known details of distribution of such a plant, or the time depth of the archaeological context. Without details of the cell shape and wall thickness or remains of vascular organs, high-confidence taxon determination is not possible. The use of the prefixes, suffixes and 'type' described for the seed determination is adopted for the final determination (see Table 3.2). With no clear diagnostic feature match with reference samples, the charred tissue can still be identified morphologically and artefactually as a root or stem tuber (see Fig. 3.2).

Determined to taxon

When the archaeological material fits all or most of the diagnostic features of a reference species, that is cell shape, cell-wall thickness, cell-content remains, vascular organ characteristics, idioblastic cells, crystals and starch grains, then the material may be identified to species. Having the cell size alone is not sufficient to have a non-prefixed determination of a charred tissue. Cell size is a complicated determination variable. One clear reason is that they undergo cell polyploid development that is especially common in root crops (Ayensu 1972), resulting in cells becoming larger at average within the same species (Galitski *et al.* 1999; Nagl 1978); with a likelihood of even growing further through continuous domestication or cultivation selection processes. This complicates determination, if solely based on cell sizes, between an archaeological sample and an incomplete modern vegetative organ reference collection. Nevertheless, the archaeological cell samples may be plotted against the range of reference species measurements, and this may provide some grounds for further identification. The use of scatter graph representation to compare clusters of measurements on both the sample and a reference collection taxon is an effective way of comparing values.

Determined as root or stem tuber

The internal analysis led to a weak determination. While the basic diagnostic attributes of a parenchyma tissue were established, it lacks the other prerequisites for a taxon determination. The sample only has

observable variables associated with parenchyma cells. When compared with the reference samples they did not fit the ranges associated with the species represented. The sample may be further determined as root or stem tuber, if parts of the pit structure survive, or the parenchyma cells look roughly oriented towards a central point.

Determined as storage organ parenchyma

Determination falls under this label when the basic diagnostic features for parenchyma are met, but the material does not fit, even in the slightest, any of the reference species—the cell shapes, size and arrangement are totally different, and measurements do not/hardly overlap with any of the ranges of reference species in the collection. The archaeological material is substantial enough to show that it was part of a large organ, but no other diagnostic features apart from those directly associated with cells were noted.

Determined as fruit parenchyma

An archaeological tissue falls in this category when there are no signs of vascular organs on the charred remains, and is comprised only of parenchyma cells; the general shape of the original organ can be discerned; or there are clear remains of the periderm and underlying phellogenetic structures. The cells have thicker walls compared with the cell walls of parenchyma from vegetative organs.

Determined as parenchyma

At this level, it is clear that the tissue being determined is not a piece of lignified charcoal. It was clearly demonstrated that it fits the characteristics of parenchyma cells and tissue as already described earlier.

Determined as unknown

A general label given to archaeological charred plant tissues, initially categorised as parenchymatous, but after analysis could not be placed with a comfortable certainty under the category of parenchyma or woody tissue, or any other type of charred plant remains. This is usually due to extensive taphonomic transformation.

A final note

In the methodology of comparing archaeological plant remains against contemporary plant references we are under no illusion that what we conclude was derived from absolute knowledge of what is, and what was. We are at best giving good approximations that are well informed—the best that anyone can say or do—with charred macro remains. Anyone who engages the reasoning behind our determination may follow the

steps taken without difficulty. The system underscores the importance of how determination is delimited at first by observations and information directly relevant to the plant remains under study (internal determination). All other variables that may help in improving the level of precision in the determination, including the skill and experience of the investigator (external determination), must be clearly limited by the extent of what can be said from the actual archaeological material, or from the limits of the internal step of the process.

It is fortunate for the discipline of Archaeology that methodologies and techniques coming from archaeobotany continue to progress. There are advances not only with the macro remains methods, but also with the smaller scales of plant remains. The micro remains of plants, represented by pollen, phytoliths and starch, are studied with the same amount of interest. Equally so are the advances in the analysis of plant isotopes and lipids, traces of which are ingeniously extracted from the archaeology. It is almost a truism that all the methods have strengths and real weaknesses. I, however, maintain that plant macro analyses have a unique advantage. It is only at the macro level that we see plant remains still with anatomical or biological features in their original physical associations with each other. We may recover charred seeds with the embryo placement in direct association with the rest of the seed components. A tissue of charred parenchyma, even when drastically transformed, may show the direct association with each other of cells, vascular bundles and other biological features embedded in tissue. With micro and molecular remains, we are dealing with relevant components and traces of plants that existed—all are totally detached from their original/natural context—churned within an archaeological sediment matrix. They are denied the advantage of being found as a compound tissue where several elements, undeniably associated features, can be brought to play in the determination. And so the philosophical cautionary question applies more heavily at the micro and molecular scale: have we eliminated all possible candidates for determination to taxon? Have we seen everything?

As always, the best way to deal with weaknesses in our methods is to bring together all possible lines of proxy evidence to support and improve determinations derived from the techniques applied. In a limited way we have been applying this approach in Island Southeast Asia in the study of people–plant relationships, where the determination of macro remains (conservative by the nature of the determination system) is improved by complementary results from parallel

determinations of micro remains (see Barton & Paz 2007; Mijares 2007). With more collaborative work, there is indeed good reason to be optimistic about the prospects of archaeobotanical methods.

I have attempted to explain better a determination system for plant macro remains that is being used and referred to at least in Island Southeast Asia and the Pacific. Perhaps it may even turn into a proper protocol, one day, across scales of plant remains. But this is not my concern. By submitting this piece for this volume, I try to honour Martin Jones and revisit, for me, a major academic root. Our generation of archaeologists came out of the Cambridge environment very confident that we could do more and continue practising and improving our craft. Many of us are still researchers and academics. There are many wonderful individuals who actively helped me in my personal growth and contributed to my grand experience. Martin Jones was definitely one of them.

A tribute

It has been over two decades since Professor Martin Jones became my mentor. The transformational experience rewarded me with at least two major lessons: first, academic mentoring should be towards bringing out the best potential of an individual, without blatantly imposing one's own ideas or interests. Second, it is important to create the appropriate conditions to allow like-minded individuals to interact intellectually and be academically productive. Martin Jones facilitated this learning process by simply granting ample freedom for diverse thinking and intellectual space. The central venue he provided was the George Pitt-Rivers Laboratory at Cambridge. Most of us brought into the 'Pitt' our own hobby-horses, rather than being topical cogs in a larger research design dictated by the big professor. There were enough of us in the same space with various perspectives to generate fascinating discussions on archaeology, archaeobotany and life in general. I came back to my home university with these lessons internalized and applied them in my effort to help develop the Archaeological Studies Program at the University of the Philippines.

When I started my graduate work, I was determined to learn a method that I could apply and teach. I scouted around and decided to learn archaeobotany generally, which was at that time still underdeveloped in Southeast Asia. The key reason for my decision was the enthusiasm I saw in the people at the Pitt-Rivers laboratory. This included the ever-present lively intellectual discourse and banter (inside the lab and in the pubs). Added to this was my outward excitement when informed that there was a way to identify tubers, and

the developer, Jon Hather, was a good friend of several members of the Pitt. At that time he was based in London at the Institute of Archaeology, University College London. It would have been logistically difficult for me effectively to learn the method, had I had regularly to commute to London. As soon as Martin learned of my research interest, he immediately called Jon Hather and set up a system for him to come over and mentor me at the Pitt. The ensuing regularity of visits by Jon was effective, and also made him a welcome addition to the dynamic intellectual and social scene.

I regret that my resulting dissertation has not yet been published in full (Paz 2001). I got as far as preparing the prerequisite work, but the project got quickly buried by complications related to my university career. Before I knew it, time had rapidly marched on. Central to my dissertation was the system of determining remains I have just presented. The system that was developed is deeply rooted in Jon Hather's pioneering work (Hather 1988; 1991; 1993; 2000). The approach has since been applied in the archaeology of Southeast Asia and the Pacific; for example in southern Indonesia (Oliveira 2008); in the Philippines at northern Palawan (Carlos 2010), and at northern Luzon (Paz & Carlos 2007); in northern Vietnam (Ceron 2013), and in the Pacific kingdom of Tonga (Ussher 2015). Those who adopted the system unfortunately laboured in reading my dissertation and I think it is about time that a useful part of that work is re-written and published—and so here we are.

I owe friends and colleagues at the Pitt-Rivers Laboratory for the intellectual discourse, and friendship, which nourished my ideas and research. This would not be at all possible if Professor Jones were a different kind of academic, and mentor.

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Chapter 4

Phytoliths and the Human Past: Archaeology, Ethnoarchaeology and Palaeoenvironmental Studies

Carla Lancelotti & Marco Madella

In this chapter we will explore the evolution of phytolith studies since its inception in Europe. We will bring together the historical development of the methodological approach and the current contribution of this proxy to our understanding of plant use, the origin of agriculture and agricultural techniques in the past.

A brief history of phytolith studies

Microscopic hydrated silica particles formed in plants have over the years been referred to as ‘opal phytoliths’, ‘biogenic silica’, ‘silica phytoliths’, ‘plant opal’, ‘biogenic opal’ and simply ‘phytoliths’. The first observation of mineral particles from plants was reported by Leeuwenhoek in 1675, though he used the term phytoliths to describe calcium oxalates (Mulholland & Rapp 1992). The term phytolith for defining microscopic opaline bodies deposited in plants initially appeared in a paper by Ruprecht (cited in Baker 1959a,b), but their discovery and description dates back to the first half of the nineteenth century. According to Powers (1992 and references therein), the history of phytolith studies can be divided into four periods.

Discovery and exploration period: (c. 1835–1900)

Struve, a German scholar at the University of Berlin, in 1835 produced a dissertation on silica in plants (cited in Powers 1992), thus placing the ‘scientific discovery’ of phytoliths one year before that of pollen. A decade later Ehrenberg, another German scholar, observed, described and classified silica particles he found in sediment samples, calling them ‘Phytolitaria’ (from the greek φυτόν/*phutón* ‘plant’ and λίθος/*lithos* ‘stones’). It was Ehrenberg himself who identified phytoliths in the samples of dust collected by Darwin on the deck of HMS *Beagle* (Darwin 1846).

Botanical research period (c. 1895–1936)

Towards the end of the nineteenth century and during the first half of the twentieth, phytoliths were

recognized as particles produced within plants and studies related to production, taxonomy and morphology flourished (Grob 1896; Haberlandt 1914; Mobius 1908). It is in this period that the first applications of phytolith analysis to archaeological studies appear (Netolitzky 1900; 1914; Schellenberg 1908). As for the previous period of discovery and exploration, the German school dominates phytolith studies and the body of literature is therefore published in German.

Ecological and paleoecological research (c. 1955–1975)

During the 1950s and 1960s, scholars from the United States, the United Kingdom and Australia started investigating phytoliths, thus producing the earliest body of literature in English. In this period morphology is examined in more detail and in many more plant families, resulting in studies that are considered the bases of phytolith classification and they are still in use (e.g. Metcalfe 1960; Twiss *et al.* 1969). Studies in archaeology also proliferate, with researchers starting to work on different types of deposits and materials (e.g. Helbaek 1961; 1969: working on ashes and ceramics from the Near East) and in different areas of the world (e.g. Watanabe 1955; 1968; 1970: identifying rice phytoliths in prehistoric deposits from Japan). A seminal publication, which contributed to increase phytoliths visibility in Quaternary studies, was the review of the potential of phytoliths in palaeoecological reconstruction published by Rovner (1971) in the journal *Quaternary Research*.

Modern period (c. 1978–2000)

The last two decades of the twentieth century are characterized by an exponential increase in phytolith studies (Fig. 4.1), both geographically and in scope. Specific studies on families or species become routine: Cucurbitaceae (Bozarth 1987; Piperno *et al.* 2000), Fabaceae (Bozarth 1990) and Cyperaceae (Ollendorf 1992; Ollendorf *et al.* 1987) become a focus of interest, as well as some dicotyledonous species for their inter-

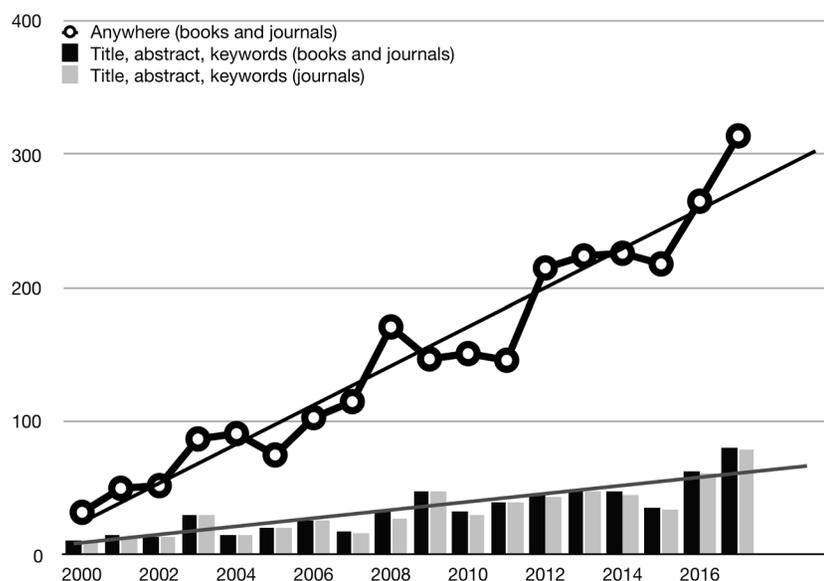


Figure 4.1. Increase in phytolith studies in the last 15 years from a search on ScienceDirect, using as keyword the term 'phytolith' in any field (trend line); only in 'title', 'abstract' and 'keywords' in both books and journals (black columns); and only journals (grey columns).

est in past vegetation and human use (Bozarth 1992). Maize (Mulholland *et al.* 1988; Piperno 1984; Piperno & Pearsall 1993), rice (Houyan *et al.* 1997) and wheat/barley (Ball *et al.* 1993; 1999) occupy, for their economic interest, a prominent spot in this area of studies. The geographical zones investigated in phytolith studies also expand, with research in Africa (Alexandre *et al.* 1997; Barboni *et al.* 1999; Jansen & van Iperen 1991; Mercader *et al.* 2000; Runge & Runge 1997), Central Asia (Madella 1997) and South East Asia (Bowdery 1999; Kealhofer & Penny 1998) appearing together with New Zealand (Kondo *et al.* 1994), Israel (Albert *et al.* 1999; 2000), China (Yongji 1991) and Brazil (Alexandre *et al.* 1999). The scope of research also widens and phytoliths are used as activity markers to study irrigation (Rosen & Weiner 1994), identify dietary practices from dental calculus (Ciochon *et al.* 1990; Danielson & Reinhard 1998; Fox *et al.* 1994) and infer function of stone tools (Anderson 1980; Jahren *et al.* 1997; Kealhofer *et al.* 1999; Sobolik 1996) and the formation of pastoral sites (Brochier *et al.* 1992). New techniques such as the isotopic study of phytoliths are also introduced (Fredlund & Tieszen 1997; Kelly *et al.* 1998; McClaran & Umlauf 2000; Shahack-Gross *et al.* 1996; Webb & Longstaffe 2000). Phytolith studies also assume the character of a mature discipline with the proliferation of meta-studies, in particular on extraction methods (Lentfer & Boyd 1998; Madella *et al.* 1998; Middleton & Rovner 1994; Powers & Gilbertson 1987).

In the next paragraphs, we will outline some of the major breakthroughs and developments in phytolith research in archaeology and palaeoenvironmental studies and, especially, in ethnoarchaeology.

Methodological advances

The stage of maturity reached by the discipline in the last 15 years is testified by the number of works published since 2000 that critically reflect on the methodology itself. At the same time, technological improvements and the introduction of more sophisticated analytical tools contributed to an increase in research involving isotopic and genetic analysis of phytoliths.

Phytolith extraction, identification and interpretation

On the one hand, phytoliths from archaeological sites have been used to document crop plants, plant food, plant-made objects like mats and baskets, fuel types and construction materials. On the other hand, phytoliths from natural sequences have been used to understand vegetation changes between major ecological types (e.g. savannah, forest, grassland, etc.) or the dynamics of soil-formation processes. Several authors, however, have concentrated on extraction methods, either proposing new and improved techniques (Lombardo *et al.* 2016), concentrating on specific and problematic types of sediments (Calegari *et al.* 2013), combining extraction of several micro-remains (Horrocks 2005), improving the efficiency both in time and cost (Katz *et al.* 2010), comparing the results of different extraction methods (Parr 2002), or assessing the best extraction method for specific analyses for example isotopic studies (Asscher *et al.* 2017; Corbineau *et al.* 2013) or genetic analyses (Kistler 2012). Other methodological aspects on which researchers have concentrated are counting and nomenclature. Strömberg (2009) and Zurro (2017) question whether changing the count size

influences the interpretations of results and propose minimum count size as well as statistical techniques to ensure the robustness of results. The creation in 2000 of the International Committee on Phytolith Morphology responded to the need of the phytolith communities to standardize the terms that were used to describe phytoliths. The main result of this committee was the publication of the first International Code for Phytolith Nomenclature in 2005 (Madella *et al.* 2005). In 2014 the International Society for Phytolith Research appointed a new International Committee for Phytolith Taxonomy to continue this effort. Their first output was the publication of standardized guides for morphometric analysis of phytoliths (Ball *et al.* 2016b). Another important issue that has been deeply addressed in recent years concerns the role of taphonomic processes on the composition of phytolith assemblages. Madella and Lancelotti (2012) have offered a comprehensive review of the possible impacts of various taphonomic processes and proposed some ways of counterbalancing them in the analysis. At the same time, Cabanes and Shahack-Gross (2015) have performed experiments to assess phytolith preservation fully in sediments and understand the role of dissolution on the robustness of interpretations.

Isotopes and DNA

Isotopes from archaeological sites have been used for understanding, among other things, climatic and environmental change, past human diet, nutrition and mobility, past animal and crop management practices, and to build reliable chronologies. The isotopic analysis of occluded carbon in phytoliths, both for dating as well as for palaeoenvironmental reconstruction purposes, is an issue that has been abundantly debated in recent years (Piperno 2016). Studies have been performed to understand soil carbon sequestration in phytoliths (Parr & Sullivan 2005; Song *et al.* 2016), as well as the incidence of atmospheric carbon occluded in phytoliths (Carter 2009). Some of these publications have generated a debate centred on the validity of carbon isotopic analyses in phytoliths and what exactly is the signature measured through this technique (Santos & Alexandre 2017; Santos *et al.* 2016). Hodson and colleagues (2008) explored the potential of oxygen and silicon isotopes alongside carbon on the same plants of *Triticum* sp. and concluded that silicon and carbon are the most promising isotopic systems to be used in palaeoenvironmental studies, while more work on oxygen isotopes was needed to explain its patterns of variation. Following this, several groups have been working on oxygen isotope methodology (Chapligin *et al.* 2011; Crespin *et al.* 2008) up to the point where this technique has been fully validated

for palaeoenvironmental studies (Alexandre *et al.* 2012). Work on silicon isotopes, on the contrary, is much rarer, although the potential of this technique is gaining recognition (Leng & Sloane 2008; Leng *et al.* 2009), to the point that Hodson (2016) recognizes it as a commonly used technique.

Ancient DNA in archaeology has been used to understand human evolution and, when extracted from plants and animals, as a way to understand the processes involved in domestication. The extraction of DNA directly from phytoliths is related to the possible presence of organic material occluded within the silica. However, this seems to be a problematic avenue of study, as observed by Elbaum *et al.* (2009). An interesting side of DNA studies and phytoliths is the exploration of the genetic mechanisms involved in phytolith production. Despite the evidence that silicon is fundamental for plant growth, as it provides strength, detoxification and protection from animals (Piperno 2006), the exact mechanism for phytolith formation is still not fully understood. Piperno *et al.* (2002) indicate that phytolith formation in Cucurbitaceae is regulated by a dominant genetic locus previously associated with the production of lignin. The same research establishes that this locus also has an important role in phytolith morphology, constituting a major breakthrough in the understanding of phytolith formation and taxonomy.

Phytoliths in archaeology

The process of domestication of plants and the setting and spread of agriculture was a transformational moment in the socio-ecological history of our species. Currently, the archaeological record shows that, starting around 12,000 years ago, plant cultivation and domestication developed independently in several regions of the world and then spread via cultural or demic diffusion into most geographical areas (Larson *et al.* 2014). Archaeobotany has focused on developing methods for identifying the domestication process, the cultivation of plants and fully fledged agriculture from wild plants and crops remains. During the last 20 years, phytoliths in all regions of the world have become an important proxy in this research, alongside macro remains, pollen and starch grains (e.g. Pearsall 2015b; Piperno 2006; 2009). After many years of work focused on the standardization of identification characteristics based on reference collections and morphometric analysis of phytoliths from wild species and crops, the discipline has finally reached sound and replicable procedures. Piperno (2006) performed the first review of crop phytoliths, followed by more recent endeavours from Piperno (2012) and Ball *et al.* (2016a).

Table 4.1. *Phytolith production and taxonomic specificity for the world's major crops.*

	Plant	Phytolith production	Taxonomic specificity	Plant Part
Southwest Asia	<i>Triticum</i> spp. (einkorn, emmer, other species)	Very high	Genus	Inflorescence bracts (glume, lemma and palea)
	<i>Hordeum</i> spp. (barley, other wheats)	Very high	Genus	Inflorescence bracts (glume, lemma and palea)
East Asia	<i>Oryza sativa</i> (rice)	Very high	Species	Glume, Leaf (bulliform cells)
	<i>Setaria</i> spp. (foxtail millets)	Very high	Genus	Glume
	<i>Panicum</i> spp. (broomcorn millets)	Very high	Genus	Glume
South and Southeast Asia	<i>Musa</i> spp. (bananas)	High	Genus, Section, Species	Leaf, Seed
	<i>Benincasa hispida</i> (wax gourd)	Very high	Genus (?)	Fruit rind
	<i>Cocos nucifera</i> (coconut)	Very high	Family or Subfamily	All plant parts
Africa	<i>Lagenaria siceraria</i> (bottle gourd)	Moderate	Genus	Fruit rind
	<i>Ensete ventricosum</i> (Abyssinian or Ethiopian bananas)	High	Genus	Leaf and seed
	<i>Sorghum bicolor</i> (sorghum)	High	Genus	Glume
Americas	<i>Zea mays</i> (maize)	Very high to low	Species	Cob (glume/cupule), Leaf, Husk
	<i>Cucurbita</i> spp. (squashes and gourds)	Very high/high	Family, Genus, Species	Fruit rind, Leaf
	<i>Lagenaria siceraria</i> (bottle gourd)	Moderate	Species	Fruit rind
	<i>Sicana odorifera</i> (cassabanana)	High	Genus	Fruit rind
	<i>Manihot esculenta</i> (manioc or yuca)	Very low	Genus	Most plant parts
	<i>Maranta arundinacea</i> (arrowroot)	Very high	Species	Seed
	<i>Calathea allouia</i> (Ilerén)	Very high to Moderate	Species	Seed, Rhizome
	<i>Ananas comosus</i> (pineapple)	Very high	Family	Leaf, Seed
	<i>Canna edulis</i> (achira)	Very high	Genus (?)	Leaf
	<i>Phaseolus vulgaris</i> and <i>lunatus</i> (common/lima bean)	Moderate	Genus	Pod
	<i>Helianthus annuus</i> (sunflower)	High	Family (Genus?)	Achene
	Arecaceae (palms)	Very high	Family, Subfamily, Genus (?)	All parts

Phytoliths have been used in a number of different ways to understand agricultural origin and dispersal:

- 1) as direct proxies for cultivation and domestication of certain species
- 2) as part of a multi-proxy research to identify past crops or wild species
- 3) as low-level taxonomic identifiers (e.g. species level) or identifiers of plant structures (e.g. inflorescences, leaves) less visible with other fossils
- 4) as proxies for the expansion of ancient crops.

Phytoliths significantly increase the traceability of several Old and New World crops, including taxa that are normally invisible in the charred record, such as some fruits or root crops, as well as enabling the identification of different plant structures pertaining to the

same crop (e.g. Corteletti *et al.* 2015; García-Granero *et al.* 2015a,b; Iriarte *et al.* 2012; Madella *et al.* 2014). The level of taxonomic significance of phytoliths will differ from species to species in the same manner as other fossil indicators of plant exploitation, such as charred remains of seeds.

In Table 4.1 we summarize the present understanding of crop identification based on phytoliths and in the following text we discuss the utility of phytoliths for identifying major crops and therefore agricultural origins and crop dispersal.

Triticum and Hordeum spp. (wheat and barley)

Wheat and barley are major silica accumulators, producing a variety of morphotypes such as the ones from epidermal cells: short cells; long cells; cork cells; papil-

lae; trichomes; and trichome bases. These bodies are very characteristic and can be diagnostic at genus level when a morphotypic and morphometric approach is used (e.g. Ball *et al.* 1999; 2009). There has also been some success in identification to species level, primarily based on the morphometric differences observed in the short cell (rondel), dendritic and/or papillae phytoliths (e.g. Ball *et al.* 1999; Rosen 1992; Tubb *et al.* 1993). Moreover, features of the anatomy displayed in the silicified epidermal tissues of cereals can be used to distinguish plant parts.

Setaria and Panicum millets (foxtail and broomcorn millets) and other small millets

Phytoliths from the inflorescence of *Setaria* and *Panicum* are extremely useful for identifying *Setaria italica* (foxtail millet), *Setaria viridis* (green foxtail) and *Panicum miliaceum* (common or broomcorn millet) and thus documenting the earliest history of domesticated millets in Eurasia (García-Granero *et al.* 2015a,b; Zhang *et al.* 2011; 2013). Important features to distinguish these taxa are the silica body shape, papillae characteristics (including presence/absence), epidermal long cell patterns and glume surface sculpture (Lu *et al.* 2009). A cautionary note is due when differentiating crop phytoliths from their Panicoid weedy wild relatives in archaeological contexts, as this can be a challenge due to similarities of identifiable Panicoid husk morphotypes. Strict identification criteria must therefore be followed for correct identifications. The discrimination between *S. italica* and its wild ancestor, *S. viridis*, is based on the morphometry of phytoliths in the upper lemma and palea (Zhang *et al.* 2011), although some uncertainty remains and more studies are needed to detect the presence of other potentially diagnostic features. Morphological and basic morphometric studies of glumes of other minor millets also show the potential of phytoliths for differentiating these important crops in the prehistory of Eurasia and Africa (Madella *et al.* 2014).

Oryza sativa (rice)

Phytoliths play a very important part in the archaeological study of rice domestication and cultivation. Currently, three distinct phytolith morphotypes are used to identify rice: double-peaked glume cells from the rice husk; bulliform cell phytoliths from the leaves; and articulated bilobate phytoliths from stems and leaves (Gu *et al.* 2013; Piperno 2006). Double-peaked glume cell phytoliths are unique to the genus *Oryza* and can discriminate domesticated rice from wild rice species of South and Southeast Asia on the basis of linear discriminant function analysis of glume cell measurements (Zhao & Piperno 2000) or three-dimensional measurements (Gu *et al.* 2013). The morphologi-

cal characters of bulliform cell phytoliths seems to be under genetic control, therefore reflecting taxonomical significance (Gu *et al.* 2013), and some features such as surface ornamentations have been employed to distinguish domesticated from wild rice (Huan *et al.* 2014; Wang & Lu 2012). Phytoliths can also be used as a tool for understanding the development and spread of rice (*Oryza* sp.) arable systems using arable weed ecologies as pioneered by Fuller and Weisskopf (2011).

Musa spp. (true bananas) and Ensete ventricosum (Ethiopian/Abyssinian banana)

The domestication and spread of true bananas (*Musa* spp.) is difficult to untangle. Current domestic bananas derive from the Eumusa (*Musa acuminata* [AA] and *Musa balbisiana* [BB]) and Australimusa (*M. maclayi*) sections of Musaceae through intra- and interspecific hybridization, polyploidization and somaclonal mutations, which resulted in seed sterility and parthenocarpy (De Langhe *et al.* 2009). Prehistoric and historical human populations spread domesticated Eumusa throughout the tropics and any evidence for *Musa* phytoliths outside Asia is indicative of cultivation (Vrydaghs & De Langhe 2003). Phytoliths can be produced in various plant tissues and organs of bananas (e.g. Chen & Smith 2013), with seed and leaf phytoliths being the most studied to date. In *Musa* and *Ensete* leaves, the silicification of cells from around the vascular tissue produces volcaniform (volcano-shaped) phytoliths (Ball *et al.* 2006). Both morphotypic (e.g. Vrydaghs *et al.* 2009) and morphometric studies (e.g. Lentfer 2009; Vrydaghs *et al.* 2009) have been carried out to be able to identify different *Musa* and *Ensete* species. The results show that volcaniform phytoliths can be discriminated at the genus level (distinguishing bananas from *Ensete* in archaeological records: e.g. Lentfer 2009; Mbida *et al.* 2001), but reliable identification at the species level is still wanting.

Sorghum bicolor (sorghum), Pennisetum glaucum (pearl millet)

A certain number of recent studies have showcased phytolith production in African domesticated grains and their wild progenitors (Logan 2012; Madella *et al.* 2014; Novello & Barboni 2015; Out & Madella 2017; Radomski & Neumann 2011). However, there are currently too few studies on phytolith production in the wild grasses inflorescences (Novello & Barboni 2015) to be able to identify specific morphotypes diagnostic to the genus or species level.

Zea mays (maize)

Maize is native to the central Balsas River region of tropical southwest Mexico (see van Heerwaarden *et*

al. 2011) and represents the main cereal crop of the Americas. More than three decades of focused research have demonstrated that phytoliths produced in the leaf and cob of maize are diagnostic, and distinguishable from those of teosinte (its wild ancestor) and other wild non-*Zea* grasses native to North, Central and South America (Ball *et al.* 2016a). The criteria used for the identification of maize phytoliths employ both size and morphology and, as with phytoliths from other crop plants, vegetative and inflorescence structures can be distinguished (leaf, stalk and seed chaff).

Cucurbita squashes and gourds and other Cucurbitaceae
Squashes and gourds pertaining to the genus *Cucurbita*, as well as other types of Cucurbitaceae, were important early plants of the Americas, and they produce phytoliths of high taxonomic information to document their archaeological history. Many parts of the squash/gourd plants are high phytolith producers and the phytoliths obtained from fruit rinds are the most diagnostic. Morphotypic and morphometric studies have been used to discriminate between wild and domesticated *Cucurbita* species, with domesticated fruits often producing much larger and thicker phytoliths (Piperno 2006). Bottle gourd (*Lagenaria siceraria*) is indigenous to Africa, but spread to other continents by the early Holocene, and its large, scalloped phytoliths from fruit rinds have been recovered from early Holocene and later deposits in Central and South America (e.g. Piperno 2011).

Maranta and Calathea (arrowroot and Ilerén, Marantaceae); Canna (Achira, Cannaceae); Manioc (Manihot esculenta, Euphorbiaceae)

These tropical root crops (roots, rhizomes, tubers and corms) are today of minor importance, with the exception of manioc. The plants from the Zingiberales (Marantaceae and Cannaceae) generally produce (abundant) phytoliths that can be taxonomically diagnostic at order, family, genus and species level (e.g. Pearsall 2015a). Manioc, today one of the major root crops of the Americas, is a low silica accumulator (Piperno 2006), but by processing considerable quantities of tissues it was possible to identify silicified secretory bodies in the root rind, leaf, stem and fruit (Chandler-Ezell *et al.* 2006).

Modern comparative approaches

Phytolith studies with an ethnoarchaeological or modern comparative approach started to become widespread from the late 2000s. This type of research concentrates on the analysis of phytoliths—often combined with other proxies—extracted from mod-

ern or historical ethnographic contexts. The aim of these studies is to build strong reference collections of phytolith assemblages produced by specific activities or materials. The rationale, grounded in middle-range theory, is that phytolith assemblages observed in ethnographic contexts can be linked directly to the anthropic or natural activity that produced them, thus offering interpretative values for archaeological and natural assemblages. The main themes in which ethnoarchaeological research on phytolith have been concentrated are:

- 1) The creation of plant and soil reference collections
- 2) Subsistence practices and other plant-related activities, such as crop processing
- 3) Use of space and spatial activities
- 4) The use of non-food plant resources, with a special focus on the identification of dung.

Plant and soil reference collections

Although not normally considered part of ethnoarchaeological research, the creation of reference collections responds to the general aim of creating a middle-range theory approach that help interpreting the archaeological (or environmental) record. Several studies have been devoted to the morphological and morphometric analyses of phytoliths produced by some of the major crops: Triticaceae and Avenae (Ball *et al.* 2009; 2017; Portillo *et al.* 2006); millets and sorghum (Lu *et al.* 2009; Madella *et al.* 2016; Out & Madella 2016; 2017; Tripathi *et al.* 2013; Zhang *et al.* 2011); and banana (Ball *et al.* 2006; Vrydaghs *et al.* 2009). Fewer studies have concentrated on non-domesticated species, focusing on phytolith production in wild grasses (Babot *et al.* 2017; Neumann *et al.* 2017), in dicotyledonous species (Collura & Neumann 2017; Mercader *et al.* 2009) or in a combination of plants (Tsartsidou *et al.* 2007). Reference collections of phytolith assemblages from sediments and soils are also investigated in order to be able to identify past vegetation cover (e.g. Blinnikov *et al.* 2013; Esteban *et al.* 2017; Gomes Coe *et al.* 2017; Iriarte & Paz 2009; Mercader *et al.* 2009). Either directed to the phytolith production of specific species or groups of species, conducted directly on the plants, or of phytolith assemblages representative of a specific vegetation type, these studies form the basis of the correct reconstruction of past plant use and plant cover.

Subsistence practices and plant-related activities

The major advances regarding subsistence practices and plant-related activities, in general, include the identification of the exploitation of wild and garden species (Weisskopf 2016) thereby addressing one of the major problems in archaeobotany, that is the vis-

ibility of so-called ‘alternative resources’. Phytoliths, being both exceedingly resistant to taphonomic alterations and plant-part specific, can be extremely useful in identifying different crop-processing steps. Harvey and Fuller (2005) showed how the *chaîne opératoire* of processing of millets and rice produces phytolith assemblages exclusive for each step. Specific stages of the crop-processing chain can also be investigated: Liu *et al.* (2017) analyse the use-wear effect of phytoliths on lithic tools, an approach that can offer fundamental insights to our understanding of pre-domestication processes. Ruiz-Perez *et al.* (2016) analysed phytolith assemblages from two ethnographic threshing floors, showing that the general pattern of phytolith deposition on the floor mirrored the circular movement of the activity performed.

Spatial analyses of anthropic activities

One of the most novel aspects of phytolith research in ethnoarchaeology is the application of multi-proxy and statistical methods for the identification of spatial distribution of activities. Briz Godino *et al.* (2011) and Zurro *et al.* (2017) use phytoliths in combination with other proxies to detail the formation processes and distinguish between specialized and generic activities in a shell-midden context in Tierra del Fuego. Hunter-gatherer contexts are especially difficult to study as they leave much more scanty evidence on the ground in respect to settled villages. Thus the work by Friesem *et al.* (2016) is particularly important in that it outlines a methodology that allows the identification of activity areas and their maintenance even in hostile preservation environments, such as tropical rainforests. On the other hand, settled farming villages produce assemblages that are much richer and often better preserved so that activities are recognizable at both domestic and village level (Jenkins *et al.* 2017; Portillo *et al.* 2014; Tsartsidou *et al.* 2008; 2009).

Use of non-food resources: dung and mud bricks

Amongst the plant non-food resources, much research has been invested in using phytoliths as one of the proxies for the identification of animal dung. Dung is widespread in archaeological contexts, although it is not always easy to identify as sometimes it leaves ephemeral traces and the most common proxy for dung—spherulites—is not always reliable (Lancelotti & Madella 2012). The correct identification of animal dung is fundamental for the implication that the use of this material has on the interpretation of human behaviour, on the one hand, for the correct identification of husbandry practices and pastoral sites (Elliott *et al.* 2015; Shahack-Gross *et al.* 2003; 2004) and on the other hand, for its importance as a fuel resource in

arid and semi-arid environments, where its presence and constant use can indicate signs of environmental degradation and wood-resource overexploitation. Ethnographic fireplaces have thus been intensively investigated in recent years in order specifically to identify signatures of dung (Portillo *et al.* 2017) or with the aim of discriminating various fuel sources (Friesem *et al.* 2017; Gur-Arieh *et al.* 2013; Lancelotti *et al.* 2017). All of these studies have highlighted the potential of phytoliths, as part of a wider set of proxies and with the right statistical treatment of data, for the identification of fireplaces and fuels, including fuels alternative to wood. Lastly, a few studies have concentrated on the analysis of construction materials, such as mud bricks (Friesem *et al.* 2014; Jenkins *et al.* 2017), to be able to distinguish between the signature left by their degradation and that of other intentional human activities.

Environmental reconstructions and past land use

Phytoliths have been successfully used as a proxy for reconstructing Quaternary vegetations, especially in depositional environments where other organic proxies are poorly preserved, such as alluvial deposits and soils (e.g. Bremond *et al.* 2017; Calegari *et al.* 2017; McMichael *et al.* 2013; Wallis 2001) and rocks (e.g. Strömberg *et al.* 2007). Phytolith assemblages from ancient superficial sediments reflect deposition from local vegetation and therefore local climatic characteristics, making it possible to use them to infer palaeoclimate and palaeoenvironments. However, precise assessment of past environments might be hampered by pre- and post-depositional processes that tend to alter the original plant community production. A diverse set of approaches supported by multivariate statistical methods, such as phytolith indexes (Bremond *et al.* 2005; 2008) and modern analogues analysis (Watling *et al.* 2016), were recently developed partly to solve this problem. The application of these qualitative/quantitative techniques has made it possible to determine which vegetation and environmental factors are dominant in influencing phytolith type distributions and to identify these parameters in the fossil phytolith assemblages on the basis of modern assemblages.

Earth system models help in understanding the earth system as a whole and the drivers of change and assist in envisaging our future. A major research question that cross-cuts the social, biological and physical sciences is to understand the scope of early human land use, the resultant changes in land cover and the consequent feedbacks to climate and human cultural systems during the Holocene and Anthropocene. There remains disagreement over the forms,

scope and intensity of prehistoric land use and the degree to which early anthropogenic land-cover change affected the global climate system. Researchers agree that the intensity and extent of human land use increased during the Holocene, when hunter-gatherer societies gave way to early pastoral and agricultural societies, which in turn increased in complexity. These effects of human land use on terrestrial ecosystems were profound at local to regional scales, but there is uncertainty about how important they were at global scale, and this uncertainty is fostered by the lack of high-quality data-based syntheses of global land use and anthropogenic land-cover change for the last 12,000 years. Phytoliths have been useful in extending on- and off-site high-quality datasets to supply more refined synthesis of land use in areas such as understanding the irrigation of crops (Madella *et al.* 2009), arable land (Golyeva & Svirida 2017), past agricultural systems (Meister *et al.* 2017) and forest management (Levin & Ayres 2017; Levis *et al.* 2017; Nogué *et al.* 2017).

Final remarks

Phytoliths were observed, as part of mineral particles produced by plant tissues, more than 340 years ago, but it was Struve who pioneered the first scientific study in 1835. Research on phytoliths has seen various moments of interest, such as the early works on plant studies and (palaeo)ecology, but it was within archaeology that phytoliths gained momentum and widespread acknowledgement. This ‘popularity’ originates in the new avenues opened by phytoliths to investigate central archaeological questions, with the possibility of identifying previously unrecognizable (or difficult to discern) plants in the archaeological record, as well as human activities (e.g. crop processing). The development and refinement of phytolith systematics and crop identification via a double morphotypic and morphometric approach were major endeavours that stemmed from archaeology. Future advances should look at augmenting the comparative collections available together with their accessibility to researchers and refining the field-sampling approach and laboratory processing to further standardization, and push on the ethnoarchaeology and experimental archaeology work to provide a framework for a better understanding of the relationship between human activities and phytolith signatures.

Acknowledgements

Martin, during his career as an archaeobotanist, has always been a visionary in the field and often engaged

with new developments and research strands. The same happened with phytolith research when he supported both of us working in this new area, and he happily embarked on helping develop what came to be the next generation of archaeobotanical proxies. During our doctoral research, he was a constant optimist, even when we could not see ‘the light’ of our work, as well as the instigator of many parties, including those with dance lessons!

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Chapter 5

Genetics and the Origins of European Agriculture

Terry Brown

I first met Martin Jones on 21 March 1990 at a conference in Glasgow organized by the Natural Environment Research Council (NERC) as part of its 'special topic' in Biomolecular Palaeontology. This research programme, which had been set up a couple of years earlier, funded a series of projects in UK universities on what at the time were referred to as 'fossil molecules'. When the special topic was planned, the emphasis had been on the use of long-lived biopolymers, derived from lipids and carbohydrates, as biochemical markers in the geological record. However, the research programme coincided with the explosion of interest in ancient DNA, engendered by the first demonstrations, by Erika Hagelberg, Catherine Hänni and others, of preserved DNA in archaeological bones (Hagelberg *et al.* 1989; Hänni *et al.* 1990). Thanks in large part to the perceptiveness of Geoffrey Eglinton, the Chairman of the Biomolecular Palaeontology steering group, the research programme expanded its objectives and funded three grants on ancient DNA, one of which Keri Brown and I were fortunate enough to receive. So on a cold and wet March day Keri and I, along with 70 other delegates, made our way to Glasgow. Exciting times! This was our first opportunity to meet other researchers interested in ancient biomolecules.

Ancient DNA from charred grain

The final hour of the Glasgow conference was given over to a discussion session, about which I remember very little, except that at various points I contributed a comment that came to my mind. Every time I said something the person sitting in front of me turned around, nodded and smiled, which I found very encouraging as I had spent most of the day feeling rather nervous and overwhelmed by the great names (Svante Pääbo, Brian Sykes and others) who were in the audience.

At the end of the session the gentleman in front introduced himself as Martin Jones, senior lecturer in archaeology at Durham University, but shortly to

move to a 'new job' at Cambridge. Martin asked me if I thought I could get DNA from the 'carbonized grains that archaeobotanists study'. I had no idea what these grains were, but those were the heady days of ancient DNA when anything was possible, so of course I said yes. Martin looked excited and asked if Keri and I would like to come over to Durham to discuss a possible project with him.

At Durham, Martin showed me some carbonized emmer grains. My heart did sink rather as they did not look promising as sources of DNA, but Keri had recently had some success in detecting DNA in cremated bone, so the fact that these grains had clearly been exposed to high temperatures did not seem an immediate reason to become gloomy. More importantly, over lunch, Martin gave me a synopsis of the origins and spread of agriculture, a topic that was completely new to me. Although I had been a plant geneticist in my pre-ancient DNA lifetime, my interests now were firmly fixed on bones, and the grant Keri and I had been awarded was intended to lay the groundwork for genetic studies of artiodactyl evolution by developing methods for DNA extraction from fossil horse bones (heady days indeed). In one hour, Martin reset my research agenda and stimulated my subsequent lifelong interest in single *versus* multiple domestications, trajectories of agricultural spread, the development of sustainable agriculture and the role of food in human society. I was totally hooked.

The next thing was to get some money to study the DNA that we both knew just had to be present in carbonized grain. We decided that the first thing was to stop referring to the grains as 'carbonized', as this implied complete conversion to carbon and hence no DNA. Martin suggested that 'charred' would be a better term. The NERC Biomolecular Palaeontology programme was no longer accepting new proposals, so we submitted our grant to the Science-Based Archaeology committee of the Science and Engineering Research Council (SERC). This was not as daunting as it might have been, as Martin was a member of this committee and so knew what was likely to interest

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DANE1  GATTACGTGGCTTTAGCAGACCGTCCAAAAATCTGTTTTGCAAAGCTCCAATTGCTCCTTGCTTATCCAGCTTCT
5 (X)  .....T.....

DANE1  TTTGTGTTGGCAAACCTGCGCTTTTCCAACCGATTTGTCTTCTCGCGCTTTCTTCTTAGGCTAAACAAACCTCA
5 (X)  .....

DANE1  CCGTGCACGCAGCCATGGTCCTGAACCTTCACCTCGTCCCTATAAAAGCCTAGCCAACCTTCACAATCTTATCAT
5 (X)  .....

DANE1  CACCCACAACACCGAGCA
5 (X)  .....

DANE2  GATTACGTGGCTTTAGCAGACCGTCCAAAAATCTGTTTTGCAAAGCTCCAATTGCTCCTTGCTTATCCAGCTTCT
SILENT .....

DANE2  TTTGTGTTGGCAAATGCTCTTTTACAACCTGACTCTATTCTTCTGTGTTTCTT---AGGCTGAACCTAACATCAC
SILENT .....T.....T.....CTT.....

DANE2  CCGTACACACAACCATTTGTCACGAACCTTCACCACGTCCCTATAAGAGCCCAACCAATCCCCACAATCTCATCAT
SILENT .....T.....A..A.....

DANE2  ACCCACAACACCGAGCA
SILENT .....

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Figure 5.1. The first ancient DNA sequences obtained from charred grain. The two sequences DANE1 and DANE2 were obtained by Robin Allaby from charred spelt wheat from Danebury, dated to the second half of the first millennium BC. The sequences are compared with the most similar of six sequences for modern glutenin genes that were known at the time, with dots indicating identities. Ancient DNA aficionados will note that most of the dissimilarities are C to T changes, which we now know to be damage artefacts typical of ancient DNA. (After Allaby et al. 1994, with permission.)

them. My contribution to the application was devising primers for polymerase chain reactions (PCRs) that would amplify three short segments of the wheat genome and describing a few standard methods for plant DNA extraction that we would tweak to deal with ‘inhibitors’. Martin wrote the rest of the proposal and produced a masterly argument that the benefits of being able to study DNA in charred wheat and barley grain were so immense that the grants panel would be foolish not to invest the meagre sum we were requesting simply on the basis that we could not provide any evidence at all that we could get DNA from these grains. I then went on study leave for six months at Washington State University in the USA. I heard that SERC had one of its periodic cash-flow problems, so there would be a 12-month delay before any new grants could begin. Martin’s message a few days later that we had got the grant delighted me, though his reference to ‘SERC being on ice’ rather puzzled my American colleagues.

Successful research requires both a good project design and a good person to do the work. With regard to the latter, Martin and I struck gold. Among the applicants for the RA position was a recent graduate from Kings College London called Robin Allaby. Robin’s enthusiasm and innovation were exactly what

we needed for this project. In those days, the now routine methods for the clean-up of ancient DNA extracts and optimization of very short PCRs for ancient DNA amplification were in their infancy. Starting from that almost zero knowledge base, Robin designed a system based on amplification of a short region of the multi-copy glutenin genes and carried out the first successful PCRs with ancient DNA from charred grain, using spelt wheat from the Iron Age hillfort at Danebury (Allaby *et al.* 1994; Fig. 5.1).

Single versus multiple origins of agriculture

Following the Danebury project, the next stages in the study of charred grain in my own lab were carried out with Martin’s indirect, rather than direct, involvement. With typical self-sacrifice, Martin had taken on the role of Chairman of the Steering Committee of the NERC Ancient Biomolecules Initiative (ABI), which funded virtually all of the biomolecular archaeology carried out in the UK during the mid 1990s, during that crucial period when the subdiscipline became established as a leading part of science-based archaeology. As Chairman of the Steering Group, Martin was barred from making applications to the ABI himself, as either principal or co-investigator, and we therefore

had to shelve plans to continue our work on ancient DNA. Instead, the two grants that I received from the ABI were joint with Glynis Jones of Sheffield, another archaeobotanist with whom I have enjoyed a productive and lengthy collaboration.

Despite Martin's involvement in the ABI, he and I did not stop working together, and my ideas about biomolecular archaeology continued to benefit from Martin's insights and encouragement. During this period—the mid-1990s—our discussions increasingly moved away from ancient DNA to the events which occurred during the origins of agriculture. At this time there was a growing movement, led by Daniel Zohary and others, in support of a model in which each of the founder crops of Near Eastern agriculture had been domesticated just once, with the possible exception of barley, for which two distinct mutations conferring the loss of ear shattering had been identified in the cultivated population, implying two separate domestications. As a geneticist, I struggled with the apparent simplicity of this domestication scenario, and in particular with the corollary, as I saw it, that the early version of a crop would have to be kept isolated from wild populations of that plant, to avoid cross-hybridization which would lead to the crop losing the domestication traits and reverting to the wild phenotype. Martin suggested that fixation of the domestication traits might occur only when early farmers moved away from areas where the wild plants were abundant. This 'edge effect' would certainly allow the domestication traits to become fixed quite rapidly, but implied that there was a preceding period during which early farmers were cultivating plants within the range of the wild population, those early cultivated forms having a wild 'pre-domesticated' phenotype. Martin also described to me a variety of ways in which humans could intervene in the life histories of their wild food plants to make these more productive, by weeding, soil improvement and so on, during stages before more sophisticated cultivation practices emerged. I gradually became convinced that the transition from gathering to agriculture had been a complex process, with many centuries elapsing between the first interventions into the growth of wild plants and the final emergence of a fully domesticated crop, and with the possibility of parallel processes, involving the same or different crops, occurring at the same time in different parts of the Fertile Crescent.

Having become convinced that agriculture emerged via a protracted and dispersed process, I was galvanized by a report in *Science* in November 1997, from Francesco Salamini's group at the Max Planck Institute in Cologne, that suggested quite the opposite (Heun *et al.* 1997). Using state-of-the-art

genotyping methods, Salamini's group had acquired data on the genetic diversity of a large collection of einkorn landraces and wild accessions, and shown by phylogenetic and population genetic analyses that all cultivated einkorns derived from a single domestication event that took place in the Karacadağ mountains of southeast Turkey, well within the natural range of wild einkorn. Although careful not to extrapolate beyond the origins of cultivated einkorn, the paper provided clear support for a rapid and localized origin of agriculture in southwest Asia, and the final statement of the paper, that 'one single human group may have domesticated all of the primary crops in the region', was quickly taken up by commentators and popular-science writers.

The notion that an enlightened group of humans invented agriculture 10,000 years ago captured the popular imagination. A suggestion by Martin, Robin and me, published in *Science* in January 1998, that the earliest archaeobotanical evidence for einkorn cultivation was not in Turkey, but 800 km to the south at Jericho, Netiv Hagdud, Gilgal and Aswad (M. Jones *et al.* 1998), was swatted down rather offhandedly by Salamini in a response that I still do not fully understand, but which seemed to say that we were perfectly correct but it didn't matter because the genetics cannot be wrong. As a geneticist I was much less confident of the pre-eminence of my discipline as a tool for answering complex questions.

Of the three of us, Robin was the one who was most convinced that the data analysis in the einkorn paper, and in the following papers from Salamini's lab on barley and tetraploid wheats (Badr *et al.* 2000; Özkan *et al.* 2002), which reached similar conclusions, were flawed. Robin embarked on a heroic series of computer simulations of increasing sophistication, which showed that a crop derived from two or more parallel domestications can appear to have a single origin, if events such as gene flow within the crop are not taken into account when the genetic data from landraces are analysed. As Robin was doing this work, Martin and I explored further the genetic and archaeological evidence in support of different models for agricultural origins, in a series of reviews and book chapters (Jones & Brown 2000; 2007; M. Jones *et al.* 1996) that culminated in a 2009 article in *Trends in Ecology and Evolution* (Brown *et al.* 2009), in which we brought together various strands of research to argue that the transition from hunting-gathering to agriculture in the Fertile Crescent should be looked on as a protracted and multi-regional process, and that 'we should view the first attempts by humans to manage their wild plant resources as the initial step on a lengthy and unbroken path that continues today

with our scientifically informed programmes of crop improvement’.

The adaptation of crops to new environments

At the same time as we were arguing for a protracted origin of agriculture, Martin and I were also exploring new ideas regarding the spread of agriculture away from the Fertile Crescent and into Europe and Asia. We became interested in the idea that phylogeographic methods that had been developed to study, for example, the past expansion of plant populations out of glacial refugia might be applied to the spread of a crop during the Early Neolithic. We were not so much interested in the trajectories of spread, as those had been mapped in some detail from the more conventional archaeological record, but we wondered whether those trajectories were accompanied, and possibly influenced, by genetic adaptation of the crop plants to the new environments to which they were taken.

Initially these were just speculations, but in 2002 I saw an opportunity to put together a grant application that would allow us to test our ideas. Martin had begun a nascent collaboration with the crop geneticists at NIAB, a plant science institute in Cambridge. During the summer of 2002, Mim Bower, one of Martin’s postdocs, visited Manchester with Huw Jones and Lydia Smith of NIAB to talk about new project ideas. Specifically, they were interested in ‘bere’, a type of barley grown in Orkney, which was thought to have been brought to northern Scotland by the Vikings. NIAB had the equipment and expertise for high throughput genotyping of multiple crop accessions, so would I be interested in applying phylogeographic methods to test the hypothesis that bere originated in Scandinavia? The short answer was no; at that time I was not particularly turned on by the bere question (though more recently I have returned to it in collaboration with Peter Martin of Orkney College). However, I was interested in a more ambitious project in which we used NIAB’s genotyping skills to obtain data from barley from across Europe, to address some of the questions Martin and I had been discussing. This would be a large project, and to fund it we would need a larger-than-normal NERC grant. We brought Glynis Jones and Mike Charles of Sheffield into the discussions, and wrote a four-partner consortium grant, somewhat mischievously entitled ‘The Domestication of Europe’, which we submitted to NERC in 2003. Initially it seemed a very long shot, as NERC only awarded two or three such grants per year, and we were uncertain if biomolecular archaeology would be sexy enough in competition with grants addressing climate change, volcanoes, tsunami

and suchlike. But all of our ideas fell into place, the reviewers were tough but fair and our responses robust and, thanks to Martin, ‘professorial’ in the way they were phrased. To cut a long story short, we got the grant.

So began one of the most enjoyable phases of my research career. Shortly after we began the project, Wayne Powell took over as Director of NIAB, and identified our project as one of the most interesting things that NIAB was doing at that time. Our regular consortium meetings, with Martin, Wayne, Glynis and Mike tossing ideas to and fro across the table, were stimulating in the extreme, and the data generated at NIAB, Cambridge and Sheffield came together into a splendid synthesis of dating, archaeobotany and genetics. My own strand at Manchester, on ancient DNA, was less successful, but I had the compensation of coordinating the writing of several of the papers that emerged from the project. The most interesting of these, from my viewpoint, was the work led by Huw Jones on sequence diversity of the *Ppd-H1* gene, one of the central genes involved in the barley flowering-time response (H. Jones *et al.* 2008). Wild plants in the Fertile Crescent flower early in the year, so seeds can be produced before the weather gets hot and the plants die. Some types of cultivated barley, on the other hand, have a mutated version of *Ppd-H1* that knocks out the flowering-time response, so these plants do not flower until later in the year, a benefit in northern Europe where the growing season is longer. Huw showed that landraces are distributed on a north–south cline across Europe, early-flowering plants with the wild-type version of *Ppd-H1* predominating in the south and late-flowering plants with the mutant gene in the north. As the mutant gene appeared to be absent in wild barley, the implication was that the mutation giving rise to the late-flowering phenotype occurred in the crop somewhere in Europe, correlating perhaps with the apparent pause that occurred as agriculture moved northwards across the Hungarian plain. Huw and I drafted a *Nature* paper, but before we had time to circulate this to the other consortium members, Huw typed *Ppd-H1* in a new set of wild barleys that he had obtained from the Vavilov Institute. A small number of these, mainly from elevated regions of the Zagros Mountains, contained the mutant version of the gene. If anything, this made the story even more intriguing, the implication becoming that the late-flowering version of barley spread to northern Europe not during the Neolithic, but at some later period, and possibly not via Anatolia, as was the case with the Neolithic spread of agriculture, but along a trajectory to the north of the Black Sea. Late flowering can therefore be looked on as an innovation that occurred well

after agriculture had become established in Europe, further emphasizing the unbroken nature of the crop improvement carried out by humans from the earliest interventions into the life histories of wild plants through to the present day.

The multidisciplinary approach to the human past

Over the last 20 years, genetic approaches, using both modern and ancient DNA, have assumed centre stage as a means of addressing a variety of archaeological questions. This is particularly true with work on human DNA, where extensive analysis of genotypes and genome sequences from modern human populations, supplemented in recent years with an explosion of ancient genomic data, has resulted in a rich narrative of the trajectories of human evolution and migration since the Palaeolithic. This has led to equally intense debate about some of the conclusions emerging from these genetic studies, in particular the occasional divergence between these conclusions and the interpretation of the past as revealed by archaeological research. An underlying theme is the extent to which there is productive discussion between geneticists and archaeologists, as suggested by Volker Heyd, who has written that ‘rather than simply handing over samples and advising on chronology, and instead of letting the geneticists determine the agenda and set the messages, we should teach them about complexity in past human actions and interactions’ (Heyd 2017, 357). Volker’s frustrations were prompted by two ancient DNA studies of Bronze Age Eurasian populations, but the lack of interaction between archaeologists and geneticists studying human DNA is arguably more general: one recent paper that uses ancient human DNA to infer the demographic structure of early farmers in the Near East cites a single book (admittedly a very good one) as a token reference to the vast archaeological literature on agricultural origins.

There has also been a huge proliferation of genetic studies of crop origins and evolution since Salamini’s ground-breaking work and since our own initial studies of the evolution of the flowering-time phenotype in cultivated barley. But those of us working in this area, whether geneticists or archaeologists, are much less aware of a divide between the contributions that our differing approaches are making to the growing development of knowledge and ideas. Studies of crop origins are revealing complex relationships between cultivated and wild populations of barley and wheat, and similar conclusions are being drawn for rice, maize and other crops from areas of the world other than the Fertile Crescent. The conclusions of these studies are, however, tempered by

reference to archaeobotanical data and to the results of broader archaeological research, and many of the papers that are published have a multidisciplinary authorship. The same is true of the burgeoning work that is being done on *Ppd-H1* and other genes involved in the annual circadian cycles of crops, as well as on genes underlying adaptations to environmental challenges such as drought and high temperature. Plant geneticists look on these genes as the key players in breeding programmes aimed at generating new varieties of crops that are resilient to future climate change. In order to understand how to manipulate these genes to tackle climate change, crop geneticists are increasingly examining how the genes evolved in the past, during and after the initial domestication of the crop. The multidisciplinary nature of this work ensures that the information provided by archaeology on the past development of agriculture is informing present-day attempts to breed crops to combat future climate change.

For me, the multidisciplinary debate that has accompanied my research activities over the last 30 years has been stimulating, challenging and hugely enjoyable. Central to this debate has been Martin Jones, whose own views on the importance of multidisciplinary, not just in studies of early agriculture but in all areas of biomolecular archaeology, has influenced an entire generation of researchers. Martin has therefore been one of those pivotal figures who has driven his research fields forward not just through the generation and interpretation of data, but also by guidance and direction as to how research should be carried out. In this way, his influence goes far beyond those subjects in which he has been directly interested, and extends now to the growing areas of research populated by his past students and postdocs, and by his academic colleagues.

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Chapter 6

Martin Jones' Role in the Development of Biomolecular Archaeology

Terry Brown, Richard P. Evershed & Matthew Collins

Martin Jones's many research interests, in particular his contributions to our understanding of early agriculture, the changing role of food in prehistory and the development of agrarian societies, are well known, as documented by the various articles in this Festschrift. Those of us who have been around since the early years are also very much aware of the crucial role, arguably as important as his academic work, that Martin played in the establishment of biomolecular archaeology as a credible sub-discipline of science-based archaeology, both nationally and internationally. Many of us owe our careers to funding initiatives that Martin conceived, lobbied for and managed, and without his early guidance biomolecular archaeology today would be a much less vibrant area of research, and there would certainly be many fewer of us biomolecular archaeologists.

Archaeological scientists have studied preserved biomolecules since the early decades of the twentieth century, but during the late 1980s developments in analytical methods for the detection and identification of DNA, proteins and lipids gave a sudden impetus to the field. In the UK, the Science-Based Archaeology committee of the Science and Engineering Research Council (SERC), which Martin chaired, funded several projects using these new techniques, and the Bio-molecular Palaeontology initiative of the Natural Environment Research Council (NERC), which ran from 1989 to 1993, supported some of the earliest ancient DNA investigations. The researchers leading these projects came from varied backgrounds, including chemistry and genetics, as well as archaeology and palaeontology. What they shared was a common interest in ancient biomolecules and how these molecules could be used to enhance our understanding of the past.

In 1992, Martin met with Geoff Eglinton, the revered organic geochemist from Bristol University who was Chairman of the Biomolecular Palaeontology Steering Group, to discuss how this fledgling community of ancient biomolecules researchers could best

be supported. In *The Molecule Hunt*, Martin says, with masterly understatement, 'born out of that meeting was a programme that the UK's Natural Environment Research Council put in place ...'. That programme was the Ancient Biomolecules Initiative (ABI), to which NERC committed the massive, for those days, sum of £1.9 million (in comparison the Biomolecular Palaeontology programme was just £629,000). Getting NERC, or any funding body, to commit such a large amount of money was no easier in 1992 than it is now, and Martin's phrase 'born out of that meeting' refers to the delicate and protracted process by which concept notes, outline bids and a full bid were meticulously drafted, modified, presented to various NERC committees, defended, redrafted and resubmitted. Think normal grant application, but ten times more complex.

The ABI was a tremendous opportunity for UK research. It was also an opportunity that could have gone spectacularly wrong. The early 1990s were, in some respects, dark days for ancient biomolecules. This was most obviously true for ancient DNA, a series of impossible claims for million-year-old DNA culminating in a report concerning a 130-million-year-old weevil, whose liking for dinosaur blood was unknown, but which *Nature* published the day after the premiere of *Jurassic Park* in the USA. Ancient DNA was in danger of becoming a laughing stock (it was described in such terms to one of us by a very eminent British cell biologist at the time). Studies of ancient proteins and lipids were facing their own challenges, with high-profile papers reporting the use of unproven immunological methods to 'identify' proteins (often supposedly from human blood) on archaeological artefacts, and inappropriate low-resolution and insensitive chemical methods being employed to make equally unsupported 'identifications' of small molecules in archaeological residues.

It was essential that the ABI funded real science, and as such it needed strong leadership. This was provided by Martin Jones, who became Chairman of the Steering Committee, and Geoff Eglinton, who acted

as Programme Manager. They were unquestionably the best two people to lead the ABI, and looking back it might seem obvious that Martin and Geoff took on those roles. Together they possessed not only a vision for where the ancient biomolecules field might lead archaeologically and palaeontologically, but also a deep appreciation of the scientific rigour that was necessary to ensure that credibility was maintained. However, it is easy to forget that Martin and Geoff's roles involved a tremendous self-sacrifice: as the Chairman and Programme Manager, they were not allowed to apply for funding from the programme, and Martin in particular was forced to withdraw from the productive collaborations that he had previously set up, notably on ancient DNA from charred grain.

Many of us who were involved in the ABI look back on that period as among the most stimulating years of our research careers. Through judicious use of the money made available by NERC, the ABI funded 18 projects between 1993 and 1998 (Table 6.1a), involving 31 principal investigators and 21 postdoctoral and postgraduate researchers. The postdocs and postgrads included Robin Allaby, Martin Richards, Oliver Craig, Angela Gernaey, Colin Smith and others, who formed a new generation of young biomolecular archaeologists. The projects covered the full scope of ancient biomolecules research, and importantly included major studies into the processes responsible for decay of DNA, proteins, lipids and carbohydrates under different environmental conditions, thereby giving credibility to the field as a whole, and making major strides towards defining what was and was not possible in terms of biomolecular preservation and establishing the right and wrong techniques to use to investigate different classes of biomolecule. Annual Meetings of Principal Investigators and Research Associates were held every January in Cambridge and workshops devoted to specialized topics were organized at various other times (Table 6.1b). Throughout the programme, Martin was a continual source of energetic encouragement, guidance and stimulation, his insistence that everything that was presented should make sense to every person in the audience, regardless of their background and specialization, forcing all of us continually to evaluate the rationale and purpose to our projects.

As well as being a research success, the ABI had a major impact on NERC, which had acquired responsibility for science-based archaeology from SERC in the early 1990s but initially did not know what to do with it. The 200 delegates who attended the grand finale of the ABI—a one-day symposium at the Natural History Museum on 7 January 1998—included the Chief Executive of NERC, along with several Council members, who were genuinely enthused by what the

programme had achieved. By now Martin had joined NERC's Terrestrial and Freshwater Strategy Board, as well as the Science-Based Archaeology Strategy Group, and his influence, along with the success of the ABI, kept ancient biomolecules high in NERC's line of sight. Funding for science-based archaeology has never been easy to obtain in the UK, or anywhere else for that matter, but biomolecular archaeology consistently punched above its weight during the late 1990s and 2000s.

Through the ABI, Martin therefore helped to establish the careers and research groups of many of the now-senior members of the UK biomolecular archaeology community. But this is not the end of the story. As early as 1993, Martin had been exploring other sources of programme funding for science-based archaeology in general and biomolecular archaeology in particular. In 1994–5, as the NERC initiative was entering its final phase, Martin approached the Wellcome Trust (WT). The Trust was funding the History of Medicine, but Martin convinced Gavin Malloch, scientific programme officer at WT, and his colleagues to fund a 10 year programme in bioarchaeology, which ran from 1996–2006. Initially, many of us in the field thought that, taking account of the WT's interest in human disease, the bioarchaeology programme might be focused specifically on palaeopathology, which at that time was an important but not predominant part of biomolecular archaeology. Martin, however, successfully argued for a broad definition of human health, which encompassed areas as diverse as diet and domestication, and continued to promote this agenda during his period as Chairman of the Bioarchaeology funding panel. The WT programme therefore became happily structured so as to build upon the previous achievements of the Biomolecular Palaeontology and Ancient Biomolecules initiatives.

A key feature of the WT programme was a focus on individuals as well as projects. The programme funded a large number of PhD students, a smaller number of fellowships for postdoctoral researchers, and a select number of University Awards, which gave senior researchers five years of funding to be followed by a full-time position. Individuals who were supported by the programme included Alan Cooper, Mike Richards, Keith Dobney, Tamsin O'Connell, Jessica Pearson, Stephen Buckley, Hannah Koon and Kirsty Penkman, and through them biomolecular archaeology has benefitted from the emergence of a second group of research leaders including Eske Willerslev, Tom Gilbert, Ian Barnes, Greger Larson, Mike Bunce, Rhiannon Stevens and Beth Shapiro.

Martin was therefore directly responsible for both the initial establishment of biomolecular archaeology in the UK during the 1990s and the subsequent

development of the field during the 2000s when many of today's research stars were trained in UK laboratories. Those of us who began our careers way back in the 1980s never could have imagined how lucky we were that Martin Jones, Geoff Eglinton, Gordon Curry and others would together convince a range of

different funding agencies to support two decades of research into ancient biomolecules. The result has been a significant new community of academics, pioneers of different aspects of ancient biomolecule research, who promise to remain at the international forefront of the field for years to come.

Table 6.1. (a) Projects and (b) Workshops funded by the NERC Ancient Biomolecules Initiative (1993–1998).

(a) Projects	
D. Briggs & R. Evershed (University of Bristol)	Animal cuticles in the fossil record: organic preservation
T. Brown & G. Jones (UMIST, Manchester & University of Sheffield)	Using ancient DNA to distinguish between tetraploid and hexaploid wheats
T. Brown & G. Jones (UMIST, Manchester & University of Sheffield)	Using ancient DNA to distinguish between single grains of tetraploid and hexaploid wheats
M. Collins (University of Newcastle)	Understanding the causes behind the diagenetic stability of the bone protein osteocalcin
M. Collins, R. Hedges & M. Riley (University of Newcastle & University of Oxford)	Improving the analysis of ancient collagen, testing a mathematical model of collagen degradation
M. Collinson, P. Finch & A. Scott (Royal Holloway University of London)	Plant cuticles in the fossil record: diversity, evolution, and preservation of resistant biomacromolecules
G. Dover, G. Barker & A. Grant (University of Leicester)	Ancient and modern genetic signatures of animal breeding and management in Britain from prehistoric times
W. Grant & T. McGenity (University of Leicester & University of Reading)	Use of molecular techniques to investigate possible long-term dormancy of halobacteria in ancient salt deposits
E. Hagelberg (University of Cambridge)	The study of prehistoric migrations using DNA markers from archaeological bone
E. Hagelberg (University of Cambridge)	Improved methodologies for the analysis of DNA from human and animal bones
I. Head, K. Farrimond & R. Pickup (University of Newcastle & Institute of Freshwater Ecology, Windermere)	Molecular records of bacterial contributions to sedimentary organic matter
A. Lister & H. Stanley (University College London & Institute of Zoology, London)	Ancient and modern DNA from a variety of sources in a study of horse domestication
J Parkes, J Maxwell and R Evershed (University of Bristol)	Why do readily biodegradable organic compounds survive to be preserved as ancient biomolecules?
S. Rowland (University of Plymouth)	Quantitative composition of ancient sedimentary organic matter (OM) and relationship to bacterial necromass
C. Shaw & P. Rowley-Conwy (University of Durham)	The genetic differences underlying morphological divergence in early <i>Sorghum</i>
A. Smith, R. Thomas & R. Fortey (Natural History Museum, London)	The search for geologically ancient DNA from amber entombed insects
H. Stanley & J. Wheeler (Institute of Zoology, London & University of San Marcos, Peru)	New World camelid domestication and pre-Spanish llama and alpaca breeds
B. Sykes & R. Hedges (University of Oxford)	Investigating prehistoric human lineages
(b) Workshops	
Ancient DNA Workshop (organizer: B. Sykes)	Part of <i>Ancient DNA III</i> , Oxford, 22 July 1995
Ancient DNA in Cattle (organizer: G. Dover)	Leicester, 30 October 1995
Ancient Protein (organizer: M. Collins)	Newcastle, 18 December 1995
Biopolymers and Lipids (organizer: R. Evershed)	Bristol, 19–20 June 1996
Microbial Signatures in the Sedimentary Record (organizer: W. Grant)	University of Leicester, 2–3 September 1996
Ancient Seeds (organizer: T. Brown)	UMIST, 6 May 1997

Part III
The Stomach and the Soul

Chapter 7

'Rice Needs People to Grow it': Foraging/Farming Transitions and Food Conceptualization in the Highlands of Borneo

Graeme Barker, Christopher O. Hunt, Evan Hill, Samantha Jones
& Shawn O'Donnell

Introduction

At the transition from the Pleistocene to the Holocene 11,500 years ago, most of the world's population lived by various combinations of hunting, fishing and gathering. By 5000 years ago a wide variety of agricultural systems had been established in the Americas, Africa and across Eurasia (Barker 2006). Though examples of sedentism, population increase, systems of inequality and conflict, separately and in combination, can all be observed in the hunter-gatherer archaeological record, these are still mostly first evident with the development of food production. Today, most of the world's 7 billion people rely on a small number of crops as their food staples: maize, rice, wheat, potato, cassava and sorghum (in descending order of annual tonnage). Only five large (over 50 kg) domestic animals are globally important: cow, sheep, goat, pig and horse. From this perspective the development of agriculture was clearly a genuine revolution in human history, in many respects the most important. All too frequently, however, despite the major successive theoretical movements in which the beginnings of farming have been studied since V. Gordon Childe (culture history, processual archaeology, post-processual archaeology, etc.), and the extraordinary parallel developments in archaeological science, the debates have remained obstinately beset by notions of 'linear progress' that would be familiar to the Victorian antiquarians and archaeologists who first proposed pathways of human progress from savagery to civilization. Though a range of different scenarios have been proposed, with foragers variously being 'pushed' or 'pulled' into food production by factors such as climate change, population pressure, contact with agriculturalists and/or internal social competition, the arguments have been predominantly based,

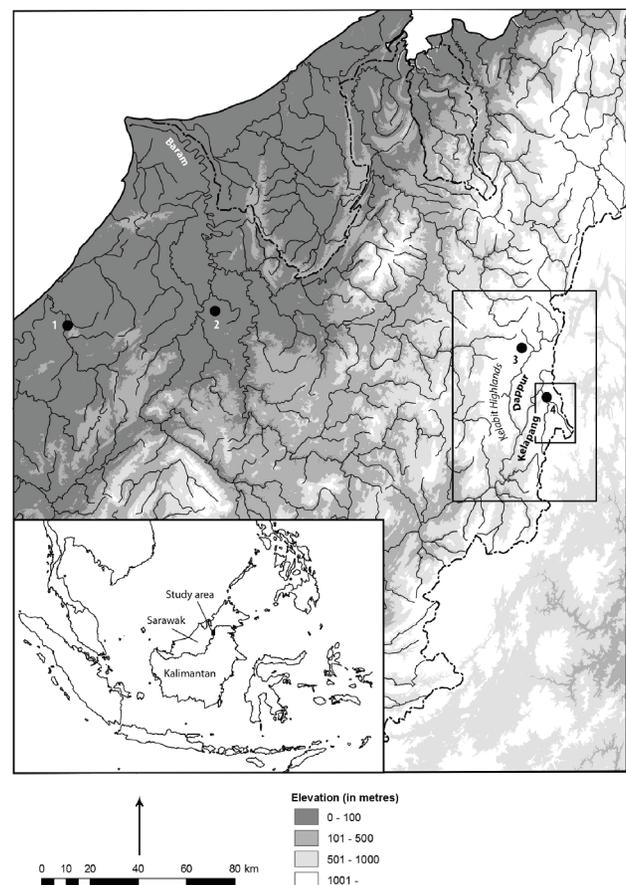


Figure 7.1. Borneo, showing the location of the Kelabit Highlands and other locations mentioned in the text: (1) Niah Caves; (2) Loagan Bunut; (3) Bario, northern Kelabit Highlands; (4) Upper Kelapang Valley, southern Kelabit Highlands. (Illustration: Lucy Farr & Chris Hunt.)

in the Old World especially, on the assumed economic value of the new resources as food staples. By contrast,



Figure 7.2. *Penan encampment in the Baram valley. (Photograph: Monica Janowski, reproduced with her kind permission, and permission from the McDonald Institute.)*

whether writing about Palaeolithic diets in Europe, or early farming in Europe or China, or the diets of later societies, Martin Jones has consistently emphasized the cultural as well as economic value of food, with the meal being the major locus of social interactions, past and present (e.g. M. Jones 2007). In this contribution, we explore how these themes intersect in the rainforest lives of Island Southeast Asians, present and past, taking as our main case study the Kelabit Highlands of interior Borneo.

The Kelabit Highlands and their present-day inhabitants

The Kelabit Highlands straddle the present-day border between Malaysian Sarawak and Indonesian Kalimantan (Fig. 7.1). Tributary rivers form on the Sarawak side that drain westwards and southwestwards to form the Baram River that eventually flows into the

South China Sea at the border between Sarawak and Brunei. The river valleys, mostly between 1000 m and 1500 m above sea level, are the most inhabited parts of the Highlands, surrounded by mountains that rise to almost 2500 m above sea level.

The region today is occupied by two main tribal groups, the Penan and the Kelabit. In recent decades the Penan, who number some 16,000 people, have been actively encouraged by the Malaysian government to settle down and engage in cultivation, including rice cultivation. Traditionally, however, they were (and a few hundred still are) foragers or hunter-gatherers who practised residential mobility: small family groups of men, women and children moved together every few weeks from camp to camp in search of food (Brosius 1991; 1999; Nicolaisen 1976; Sellato 1994; Urquhart 1959). Their camp-sites were ephemeral, consisting of flimsy roofed shelters mostly without walls (Fig. 7.2).



Figure 7.3. Kelabit longhouse at Pa'Daleh, southern Kelabit Highlands: (above) external view showing the family structures attached to the main communal area and (below) internal view showing the communal area and the family hearths on the right. (Photographs: Graeme Barker.)

During their seasonal cycle of mobility, the Penan collected a wide range of edible plants, but obtained most of their carbohydrates by extracting starch from the sago palm *Eugeissona utilis* (Brosius 1991). Cut stems were pounded to a mash and this was then washed on matting at a stream to produce a kind of dough. The trees were carefully managed by thinning branches and clearing competitor vegetation, a system of protection or management that the Penan termed *molong* ['stewardship' or 'caring for']. The Penan also hunted a wide range of animals with dogs and (before the advent of guns) spears and blowpipes, the most valued prey being the bearded pig (*Sus barbatus*), which could sometimes be killed in numbers during their movements through the forest in search of fruiting trees. Other favoured game included sambar deer (*Cervus unicolor*) and barking deer (*Muntiacus muntjac*). Traditionally the Penan also traded forest products such as baskets, rattan mats, *dammar* resin from dipterocarp trees, bezoar stones from monkey intestines, rhinoceros horn, camphor and hornbill feathers for metal, cloth, salt and tobacco, obtained from neighbouring agriculturalists.

The Penan term for forest, *tana'*, refers to the entire forest world of which they are a part, a forest animated by spirits that need nurturing (and sometimes appeasing) through *molong*. They take care only to leave footprints (*uban*) in the forest as a record of their passing, marks or pathways through the forest that, though ephemeral in the literal sense, endure in memory from generation to generation as evidence of their continued 'belonging' to the forest (Janowski & Langub 2011, 121).

The Kelabit are one of the smallest ethnic groups in Sarawak, numbering only about 6600 people, most of whom have migrated to the coastal towns such as Miri in recent decades; many work in the off-shore oil industry, for example. Only about 1500 Kelabit still live permanently in the Kelabit Highlands, though urban Kelabit frequently visit their family villages, a journey made far easier in the past 15 years or so by the construction of logging roads into the interior. The Kelabit live in small communities of about 100 people in substantial timber longhouses, usually two or three per settlement (Fig. 7.3). Each longhouse is divided into a public area (*tawa'*) with sleeping spaces for separate families (*telong*) down its side, each family's private space fronted by a substantial cooking hearth (Janowski 2003). The Kelabit grow rice, both wet rice on bottomland paddies and hill rice on cleared swidden fields that are used for a few years and then left to revert to secondary forest. They also grow a range of vegetables and fruits, and keep chickens, pigs and buffalo, but they derive much of their fruit and

vegetables by gathering in the secondary forest (the 'women's forest') and most of their meat by hunting, the latter especially in the untouched primary forest or 'men's forest' reserved for hunting so game is not scared away. Before the availability of metal sheets for roofing, the Kelabit used sago leaves for thatch, and they eat sago shoots as a vegetable, but they do not process sago for its starch like the Penan, nor practise *molong* of forest resources.

In her 1980s study of the Kelabit community of Pa'Dalih in the Upper Kelapang Valley in the southern Highlands (Fig. 7.1: site 4), Janowski (2003) described their social relations as 'rice-based kinship', with the thrice-daily rice meal creating the appropriate hierarchical relations between parents and children. Rice and rice growing were also the key signifiers of status: those who provided food for others in the community, most commonly in the 'hearth group' to which they belonged, had higher status than those who were fed. The group leaders—of groups of longhouses, or of single longhouses, or of hearth groups within a longhouse—were invariably leaders in rice cultivation. 'Rice, then, both organizes Kelabit kinship and makes it hierarchical' (Janowski 2003, 51).

Before their conversion to Christianity in the 1950s, an important component of Kelabit traditional life was the making of 'marks' (*etuu*) on the landscape that, unlike the Penan's *uban*, were intended as permanent records of how Kelabit lives were imposed on the forest. 'An *etuu* is a long-lasting mark on the landscape, with the most important *etuu* involving the moving of stone or earth' (Janowski & Langub 2011, 127). Stone menhirs (*batu senuped*) were erected; stone slabs were cut to make burial cists (*batu nangan*) and stone jars (*batu longon*) were carved as burial containers; boulders were incised, including with anthropomorphic figures (*batu narit*); stone mounds (*perupun*) were raised; ditches (*nabang*) were excavated and tree-lines (*kawang*) cut in prominent locations such as sharp-sided ridges to be visible from a distance; and rice fields were constructed. In living memory, and according to the Kelabit in the past too, the death of a prominent individual was marked by the communal enterprises such as constructing *perupun* for depositing valuable possessions of the deceased, or cutting *nabang* and/or *kawang*, followed by a feast (*irau*) at which a pig or buffalo would be killed.

Though in terms of their subsistence economy the Kelabit are profoundly reliant on the forest for meat and many vegetable foods as well as for materials for longhouse building and craft products, they are also reliant on it in psychological terms because the wild life force (*lalud*) of the forest has remained central to their sense of place in the cosmos, despite (and in

fact accommodated within) the tenets of Christianity following their conversion. Whilst domestic animals were slaughtered at *irau*, *lalud* was acquired by consuming meat from animals killed in the forest. For the people of Pa'Dalih in the late 1980s and early 1990s, rice was categorically opposed to forest products, both meat and handicraft materials: '[rice] was, in fact, the antithesis of forest products, because it can only grow in the tropical forest if people plant it, whereas forest products grow on their own (*mulun sebulang*)' (Janowski 2003, 51). The Kelabit were self-conscious rice growers, rice growing making a statement about their *non*-reliance on the forest. Rice had a special role in defining and creating human culture (*ulun*): its cultivation symbolized the control of nature. Rice was eaten three times a day, always with foods from the forest, so eating the latter brought *lalud* into the home, whereas eating rice made *ulun* possible.

Rice-growing and the Austronesian hypothesis

The Penan and the Kelabit speak languages that belong to the Malayo-Polynesian branch of the Austronesian language family that is spread widely across Island Southeast Asia and the Pacific, with outliers to the west in Madagascar. For almost four decades, research on the origins of rice farming in Island Southeast Asia has been dominated by debates about the strengths and weaknesses of the Austronesian language and farming dispersal model initially proposed by Peter Bellwood in 1985, and since expanded and defended by him in numerous publications (e.g. Bellwood 1988; 1996; 1997; 2001; 2002; 2005; 2011; Bellwood *et al.* 1992; Diamond & Bellwood 2003). The thesis derived originally from linguistic arguments that the language family had its origins in Taiwan, the region of highest linguistic diversity (Blust 1976; Pawley & Green 1975; Shutler & Marck 1975). Bellwood argued that rice cultivation and animal husbandry (of pigs, dogs and chickens) began in mainland China and then spread to Taiwan, and that (proto)-Austronesian-speaking Neolithic farmers then spread southwards across Island Southeast Asia and onwards to the further Pacific, taking with them the practices of rice farming and animal husbandry (of pigs, dogs and chickens) and new sets of material culture (pottery, polished stone tools and shell ornaments). Sites with Neolithic material culture had been dated to *c.* 6000 BP in Taiwan, *c.* 5000/4500 BP in the Philippines and Sulawesi and *c.* 4000 BP in East Timor (Bellwood 1985), indicating a broad chronological trend from northwest to southeast that fitted the hypothesis of a maritime Austronesian/Neolithic colonization movement, memorably described by Jared Diamond (1988) as the 'Austronesian express train'.

Since the formulation of the model, however, genetic studies of modern populations in Island Southeast Asia have shown that the main population movements that formed them were not in fact at the time of the putative Austronesian expansion, but in the Late Pleistocene, when the region was first colonized by modern humans, and especially at the beginning of the Holocene, when an area of continental shelf the size of Europe was flooded by rising sea levels (Soares *et al.* 2008). Most of the present-day diversity of Near and Remote Oceanian populations was already established by the end of the Pleistocene (Soares *et al.* 2011). Mitochondrial DNA, Y-chromosome and genome-wide data do not indicate significant population movement in the mid-Holocene out of Taiwan around 5000 years ago. Two minor flows, one from Mainland Southeast Asia to Java, Sumatra, Borneo and possibly Sulawesi, and another from South China via Taiwan into the Philippines but not beyond, are interpreted as evidence of small-scale migration and language drift, rather than a large demographic event (Soares *et al.* 2016).

Direct evidence for domesticates associated with Neolithic material culture in Island Southeast Asia, and even more so for a dietary reliance on them, remains remarkably thin on the ground. Rice grains in pottery temper have been reported from Neolithic sites in the northern Philippines, but their domestic status was not demonstrated in detail (Snow *et al.* 1986). Grains and phytoliths of domestic rice have been found as pottery inclusions in Gua Sireh cave in Sarawak, northern Borneo, dated to *c.* 4300 cal. BP (Bellwood *et al.* 1992; Datan 1993). Grains of domestic rice were found as inclusions in 14 of the *c.* 1500 Neolithic sherds from the 1950s and 1960s excavations by Tom and Barbara Harrison in the Niah Caves (Doherty *et al.* 2000; Fig. 7.1: site 1) and, whether imported or grown locally, rice appears to have made a negligible contribution to the diet, which, as in the earlier Holocene, was based almost entirely on forest foods (Lloyd-Smith *et al.* 2013). Rice phytoliths have been recovered from sediments at Minanga Sipakko and Kamassi in western Sulawesi dated to *c.* 3600–2900 cal. BP associated with Neolithic material culture, but whilst their bilobate and fan morphologies are similar to those of modern domestic rice, they may derive from an unknown species of wild rice (Anggraeni *et al.* 2014, 750) like the rice phytoliths dated to around 6000 cal. BP in a sediment core from Loagan Bunut lake near the Niah Caves (Hunt *et al.* 2016; Fig. 7.1: site 2). Bones of domestic pig associated with Neolithic material culture have been identified at Nagsbaran in the northern Philippines dated to 4500–4200 cal. BP (Piper *et al.* 2009) and (together with bones of domestic

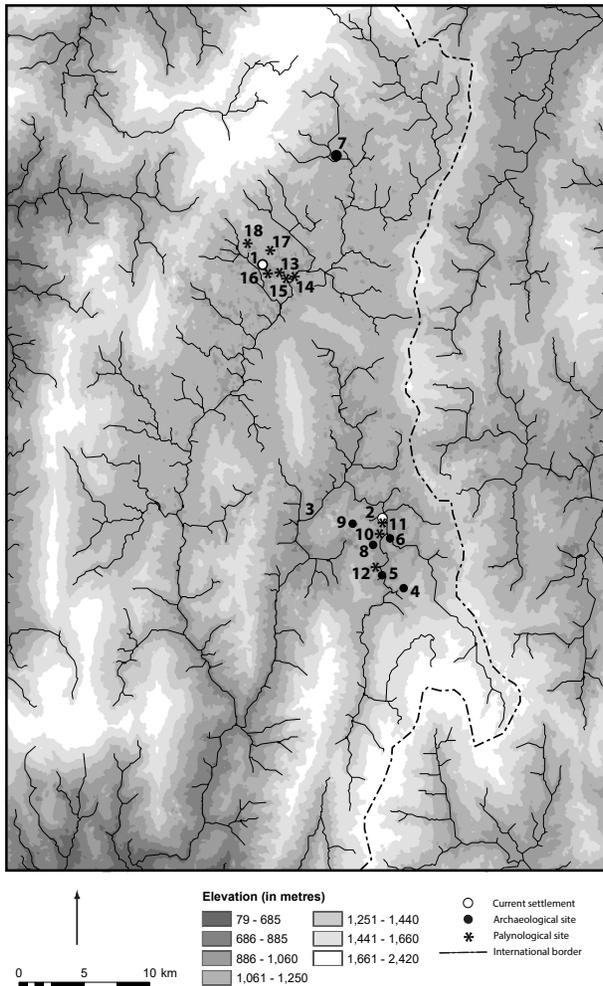


Figure 7.4. Map showing key sites and locations in the Kelabit Highlands investigated by the Cultured Rainforest Project. Modern sites: (1) Bario; (2) Pa'Dalih; (3) Kelapang River. Archaeological sites: (4) Lepo Batu; (5) Rumah Ma'on Dakah, Rumah Ma'on Taa Payo, Perupun Long Kelit; (6) Menatoh Long Diit; (7) Perupun Rayeh, Pa' Lungan, Ra'an Ma'on Ubud; (8) Perupun Payeh Telipa; (9) Rumah Ma'on Raan Berangan. Landscape sites: (10) PDH212; (11) PDH223; (12) BPG, Pa' Buda; (13) Ba (Bario); (14) BIO5; (15) BIO7; (16) BIO16; (17) BIO50; (18) BIO51; (19) BIO53; (20) BIO54; (21) CO1. (Illustration: Lucy Farr & Chris Hunt.)

dog) at Minanga Sipakko and Kamassi in sediments dated to 3600–2900 cal. BP (Anggraeni *et al.* 2014), but in both cases the principal fauna consisted of game. Rice grains and chaff in Metal Age pottery from a number of coastal sites in Sarawak suggest that rice growing only became widespread in this part of Borneo through this period, which is dated from around 2000 to 500 years ago (Doherty *et al.* 2000). A pollen

core in coastal swamp forest in Batulicin in southern Kalimantan (southern Borneo) likewise indicates that rice growing only became common in recent centuries (Yulianto *et al.* 2005). Bones of domestic pigs and dogs also only occur in the Niah Caves in Metal Age deposits (Szabó *et al.* 2013). So why was rice not adopted immediately as a staple food? And when, how and why did the present-day subsistence systems and associated cosmologies of the Penan and Kelabit in interior Borneo develop?

The history of people and rainforest in the Kelabit Highlands

Both the Penan and the Kelabit believe that they and their very different ways of living in the forest have a deep antiquity, but until a decade ago there was virtually no evidence about the character of past societies and land-use systems in the Kelabit Highlands beyond their origin myths. The Cultured Rainforest Project was an investigation of past and present-day 'rainforest lives' in the Kelabit Highlands, funded primarily by the UK Arts and Humanities Research Council as a contribution to its Landscape and Environment programme (Barker *et al.* 2008; 2009; 2016; Janowski & Langub 2011; Lloyd-Smith *et al.* 2010). Its fieldwork, primarily conducted between 2008 and 2011, combined anthropological and ethnographic studies of present-day Penan and Kelabit communities with mapping and excavations of selected archaeological sites and monuments, mainly in the southern Highlands, and sediment coring in both the northern and southern Highlands for palynological analysis of forest history, including human impacts on the forest (Fig. 7.4).

The archaeological and palynological components of the project identified a complex Late Holocene history of human activity and vegetation change, which is summarized in Figure 7.5. Here, the Oxcal plot of summed radiocarbon dates on charcoal found in our landscape evaluations provides an indication of the frequency of fire in the landscape, while summed dates from archaeological sites provide evidence for phases of human presence. The presence of pollen of key starchy food plants in our cores is also indicated. The summed radiocarbon dates are listed in Table 7.1. We make the assumption from the pattern of dates that human activity is the most common cause of fire in this landscape, in which there is no true dry season. It must not be forgotten that radiocarbon dates on charcoal record the date of the growth of the part of the tree that was later burned, and not the date of the burning. Trees in Borneo do not seem to reach great ages, but some of the dates discussed below may well pre-date the fires that produced the charcoal by one or

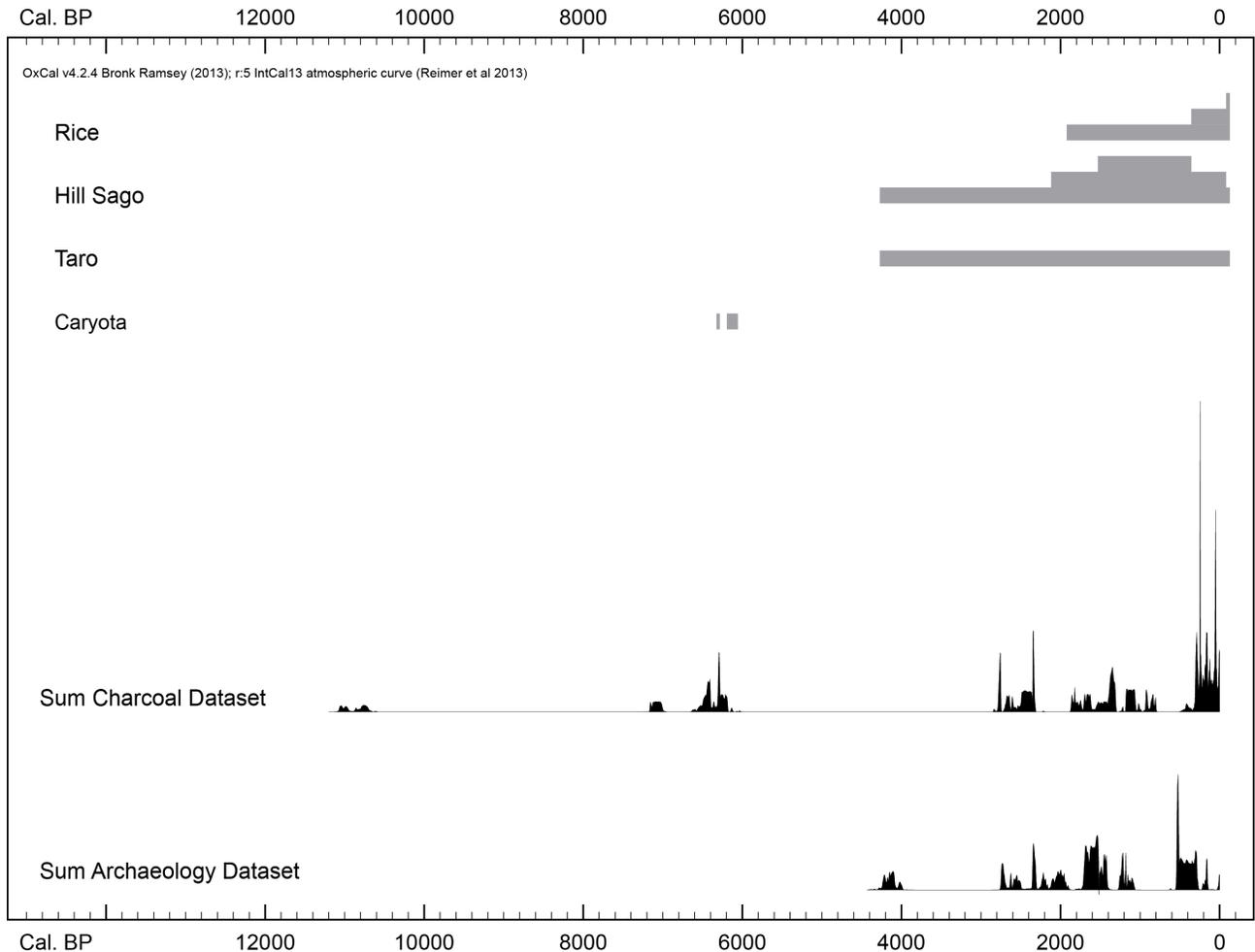


Figure 7.5. Oxcal plots of summed probabilities from the radiocarbon dates from charcoal from archaeological and landscape sites, providing an indication of the timing of human activity in the Kelabit Highlands, and evidence from our cores for the presence of important starchy food plants. (Illustration: Chris Hunt & Evan Hill.)

two centuries. The very recent charcoal-based dates recorded in Table 7.1 suggest that, in some cases, much younger plants were burned, however, and in older dates the cumulative radiocarbon errors are well over a century, so we are not adding a correction for old wood to the discussion of the charcoal dates. In the last *c.* 3000 years there is a fair degree of correspondence between the broad patterns, although very young archaeological sites were not dated by radiocarbon and Oxcal will not calibrate post-1950 dates, thus truncating the landscape record, which contains several very recent dates (Table 7.1).

Although the Kelabit Highlands record of human presence only goes back around 6000 years, from our earlier work at the Niah Caves on the Sarawak lowlands we know that people in Borneo—anatomically modern humans, on the evidence of the ‘Deep Skull’ found in the 1958 Harrison excavations of the

West Mouth of Niah Great Cave—were systematically burning the forest from as early as 50,000 years ago (Barker 2013; Barker & Farr 2016; Barker *et al.* 2007; Hunt *et al.* 2007; 2012; 2016). A wide range of archaeological evidence (carbonized plant remains such as fruits and nuts, tuber parenchyma, phytoliths and starch grains in sediments and in organic residues attached to stone artefacts) suggests that foragers were combining hunting, fishing and gathering with the management (‘vegiculture’) of tuberous plants such as taro and yams, and sago palms, presumably making use of the clearings being created by firing forest edges (Barker *et al.* 2007; 2011; Barton 2016; Barton & Denham 2011; Barton *et al.* 2016). Similar evidence has been found elsewhere in Island Southeast Asia and New Guinea (Barker *et al.* 2011; Hunt & Rabett 2014; Summerhayes *et al.* 2010). Remarkable evidence for the ability of these rainforest foragers to translocate plants

Table 7.1. Radiocarbon dates from archaeological and palynological sites in the Kelabit Highlands, calibrated using Calib 7.0.4, CALibomb and the INTCAL13 and INTCAL13.f14c calibration curves (Hua et al. 2013; Reimer et al. 2013).

Sample code	Lab. code	Material	Radio-carbon age BP	±	AMS $\delta^{13}\text{C}$	F ¹⁴ C	±	Cal. age ranges 2 σ	Cal. age ranges BP 2 σ	Probability
<i>Archaeological sites</i>										
Perapun Raya Pa' Lungan	Beta-280504	Burnt bone	1980	40	-19.8			86–78 BC 55 BC–AD 90 AD 98–124	2027–2035 1860–2004 1826–1852	0.008 0.958 0.0337
Rumah Ma'on Raan Berangan	Beta-237854	Charcoal	400	40				AD 1432–1526 AD 1556–1632	424–518 318–394	0.700 0.300
Menatoh Long Kelit	Beta-237848	Charcoal	240	40				AD 1520–1592 AD 1620–1684 AD 1733–1807 AD 1928–1956	358–430 266–330 143–217 –6–22	0.150 0.414 0.318 0.119
Perupun Long Kelit	UBA-1221	Charcoal	501	22				AD 1408–1441	509–542	1.000
Laman Pa' Ramain	Beta-424168	Charcoal	1740	30				AD 237–384	1566–1713	1.000
Rumah Ma'on Dakah, Long Kelit	Beta-280502	Charcoal	2050	40				173 BC–AD 28 AD 40–48	1922–2122 1902–1910	0.987 0.013
Rumah Ma'on Dakah, Long Kelit	Beta-237849	Charcoal	3770	40				2334–2325 BC 2301–2114 BC 2101–2037 BC	4274–4283 4063–4250 3986–4050	0.007 0.864 0.129
Lepo Batu	Beta-237853	Charcoal	2550	40				806–728 BC 713–710 BC 693–658 BC 653–542 BC	2677–2755 2659–2662 2607–2642 2491–2602	0.464 0.003 0.126 0.406
Rumah Ma'on Taa Payo	Beta-237850	Charcoal	1620	40				AD 345–372 AD 376–541	1578–1605 1409–1574	0.056 0.944
Rumah Ma'on Taa Payo	Beta-280503	Charcoal	1630	40				AD 339–538	1412–1611	1.000
Menatoh Long Diit	UBA-12420	Charcoal	1238	22				AD 688–754 AD 757–779 AD 789–872	1196–1262 1171–1193 1078–1161	0.525 0.165 0.310
Menatoh Long Diit	Beta-280500	Cremated bone	310	40				AD 1471–1654	296–479	1.000
Menatoh Long Diit	Beta-280499	Charcoal	1710	40				AD 241–409	1541–1709	1.000
Menatoh Long Diit	Beta-280501	Charcoal	2300	40				1606–1583 BC 1559–1553 BC 1546–1405 BC	3532–3555 3502–3508 3354–3495	0.034 0.006 0.960

is the presence of swamp sago, *Metroxylon*, which is native to the islands east of the Wallace Line but not to Borneo, in layers dated to around 10,000 cal. BP from a deep sediment core at Loagan Bunut in the lowlands close to Niah, where it is associated with evidence for persistent vegetation management by fire (Hunt & Premathilake 2012; Hunt & Rushworth 2005). Furthermore, the 'Deep Skull', part of a secondary burial

dated by uranium series to some 37,000 years ago (Pike 2016), is associated with unworn quartz crystals brought from one of the granites in the interior (Hunt & Barker 2014). We found charcoal in several Late Pleistocene and Early Holocene sequences from cores in both the northern and southern Highlands that is suggestive of fires (S. Jones *et al.* 2014), but there is no archaeological evidence that would allow us to link

Table 7.1. (Continued.)

Sample code	Lab. code	Material	Radio-carbon age BP	±	AMS $\delta^{13}\text{C}$	F ¹⁴ C	±	Cal. age ranges 2 σ	Cal. age ranges BP 2 σ	Probability
<i>Palynological sites</i>										
PDHCOL1 161-163	UBA-8126	Charcoal	972	28				AD 1075–1154 AD 1065–1075 AD 1016–1059	891–934 875–885 796–875	0.399 0.020 0.581
PDHCOL1 265.5-271.5	UBA-8127	Charcoal	92	31				AD 1683–1735 AD 1806–1930 AD 1955–1955	215–267 20–144 –5– –5	0.279 0.720 0.001
PDHCOL1 324-326	UBA-8128	Charcoal	190	26				AD 1654–1687 AD 1730–1809 AD 1926–1955	263–296 141–220 –5–24	0.218 0.572 0.210
PDHCOL1 360	UBA-8129	Charcoal	1180	32				AD 919–962 AD 769–902 AD 728–736	988–1031 1048–1181 1214–1222	0.095 0.893 0.011
PDH 212 31	UBA-10584	Charcoal	43	17		0.9946	0.0021	AD 1707–1719 AD 1825–1832 AD 1884–1913 AD 1955–1956	231–243 118–125 37–66 –6– –5	0.051 0.024 0.872 0.053
PDH 212 95-97	UBA-12735	Wood	329	23				AD 1607–1641 AD 1486–1604	309–343 346–464	0.211 0.789
PDH 212 193-194	UBA-10585	Charcoal	2655	23				842–795 BC 888–882 BC	2744–2791 2831–2837	0.991 0.009
PDH 223 144–146	UBA-10593	Charcoal	1751	19	–23.0			AD 237–342	1608–1713	1.0
PDH 223 178–182	UBA-10594	Charcoal	1867	18	–28.0			AD 82–215	1735–1868	1.0
PDH 223 275–278	UBA-10595	Charcoal	2308	18	–28.3			402–371 BC	2320–2351	1.0
BPG 89	UBA-8130	Charcoal	5692	43				4623–4449 BC 4682–4632 BC	6398–6572 6581–6631	0.930 0.070
BPG 152-154	UBA-9305	Charcoal	6177	23				5213–5055 BC	7004–7162	1.0
BPG 156-158	UBA-9308	Charcoal	5396	27				4195–4175 BC 4334–4230 BC	6124–6144 6179–6283	0.045 0.955
BPG 170-172	UBA-9309	Charcoal	5495	24				4291–4266 BC 4365–4321 BC	6215–6240 6270–6314	0.124 0.876
BPG 192-194	UBA-9306	Charcoal	5633	23				4423–4372 BC 4528–4442 BC	6321–6372 6391–6477	0.185 0.815

these fires with human activity. Hence it is very likely that people were foraging in the Kelabit Highlands leaving little trace of their passing much earlier than our first clear indications of human presence.

The ensuing record of human activity can be divided into four main phases.

Phase 1: 6200–4200 years ago; possible clearance for foraging-arboriculture

The first stage in the sequence is marked by phytoliths, pollen and charcoal in core BPG taken in a riverine

deposit at Pa'Buda in the southern Highlands (Fig. 7.6). The two basal dates in the borehole are in stratigraphic order, suggesting that the three higher, older dates are on recycled material or derived from charcoal from older wood. Phytoliths in the core are consistent with hot fire and the spread of grass-based vegetation that are associated elsewhere in Australasia and Island Southeast Asia with anthropogenic clearance. The first canopy-opening episode in the core was followed by pollen evidence for palm trees, including the sago palm (*Caryota*), fruit trees and grassy areas in an

Table 7.1. (Continued.)

Sample code	Lab. code	Material	Radio-carbon age BP	±	AMS $\delta^{13}\text{C}$	F ¹⁴ C	±	Cal. age ranges 2 σ	Cal. age ranges BP 2 σ	Probability
BIO16 13-13.5	UBA- 9993	Charcoal	2426	25	-24.9			551–405 BC 665–645 BC 744–687 BC	2354–2500 2594–2614 2636–2693	0.789 0.045 0.166
BIO16 21-22	UBA- 9994	Charcoal	1594	48	-29.9	0.8199	0.0050	AD 380–573 AD 351–367	1377–1570 1583–1599	0.985 0.015
BIO16 32.5-33	UBA- 9995	Charcoal	2428	42	-28.3			594–403 BC 669–611 BC 753–681 BC	2352–2543 2560–2618 2630–2702	0.670 0.118 0.211
BIO16 140- 141	UBA- 9997	Charcoal	1473	25	-24.3	0.8324	0.0027	AD 550–640	1310–1400	1.0
BIO16-A 190 cm	UBA- 10592	Charcoal	49	26	-26.0	0.9939	0.0033	AD 1695–1726 AD 1813–1839 AD 1841–1854 AD 1867–1918 AD 1955–1956	224–255 111–137 96–109 32–83 –6––5	0.011 0.594 0.032 0.152 0.211
Ba 29–31 cm	UBA- 15637	Peat	1433	23				AD 585–653	1297–1365	1.0
Ba 32.5–33 cm	UBA- 9995	Charcoal	2428	42				594–403 BC 669–611 BC 753–681 BC	2352–2543 2560–2618 2630–2702	0.670 0.118 0.211
Ba 47–49 cm	UBA- 10000	Wood	1719	25	-25.5	0.8073	0.0026	AD 310–388 AD 252–308	1562–1640 1642–1698	0.598 0.401
Ba 59–65 cm	UBA- 10001	Wood	4841	29	-25.2	0.5473	0.0020	3581–3533 BC 3672–3630 BC 3695–3677 BC	5482–5530 5579–5621 5626–5644	0.287 0.658 0.054
PPP10	Beta- 292528	Organic mud				1.038	0.005	AD 1955.3–1956.2 AD 1956.7–1957.7 AD 2007.9–2008.5 AD 2009.0–2009.5	–6.2––5.3 –7.7––6.7 –58.5––57.9 –59.5––59.0	0.092 0.660 0.122 0.126
PPP40-42	UBA- 25831	Organic mud	10808	49		0.2604	0.0016	10,824–10,709 BC	12,658–12,773	1.0
PPP60-62	UBA- 25832	Organic mud	2532	25		0.7296	0.0023	646–549 BC 687–664 BC 795–739 BC	2498–2595 2613–2636 2688–2744	0.439 0.136 0.425
PPP90	UBA- 292529	Organic mud	4480	40	-28.5			3068–3026 BC 3348–3082 BC	4975–5017 5031–5297	0.083 0.917
BIO5-1	UBA- 19805	Charcoal	227	32	-30.9	0.9721	0.0039	AD 1532–1536 AD 1636–1683 AD 1734–1806 AD 1929–1956	414–418 267–314 144–216 –6–20	0.005 0.420 0.420 0.156
BIO5-2	UBA- 19806	Charcoal	245	64	-27.4	0.9699	0.0078	AD 1470–1697 AD 1725–1815 AD 1835–1877 AD 1917–1956	253–480 135–225 73–115 –6–33	0.603 0.261 0.034 0.102
BIO5-3	UBA- 19807	Charcoal				1.5020	0.0054	AD 1963.0–1963.5 AD 1968.5–1968.6 AD 1969.7–1971.2 AD 1971.6–1972.3 AD 1973.6–1973.7	–13.5––13.0 –18.6––18.5 –21.2––19.7 –22.3––21.6 –23.7––23.6	0.095 0.004 0.448 0.446 0.007

abnormal—delayed—regeneration sequence (S. Jones *et al.* 2013b). This is perhaps broadly consistent with the evidence compiled by Hunt & Rabett (2014) for the

presence of people practising extensive, low-density, foraging-arboricultural lifeways, with starchy plants being grown in fairly short-lived forest clearings

Table 7.1. (Continued.)

Sample code	Lab. code	Material	Radio-carbon age BP	±	AMS $\delta^{13}\text{C}$	F ¹⁴ C	±	Cal. age ranges 2σ	Cal. age ranges BP 2σ	Probability
BIO7-C 20-19 cm	Beta-396778	Organics	8520	30				7591–7534 BC	9483–9540	1.0
BIO7-A 52 cm	UBA-19812	Wood	23521	175	-26.7	0.0535	0.0012	26,719–25,937 BC	27,399–27,929	1.0
BIO7-B 67 cm	UBA-19813	Wood	3606	35	-27.9	0.6384	0.0028	2039–1883 BC 2118–2097 BC	3832–3988 4046–4067	0.972 0.028
BIO50-A	UBA-19808	Plant fragments			-29.5	1.0634	0.0046	AD 1957.6–1957.9 AD 2003.1–2003.4 AD 2004.0–2009.1 AD 2009.5–2009.5	-7.94– -7.7 -53.4– -53.1 -59.1– -54.0 -59.6– -59.5	0.041 0.006 0.949 0.004
BIO50-B	UBA-19809	Plant/charcoal fragment	1457	29	-28.2	0.8341	0.0030	AD 558–648	1302–1392	1
BIO51-A	UBA-19810	Plant fragments	26835	262	-31.6	0.0354	0.0011	29,591–29,013 BC	30,599–31,288	1
BIO52-C	UBA-19811	Charcoal	9517	43	-26.6	0.3058	0.0016	8932 – 8719 BC 9132–8978 BC	10,668–10,881 10,927–11,081	0.574 0.426
BIO53-13/1	UBA-19815	Charcoal			-28.2	1.0000	0.0027	AD 1895–1904 AD 1955–1956	46–55 -7– -5	0.171 0.829
BIO53-14/2	UBA-19816	Charcoal	103	30	-26.4	0.9873	0.0037	AD 1682–1737 AD 1757–1761 AD 1803–1936 AD 1955–1955	213–268 189–193 14–147 -5– -5	0.284 0.006 0.708 0.001
BIO53-15/4	UBA-19818	Charcoal	102	29	-23.4	0.9874	0.0035	AD 1682–1736 AD 1759–1760 AD 1804–1936 AD 1955–1955	214–268 190–191 14–146 -5– -5	0.284 0.001 0.714 0.001
BIO53-16/10	UBA-19823	Charcoal	193	29	-27.6	0.9762	0.0035	AD 1649–1690 AD 1729–1810 AD 1925–1955	260–301 140–221 -5–25	0.235 0.559 0.205
BIO53-17/5	UBA-19824	Charcoal	227	29	-29.1	0.9722	0.0035	AD 1640–1682 AD 1737–1758 AD 1761–1804 AD 1936–1956	268 – 310 192–213 146 -189 -6–14	0.439 0.039 0.372 0.150
BIO54-A	UBA-19825	Charcoal	1192	28	-27.7	0.8621	0.0030	725–738 768–895 928–941	1212–1225 1055–1182 1009–1022	0.023 0.957 0.020

alongside rivers. Unfortunately, there is no strong evidence to verify that the palm trees were being managed for their edible sago: the sago palm (*Caryota*) only shows a sporadic appearance, whilst *Eugeissona* (the main sago palm managed today) is not present at all in the sequence. Given such tentative evidence of human activity, the possibility of a climatic event wholly or partly causing the palaeoecological signal should not be ignored, although palaeoclimate investigations in lowland Sarawak suggest that the period between 7000 and 4000 cal. BP was marked by a hot, very wet climate (Cole *et al.* 2015).

Phase 2: 4200–2000 years ago—living in the forest with Eugeissona sago and tubers

A little more than 4000 years ago, a more definite and widespread human presence is manifested by occupation evidence on a river terrace site at Rumah Ma'on Dakah, Long Kelit, including a large post-hole and earthenware potsherds, a polished stone fragment and burnt stones (Barker *et al.* 2016). This site is broadly contemporaneous with the occurrence of pollen of 'hill sago' (*Eugeissona*) in colluvial sediments underneath a stone mound called Perapun Paya Telipa (S. Jones, unpublished) and of taro (*Colocasia*) in peat in Bore-

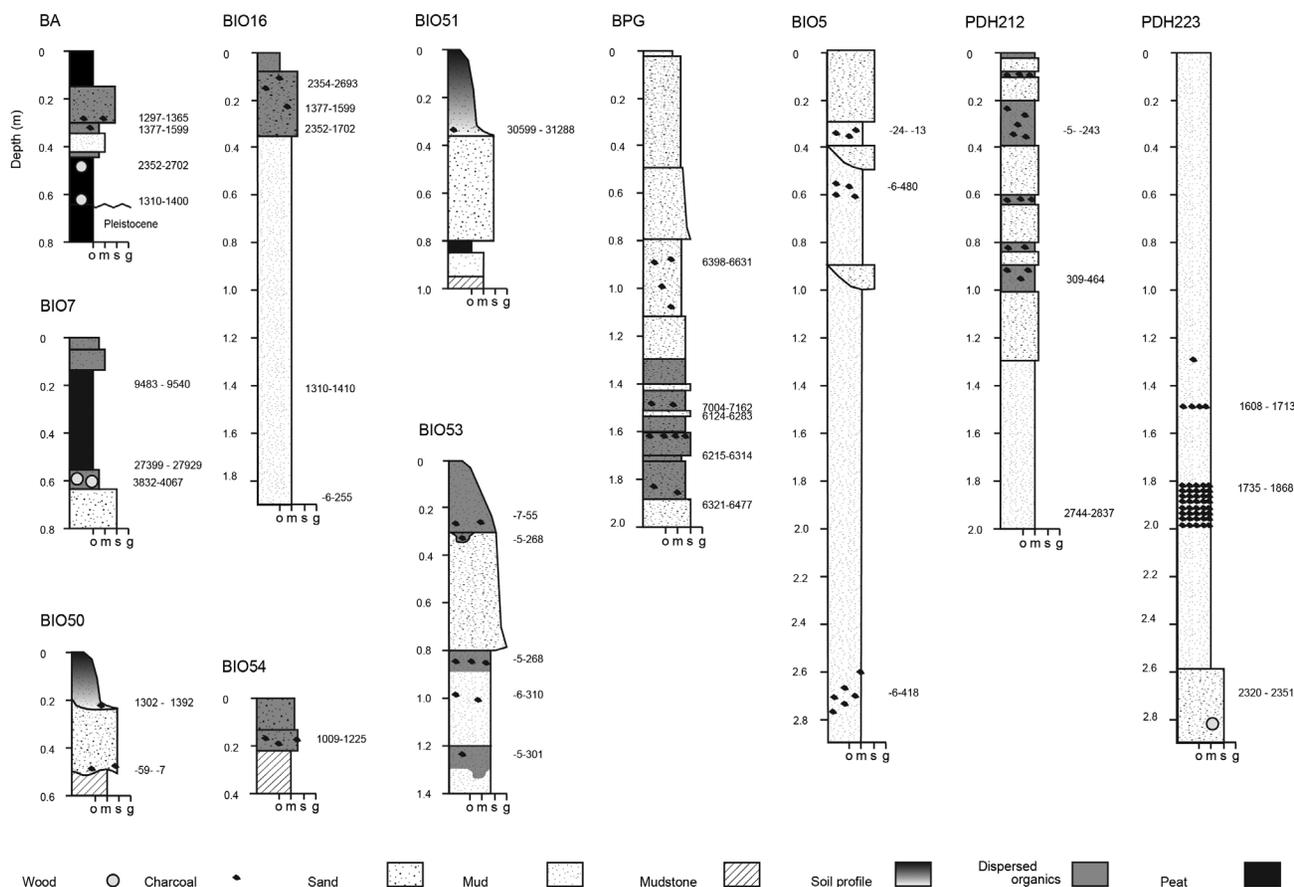


Figure 7.6. Stratigraphic summaries of the cores and geoarchaeological sites investigated by the Cultured Rainforest Project, with calibrated BP radiocarbon dates. (Illustration: Chris Hunt.)

hole BIO7 near Bario (Barker *et al.* 2016; O'Donnell 2016). Pollen of open-ground plants in layers below the appearance of *Eugeissona* suggests that the forest around Perapun Paya Telipa had been disrupted around 5000 years ago, but the level of disturbance indicators rose significantly with the appearance of *Eugeissona* and continued at this site until sub-recent times. It is difficult to make much of the evidence, except to say that human activity was probably very sparse and ephemeral at any given location, and based on a combination of vegeculture, arboriculture and foraging. The long-term nature of the pollen record for sago at Perapun Payo Telipa suggests the tending of this resource over several millennia.

Phase 3: 2000–600 years ago—*Eugeissona* and rice in tandem

Construction of stone mounds seems to have started a little more than 2000 years ago on the evidence of cremated bone at Perupun Raya Pa'Lungan (Lloyd-Smith 2012). A remarkable and substantial open site, Ruma Ma'on Taa Payo, consisting of stone-built structures on

a riverside promontory enclosed by a ditch, dates from 1600–1400 years ago (Barker *et al.* 2016; Lloyd-Smith *et al.* 2010). The appearance of these monuments could suggest that populations were sufficiently dense that people felt the need to mark key sites in the landscape, and indeed the rising density of activity is mirrored by the spread of *Eugeissona* and a more continuous pattern of radiocarbon dates (Fig. 7.5). The denser populations supported themselves by a mixture of hunting (burnt medium-sized fragments of animal bone were recovered by Tom Harrisson at Perapun Rayeh Pa'Lungan: Lloyd-Smith 2012), foraging and using starchy plants. *Eugeissona*, although less sweet than *Caryota*, provides significantly greater quantities of starch (Kedit 1982). It may be that it was at this stage that a more sedentary lifestyle developed tied to the exploitation of *Eugeissona* sago-palm groves in the manner of the present-day Penan. Related to this, perhaps the trend towards the modern Kelabit differentiation between 'women's forest' used for foraging and untouched 'men's forest' reserved for hunting developed at this time. The large quantity of

cremated animal bone at Perapun Rayeh Pa'Lungan (Lloyd-Smith 2012) may also be evidence for an *irau*-like feast of the kind practised by the Kelabit today. In other respects, though, the pattern of landscape use differed from that of today and of recent memory, as *Eugeissona* was grown in valley-floor sites, whereas today it is mostly on ridge tops.

The first indications of rice cultivation consist of extremely rare rice phytoliths in core PDH212 at Pa'Dalih. These occur in an area where there was established, though episodic, sago growing with a return interval of around 400 years. The rice phytoliths are associated with one of the peaks of sago pollen, around 1800 years ago (S. Jones *et al.* 2013a). It is possible that rice was eaten alongside sago, although sago and perhaps other root crops likely remained the preferred choice of food (or at least the necessary staple) until the historic period, with rice remaining extremely rare (Barton 2012). Rice is difficult and laborious to grow, and it does not make ecological sense to grow it in tropical rainforest alongside the wealth of other plant resources in the forest (Barton & Denham 2011). Also, growing significant quantities of rice requires efficient tools to clear land for fields, and the rarity of iron in the Highlands may have contributed to the high status of both rice and the iron tools needed to cultivate it on any scale. In this phase, therefore, rice cultivation and consumption may have been a means by which some groups started to differentiate themselves in a form of conspicuous display alongside monument building.

Phase 4: 600 years ago to the very recent past—a busy landscape

In this phase archaeological sites become more widespread, with stone jar cemeteries, former longhouse sites and ridge-top settlements known, and in the palynological record there is consistent evidence for a dramatic increase in the scale, extent and frequency of clearance activities (Barker *et al.* 2016; S. Jones *et al.* 2013b; 2016). Rice and sago spread into new locations, and stratigraphic and dating evidence indicates a shortening to around 60 years of return periods to fields after the cycle of clearance, use and fallow ('abandonment'), the pattern recorded ethnographically. In combination these changes suggest that there was a need to bring more land into use, and intensify the use of fields, to feed an increasing population.

The ways in which people marked the landscape with new monuments such as stone jar cemeteries and *perupun*, and reused existing monuments, may have been related to the same phenomenon: in an increasingly crowded landscape, there may have been a need to mark sections of it as belonging to particular groups.

One aspect of the use of these monuments after around 400 years ago is the deposition of 'exotic' materials, particularly Chinese ceramics. The presence of these 'exotic' goods suggests the connection, however indirect, of the populations in the Kelabit Highlands with the emerging global commercial system of the period and the development of distant markets for forest products, such as dammar resin (Ewart 2009). Presumably some Highland people could display prestige and extra-regional connections through their conspicuous disposal of 'exotic' goods into monuments.

It is likely that it was this more competitive, as well as crowded, landscape of recent centuries that provided the context in which rice transitioned from being a prestige food to a staple food, as precursor Kelabit communities began to identify themselves both through cultural practices such as living communally in longhouses and making 'marks' on the landscape and through distinctive dietary practices focused on rice growing. It would have been a way of life increasingly separate from precursor Penan communities combining foraging with managing sago on the margins of the rice-growing areas.

Discussion and conclusion

One of the major themes running through the long landscape history that can now be proposed for the Kelabit Highlands is the evidence, both palynological and archaeological, for the rainforest being a repository of memory of past generations. Human activity returned over long periods, sometimes millennia, to the same favoured places in the landscape. This may imply the sheer suitability of some of these sites for the activity that happened on them, but it is consistent with a memory of important places in the landscape being transmitted over the generations. This memory was undoubtedly augmented by both purposeful and inadvertent changes to the plant communities of these sites, even in the absence of visible monuments. Informants told us about longhouses being abandoned and rebuilt on sites at approximately 60-year intervals. At PDH212, the site of a longhouse abandoned approximately 60 years ago, the presence of five distinct burning horizons within the last 400 years suggests a similar timing of return through this period. A repeated pattern of return and clearance over the last 300 years may also be suggested by pits and two palaeosoils interbedded with colluvium at BIO53, a site recently cleared for residential and agricultural activity. Further back in time, the pattern of return seems to have been longer, for instance about 400 years between sago-growing phases around 2000 years ago at PDH212. The pattern of episodic return is

also shown by the chronological evidence of ^{14}C dates and artefact typology of sites such as Perapun Rumah Pa'Lungan (Lloyd-Smith 2012), Rumah Ma'on Dakah, Long Kelit and Menatoh Long Diit (Barker *et al.* 2016), where people re-used these structures several hundred years after their first use.

At other times it is possible that the return interval was much longer (although the 'gap' between dates may also reflect that preservation of evidence on some sites was patchy). A good example is BIO54, a site with huge durian trees, which were apparently planted over 100 years ago, but also bearing clear cultivation ridges from the cultivation of beans, which ceased around 1970. Underlying the cultivation ridges was a palaeosol rich in charcoal that gave a ^{14}C date of around 1100 years ago. Sites such as BIO16 and BIO50 yielded charcoal with dates not in stratigraphic order, pointing perhaps to earlier human activity, although erosive processes have disrupted sedimentary sequences. The current Pa'Dalih longhouse site seems to have been a focus for activity including burning, sago arboriculture and rice cultivation intermittently since around 2330 years ago, from the evidence of boreholes PDH223 and PDH212. Earlier dates of human arboriculture are more tentative and possibly blurred with the impacts of climatic episodes. Pa'Buda, for example, shows a major canopy-opening episode, followed by abnormal regeneration flora, around 6200 years ago, that may well be representative of low-intensity arboriculture. Climate-induced aridity oscillations in the period 8000–6000 BP have been reported in Java and Kalimantan (Sémah *et al.* 2004; Stuijts 1993), although the closest record, in Sarawak, shows this to be a period of high rainfall and without hydrological stress (Cole *et al.* 2015).

After 4000 cal. BP, arboriculture seems to have provided stable focal points in the landscape over extended periods. In recent times the durians and other fruit trees at BIO 56 and PDH 212 provided markers for earlier episodes of human activity and places to harvest desirable fruit. The stability of the pollen signal for *Eugeissona* over nearly 700 years (2340–1655 years ago) at PDH223 and over 4000 years at Perupun Paya Telipa suggests the maintenance of this arboricultural resource over a very extended time, since the sago trees would have been overwhelmed by taller vegetation without consistent management.

Another theme regarding the enculturating activities of past rainforest populations is plant translocations. *Eugeissona* (apart from a single occurrence in Bario), *Caryota* and *Colocasia* have not been recognized in Pleistocene or Early Holocene records in the Kelabit Highlands (S. Jones *et al.* 2013b; 2014; 2016), so may all be introductions from the lowlands, where all three

taxa were part of the group of plants exploited at Niah during the Late Pleistocene (Barton *et al.* 2016). *Eugeissona* and *Caryota* were also present in the Loagan Bunut core during the Early Holocene (Hunt & Premathilake 2012). It is noticeable that there is a broad chronological coincidence between the occurrences of cultivated rice at Gua Sireh and Niah on the lowlands and the appearance of *Eugeissona* and *Colocasia* in the Kelabit Highlands, but at the moment we can only speculate whether the translocation of the latter starchy plants into the Highlands accompanied the movement of people in response to the growth of rice using on the lowlands, or was accomplished by some other mechanism. *Eugeissona* seems to have spread slowly through the Highlands, being present in valley-floor deposits at Pa'Dalih around 2320 years ago and at Bario around 1300 years ago (S. Jones *et al.* 2013a,b). These occurrences suggest that the locations in which people practised propagation in the past were more varied than the current hilltops and ridges where the sago groves exploited by the Penan are mostly located.

There seems to be a period of about 2000 years between the first documented presence of domesticated rice varieties on the coast and their appearance in inland Borneo. A very similar pattern is evident in Sulawesi, where rice is thought to have arrived on the lowlands around 4000–3500 years ago, but was only present in the Besoa Valley in upland Sulawesi around 1870 years ago (Kirleis *et al.* 2011). There is a similar sequence of disjunctures in upland Sumatra: forest-disturbance episodes occur from about 7500 years ago, the first recognizable use of a starchy species seems to have been the appearance of the sago *Arenga* around 4000 years ago, and systematic rice cultivation is evidenced in the palynological record only in the last few centuries, as in the Kelabit Highlands (Flenley 1988). It is possible that these delays reflect in part the time necessary for rice to become adapted to the montane climate, but there is also mounting evidence that many foragers and vegiculturalists actively resisted using it as a food staple (Barton 2012; Barton & Denham 2011).

For the Kelabit and Penan of today and living memory, very different concepts of the forest and humans' relationship to it underpin the former's celebration of rice fields and rice cultivation as the principal way of marking themselves out as forest domesticators and the latter's reluctance to separate themselves from the forest and its benevolent spirits. The palynological and archaeological data collected by the Cultured Rainforest Project suggest that this conceptual divide between rice-growing, sago-avoiding Kelabit and rice-avoiding, sago-managing Penan may only have an antiquity of a few centuries (our Phase 4). Before that, in our Phase 3, the rainforest people

of the Highlands appear to have combined elements of both ways of life in ways that do not have modern analogues: foraging, managing sago and perhaps cultivating rice on a small scale, the latter perhaps undertaken or organized by emergent elites to produce a luxury food for *irau*-type feasts as a means of conspicuous display. Whether rising populations and/or social competition and/or trading opportunities drove the accelerating commitment to rice farming by the ancestral populations of the present-day Kelabit, what is most striking is that rice's 'need for people to grow it' went hand-in-hand with entirely new ways of living in communal longhouses that provided both protection from external aggressors and a very public arena for social actions and display. Intriguingly, the foods of the forest that accompany rice in most Kelabit meals today are willingly shared between neighbouring hearth groups in the longhouse, but not rice. Rice 'is the glue that holds a community together and which to a large extent dictates the roles which people take vis-à-vis each other' (Janowski 2003, 51). In the rainforests of the Kelabit Highlands we can begin to discern a shifting web of domesticatory relationships in which people, plants and animals were implicated in different ways at different times and with different trajectories. The complex history of rice in Borneo, from its first appearance several millennia ago to its adoption as a food staple in recent centuries, and of the equally complex history of sago, underlines the challenges that archaeologists face in trying to model foraging/farming transitions in a deep past unencumbered by post-Enlightenment rationality.

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Chapter 8

How did Foraging and the Sharing of Foraged Food Become Gendered?

Cynthia Larbey

Introduction

In his 2007 book *Feast: Why humans share food*, Martin Jones showed how something as simple as sharing food together was a social behaviour formed early in human evolution. The simple process of sitting around a fire and sharing food was a major social transition for early humans and one that every culture today incorporates into its feasting rituals. As a PhD student of Martin's, it was impossible to be excavating hearths in early modern human archaeological sites, dated to 120,000 years ago, and not think about concepts of food sharing and its implications. My research has focused on looking for early evidence of roasting roots and tubers—our early carbohydrate diet. Whilst taking samples from some of the earliest hearths around which humans would have gathered at Klasies River Cave, South Africa, the similarities between the small round hearths that are typical of the site and those of modern Khoisan hunter-gatherers were striking. This paper is inspired by the everyday food sharing that these small hearths appear to represent: the gathering and sharing of foraged plant foods, the baked beans on toast, rather than the five-course feast.

The inevitable question is 'why is food sharing so important?' and there are a number of answers to this question but in human evolution, the sharing of food was one of the first behaviours seen in the archaeological record that differentiated humans from other primates or hominins. These early humans took food back to a base and it was not consumed at the point of kill/collection (Isaac 1978a). The importance of sharing plant food, and in particular starchy plants, has rarely been discussed.

This paper reviews common ethnographic foraging and foraged food sharing practices of modern hunter-gatherer groups from rainforests, savannas, deserts and Arctic tundra, primatological and archaeological evidence for food sharing, archaeological evidence for foraged plant food and the role of cooking in human evolution. It then considers new biological

and genetic research and discussion in the context of these narratives. The hard science suggests that these genetic adaptations and strong selective sweeps that are specific to humans support a hypothesis that the carbohydrate diet supports the glycaemic metabolism of mothers who are able to give birth to fatter babies and who are more capable of breastfeeding and successfully weaning infants, and hence have a better chance of raising children to adulthood. This successful strategy was realized by early *Homo* female hunter-gatherers foraging for plants foods that included starchy plants that provided carbohydrates, nuts and seeds that provided proteins and essential fatty acids, and other plant foods that provided essential micro-nutrients—a strategy that is still visible in the foraging of modern hunter-gatherers.

Ethnographic observation of foraging

It is difficult to compare the lifeways of modern hunter-gatherers with the patterns in the archaeological record left by hunter-gatherers 100,000 years ago. Today's hunter-gatherers have different technologies and material culture and ultimately are not removed from modern society. The aim of this ethnographic comparison is to look at the patterns of foraging for starchy plants and the social importance of this food in hunter-gatherer communities that might be compared to our scientific understanding of our biological need for starch, particularly during pregnancy and weaning.

Regardless of climate, from the temperate zones of North America to the Tropics, hunter-gatherer societies have substantial plant-food foraging economies and starchy roots and tubers form a substantial part of their diet (McCune & Kuhnlein 2011). The pioneering work of anthropologists has defined various foodways among hunter-gatherer communities and while there are great variations in how plant foods are collected, there are also important similarities.

While patterns of foraging vary between communities in different parts of the world, there are

similarities common to all such groups. Foraging can be done by men, women and children, but whatever the culture it is always done by women. Cooking and snacking occurs on foraging trips—as well as men's hunting trips—but food is always brought back to camp (Hawkes *et al.* 1982; Hayden 1981; Hill 1988). The food foraged is highly seasonal for both plants and animals (Hill *et al.* 1984; Wehmeyer *et al.* 1969). Foraging often includes the snaring or capture of small animals, such as armadillos by the Ache women and lizards by Australian Aborigine women (Bliege Bird & Bird 2008; Bliege Bird *et al.* 2008; Hill 1988), although plant foods, and carbohydrates in particular, form the bulk of subsistence for most of the modern foraging societies.

Plant foods account for the bulk of the calorie intake in many societies: up to 90 per cent plant food among Australian Aborigines (R. Jones 1980), around 50 per cent among the Ache of Paraguay and the Yora of Peru (Hill 1988; Kaplan *et al.* 1985), 60–80 per cent among the !Kung (Draper 1975; Lee 1979) and 99 per cent in the case of the Tsembaga Marina people of Highland New Guinea (R. Jones 1980). Even among circum-Arctic people, where foraged plant food may represent only 10 per cent of their total calorie intake, the collecting and drying of berries, sorrel and tree cambium that form this 10 per cent is controlled by women (Hayden 1981).

The knowledge of what plants are available where, in which season, how they should be processed and which foods should be eaten as 'medicine' and which used for wounds or infections is a skill handed down through generations. Amongst some modern hunter-gatherers, their plant knowledge may only extend to a limited number of species, as with the Hadza (Schnorr *et al.* 2014), whilst others may have an extensive list of hundreds of plants (Bliege Bird & Bird 2008). Among the Zu/'hoã people of the !Kung, only the exploitation of seasonal water and other plant resources determines the move to other camps away from camps around trees producing mongongo nuts (Barnard 1992). Martin Jones defined the term 'ecological intelligence' to explain hunter-gatherers' deep understanding of the plantscape and in archaeology we see evidence of this from the past in the way that some plants, such as sedge grasses with anti-parasitic properties, were used for bedding, seen at Sibudu Cave 70,000 years ago (Wadley *et al.* 2011). Other plants were included in an adhesive mix used for hafting spears, while some plant toxins were used on the tips of spears (Lombard 2005; Wadley *et al.* 2009). In arid regions some tubers can provide necessary water (Steyn 1984).

Significantly, however, the fruits, nuts, seeds and leaves, roots and tubers provide a breadth of

both macro- and micro-nutrients that are essential both to pregnant women and to growing children (Cunnane & Crawford 2003). That women and children often dominate foraging has been suggested as having evolutionary implications, because this food source is associated with providing proteins and lipids (including essential fatty acids that are only obtained from plant foods and carbohydrates necessary for successful reproduction) and with breastfeeding and weaning. Women and children are able both to eat whilst foraging and to bring food back to the camp to be shared, and are not dependent upon the success of hunting (Woodburn 1982); this form of sharing of plant food is important.

Ethnographical evidence of food sharing

The timing for the emergence of the human species (*Homo sapiens*) has recently changed with the discovery of 300,000-year-old fossils in Morocco (Hublin *et al.* 2017; Richter *et al.* 2017) and behaviour that has defined modern humans has been challenged by the discovery of cave burials by the new human species, *Homo naledi* (Berger *et al.* 2015). Despite these discoveries, one of the early behaviours that defined humans has been the sharing of food: the collecting of food that is taken to a base camp and eaten together (Foley & Lee 1989; Isaac 1978a,b). It distinguishes us from other primates, among which the sharing of food is not common (Zihlman 1978).

Chimpanzees rarely share plant foods except between mothers and weaning infants (McGrew 1981, 47). The hunting and sharing of meat among chimpanzees, on the other hand, is a cooperative, highly structured, often political process that, while not competitive, is a means of reaffirming social relationships and alliances within the group (M. Jones 2007; Teleki 1973). While every other part of a kill is shared, the head/brain is retained by the dominant male/hunter (Teleki 1973). The brain is a rich source of lipids (fat) and in a diet that is primarily based on plant foods, but supplemented regularly by hunted meat, fat seems to be the key missing element. The only chimpanzees not sharing in this kill are the infants. Infants are never given meat, so weaning must be solely based on plant foods given by the mother; a photograph in Teleki (1973, 42) shows a juvenile chimpanzee in supplication, requesting some of the leaf wad his mother is chewing, which suggests that weaning is achieved partially by pre-chewed plant food. Some modern hunter-gatherer societies pre-chew food to wean children (Han *et al.* 2016).

Whilst foraging societies vary widely across the world, food sharing is common to all communities

and has become a key theme among anthropologists. Food is shared with many different objectives, mostly applied to the sharing of meat: a) food for foraging partners; b) food for family; c) reciprocity now or delayed for some time in the future when food might be scarce or a mother may need help with feeding older children (Woodburn 1982); d) food for non-food benefits, such as sex; e) costly showing-off, which is associated with display and associated with (d); and f) tolerated scrounging/theft (Marlowe 2004). Foraged plant-food sharing is generally focused on (b) and (c).

The social models of hunter-gatherers or foraging societies vary across the world and across all latitudes. Nevertheless, in both egalitarian societies such as the !Kung in the Kalahari, the various groups of the Khoisan of South Africa, the Hadza of Tanzania, the Batek in Malaysia, the Ache of Paraguay and the Agta of the Philippines (Barnard 1992; Endicott 1984; Endicott & Bellwood 1991; Endicott & Endicott 2008; Estioko-Griffin & Griffin 1981; Hill 1988; Lee 1978; 1979; Woodburn 1982), and in more male-dominated societies, such as the Australian Aborigines, North-western peoples or American First Nation peoples (Bliege Bird & Bird 2008; Bliege Bird *et al.* 2008; Gould 1986; Hamilton 1975; Hayden 1981; Watanabe 1968), women are mostly responsible for foraging food, for control of the domestic space (even if that is only a hearth) and for the sharing of foraged food.

In some hunter-gatherer communities, such as the Shoshoni of North America, the Onge of the Andaman Islands and all Inuit communities, plant foods may not be shared at all. Meat, on the other hand, which forms 90 per cent of their diet, is shared widely, not just amongst family, but with the entire band (Bodenhorn 2000). The reasons for this are not offered. It could be that plant foods are so scarce in these regions they are highly valued, or that the toxicity profile of the plant foods was sufficiently high that people preferred to pick and process their own (Nolan & Turner 2011).

A significant feature of women controlling the process of sharing of foraged food is that this carries great social significance in many cases (Draper 1975; Gould 1986; Hamilton 1975; R. Jones 1980; Marlowe 2004; Steyn 1984; Woodburn 1982; Wrangham *et al.* 1999). Among the Khoisan, the sharing of plant foods defines membership of a family unit, while meat is shared throughout the band. Both Khoe Khoe and Nharo women of the Khoisan have authority over the house and food and control over the gathering and distribution of plant food (Barnard 1992). This affords women significant economic power when a large percentage of modern hunter-gatherer subsistence comes from foraged plants and is shared out only by women.

At the centre of food sharing is the strategy of survival, an important part of which is feeding children. Although these ethnographic studies show that women are generally independently capable of finding the foods they need for the health of themselves and their babies, there is great variance in the strategies communities employ to care for and feed older children. Often young children up to five years old will follow their mother until they can forage for themselves (Lee 1979). Sometimes siblings or grandparents take responsibility for them, as in the Hadza (Crittenden *et al.* 2013), but in other regions there is a more corporate responsibility for children within the community and reciprocity is a system that can be relied on at a time when the food supply may need to be buffered (Endicott & Bellwood 1991; Estioko-Griffin & Griffin 1981). Among the Hadza, any pregnant woman is able to ask for food from anyone at any time and she is deemed to be at risk if refused food (Woodburn 1982). These cooperative forms of food sharing, such as that seen among groups such as the Efe in the Ituri forests of the Democratic Republic of the Congo, the Ifaluk on the Pacific Island of Ifalik or the Meriam of the Torres Straits, are highly geared towards reproductive success (Betzig & Turke 1986; Bliege Bird & Bird 1997; Ivey 2000).

Whether or not hunting and meat form a large part of the overall community economy, regardless of social model, the foraging for and sharing of staple plant foods, dominated by carbohydrates in the form of roots and tubers, fruits, nuts and seeds, appears to be a fundamental system for ensuring a healthy reproductive process and is controlled by women (Adams & Smith 2011; Gould 1986; Hayden 1981; Lee 1978; McCune & Kuhnlein 2011; Rosner 2007; Woodburn 1982). However, until recently, the discussion on potential parallels with human evolution and the archaeological narrative on the evolution of the human diet has been dominated by the role of meat/protein. The role of carbohydrates and plants foods in human evolution is becoming an increasing research focus.

The archaeological evidence

Food sharing

Although chimpanzees organize and cooperate in hunting and the process of meat sharing as a part of primate social and dietary behaviour, it seems likely that advances in foraging and gathering distinguished the later Australopiths such as *A. aethiopicus* (2.7 million years ago) from non-human primates (M. Jones 2007; McGrew 1981; Teleki 1973; Zihlman 1978; Zihlman & Tanner 1978).

The advances in foraging efficiency among Australopiths were about their increasing ability to predict and detect plant food sources in a period of climate change, remembering where and when these plants grew and in which seasons (McGrew 1981). Increased cognition would have been needed to develop a mental topographical map that would have allowed these early hominids to plan foraging and recognize underground tubers, rather than foraging opportunistically (McGrew 1981, 59).

The earliest evidence of food sharing behaviour comes probably from an early *Homo* species, *Homo habilis*, in East Africa 2 million years ago, where the evidence of animal bones and stone tools in a base camp suggests food was collected elsewhere and brought back to camp. This delayed consumption distinguishes humans from other primates (Isaac 1978a) and is important as a basis for looking at how a family unit might share food. Later evidence from the Magdalenian period (20–17,000 years ago) in Pincevent, France, also indicates food sharing, suggested by the refitting of bones from one reindeer that had been shared among a number of hearths on the one site (Enloe 2010).

It is difficult for archaeological food sharing evidence to be used as evidence of social structure. Many external factors influence food gathering behaviours. These are primarily climate driven; for example, in areas or periods where food is scarce, cooperation in food collecting and sharing is less likely (Foley & Lee 1989). Even a rainy day can mean more food is cooked in a rock-shelter than in the open (Woodburn 1982). The archaeological spatial patterns of hearths, middens, bones or ash dumps are difficult to interpret; the signatures of egalitarian or non-egalitarian hunter-gatherer communities can often be similar and, furthermore, are not indicative of the number of families (Domínguez-Rodrigo & Cobo-Sánchez 2017).

The archaeological evidence of shared foraged plant food is even more difficult to interpret and can only be inferred by plant foods brought back to camps. Whilst this body of evidence is growing, evidence of plant-food sharing has been rare. It is, therefore, interesting to consider the themes of food sharing in the context of the recent discovery of charred remains of roots and tubers from the Middle Stone Age (MSA) site of Klasies River, South Africa.

Discovered in the ash deposits of undisturbed hearths both from the 120,000-year-old MSA level and the 58,000-year-old Howiesons Poort levels, this evidence of processing roots and tubers is among the earliest evidence found for humans cooking starchy plants (Larbey *et al.* in preparation). More direct evidence from starch grains of roots or tubers and grass

seeds, fossilized in dental calculus, was obtained from skeletons discovered in Cave 1b at Klasies River, with further evidence of tuber consumption from Blombos Cave in the Western Cape (Henry *et al.* 2014). This combined evidence suggests that 100,000 years ago, early humans in South Africa had a foraged diet that included cooked roots and tubers, together with seeds and augmented with fat and protein in the form of shellfish, ostrich eggs and small mammals, such as tortoises and hyrax, very similar to the diet Pontzer suggested would be needed by the *Homo* genus to meet their energy requirement (Pontzer 2012).

The archaeobotanical samples from Klasies River were taken from undisturbed hearths for two reasons: firstly, burnt plant remains are preserved as carbon (one of the few ways in which it is possible to find plant remains in deep time contexts); secondly, if they are associated with other food remains, rather than fuel or burned bedding, it suggests that these plants were probably cooked for food. These samples were associated with other food remains and were clearly not bedding, either in context or from the fact that they were roasted from fresh; fresh tubers being unlikely to be in either bedding or used as fuel.

At Klasies River there are differences in the size and content of the combustion features or hearths in the Main Cave site. Throughout all occupation periods, the site is characterized by small (*c.* 30 cm diameter), circular ash-filled depressions with very little charcoal (Deacon 1993). During MSA1 (MSA1 covers the period in Africa from 280–40,000 years ago), these individual hearths include burnt shell, micromammal bone and small fragments of both faunal and plant remains. By contrast, at Klasies River main cave, the mega-faunal remains, those of elephant, rhinoceros, hippopotamus and the now extinct giant buffalo (Van Pletzen 2000), appear to be in much larger hearths, with a greater prevalence of charcoal. Certainly the presence of big game would suggest cooperative hunting, which would further imply a system of food division. This big hearth/little hearth scenario may reflect different forms of social behaviour and food sharing and is potentially consistent with big hearths relating to feasting/community sharing and little hearths relating to more frequent foraged food, for smaller groups.

Archaeological evidence for Palaeolithic plant food

Although early evidence is limited, evidence for plant food found in the Upper Palaeolithic/Late Stone Age/Epipalaeolithic is consistent across the world. The remains of cereals, nuts, roots and tubers have been found from 40,000 years ago and this evidence provides a clear picture of an already well-developed ecological intelligence that is allowing humans fully

to exploit starchy plant resources in a wide variety of biomes (Table 8.1).

Archaeology—foraged plant foods and their role in human evolution

The importance of gathered plant foods in early human evolution has been generally acknowledged from some of the earliest hominids, Australopithecines (4–2 million years ago). The early Australopithecines, such as *A. anamensis*, appeared 4 million years ago, with *A. africanus*, the most likely ancestor of the *Homo* genus, appearing 3.3 million years ago (most likely because in *A. africanus* we see the adaptation of the lower spine, the lumbar lordosis, to allow a bipedal female to adapt her centre of gravity when pregnant: Whitcome *et al.* 2007). The appearance of savannas and marshland caused by climate change that isolated patches of previously extensive forest prompted Australopithecines (4–1.2 million years ago) to adapt to foraging for a diet that included sedge grasses and tubers and occasionally meat; in general, greater dietary flexibility and mobility would have been needed (Cerling *et al.* 2011; Lee-Thorp *et al.* 2012; Macho 2014; Schoeninger 2014; Sponheimer & Lee-Thorp 2015).

Changes in stable isotope signals from the bones and microwear on the teeth of *A. robustus* and *A. boisei* (2–1.2 million years ago) signal an alteration in diet compared to the earlier *A. anamensis* (4 million years ago: Sponheimer & Lee-Thorp 1999; Sponheimer *et al.* 2006; Ungar *et al.* 2006; Van Der Merwe *et al.* 2003). During an almost two-million-year period, there was a shift from a plant diet that consisted purely of forest-based fruits and fibrous leaves, stems and bark to a plant diet that included grasses and roots and tubers and increasing quantities of meat (Dominy *et al.* 2008; Lee-Thorp *et al.* 1994; Peters & Vogel 2005; Pontzer *et al.* 2011; Sponheimer & Lee-Thorp 2015; Sponheimer *et al.* 2005a,b; 2013; Van Der Merwe *et al.* 2003).

Although the transition from a fibrous plant-based diet to a diet consisting primarily of meat has been described as the major driver behind larger brains (Aiello & Wheeler 1995), it is more likely that the high energy cost for the complex suite of morphological changes, such as larger brains, smaller guts, bipedalism, longer limbs and enlarged lung capacity, had to have been met by glycaemic (digestible) carbohydrates (Bramble & Lieberman 2004; Hardy *et al.* 2015; Leonard & Robertson 1997; Leonard *et al.* 2003). A diet that comprises largely leaves, stems and fruits consists primarily of dietary fibre or non-starch polysaccharides (nsp), such as cellulose, lignins or oligosaccharides, which are indigestible by humans (Englyst & Englyst 2007). Such a diet is unlikely to meet this energy requirement. Plant foods such as

roots and tubers provide more digestible starches and fewer nsp, increasing the energy available from that food and reducing the need for a large gut to process large quantities of highly fibrous plant food (Aiello & Key 2002). Savannas and wetlands were prime sources for these underground storage organs and it is these roots and tubers, combined with an increased meat diet, which are most likely to have given early *Homo* the energy resource to make significant morphological changes (Hardy *et al.* 2015). Earlier *Homo* species such as *H. habilis* (2.1–1.5 million years ago), *H. heidelbergensis* (600–200,000 years ago) and *H. ergaster/erectus* (1.9 million–143,000 years ago) are similarly acknowledged as having a diet that included meat, roots and tubers, and seeds (Antón & Snodgrass 2012; Perez-Perez *et al.* 1999; Pontzer 2012; Wood & Strait 2004).

Archaeology—cooking and evolution

For *Homo erectus* and the later *Homo* species, increased energy from food also came from one of the biggest technological leaps made by humans: the control and manipulation of fire and the cooking of food.

Cooking food represented an evolutionary step-change for humans. Martin Jones describes in detail the social step-change not only in controlling fire, but in the ability to make eye contact across it as humans sat around it and to share food around a hearth without the aggression this might normally trigger in all other mammals (M. Jones 2007). Cooking increased the calorific value of meat and plant foods and would have increased the breadth of diet, bringing previously indigestible foods into their dietary choices (Carmody & Wrangham 2009; Wrangham 2009; Wrangham & Carmody 2010). The cooking of meat, eggs and starchy tubers will increase their exposure to digestive enzymes, making them more digestible and palatable. Even brief roasting will neutralize anti-nutrients such as plant secondary metabolites, pathogens and parasites in meat (Carmody *et al.* 2011; Schnorr *et al.* 2016). The cooking of plant foods such as roots and tubers would essentially pre-digest them, turning them into preformed glucose and allowing greater energy to be derived from any given quantities of foraged food (Carmody & Wrangham 2009; Carmody *et al.* 2016; Wrangham & Carmody 2010). The increase in energy provision also supported the evolution of larger brains and the significant morphological changes.

The earliest evidence of cooked food dates to 790,000 years ago (Alperson-Afil 2008; Goren-Inbar *et al.* 2002; Melamed *et al.* 2016) which coincides with the evolution of *Homo erectus* (Hardy *et al.* 2015). Features such as larger bodies (particularly of females), longer gestation, the presence of fat deposits on infants, lactation and decreased birth intervals would have

Table 8.1. Published studies on remains of starchy plants during prehistoric hunter-gatherer periods (not exhaustive).

Region	Age (millennia)	Period	Type of plant remain	References
<i>East & Southeast Asia</i>				
Zengpiyan, China	12–7	Upper Palaeolithic	Charred parenchyma	Zhao 2011
Shizitan, China	13.8–8.5	Mesolithic	Micro-fossil yam & acorn residues on grindstones	Liu <i>et al.</i> 2011
Higashi-Kurotsuchida, Japan	13.6–0.3	Incipient Jomon	Charred walnuts, acorns	Kobayashi 2004
Niah Cave, Sarawak, Borneo	27–10	Upper Palaeolithic	Charred parenchyma, nuts, fruits, seeds	Barker <i>et al.</i> 2007; Barker & Paz 2007; Barton <i>et al.</i> 2016
Baguia & Baucau, Timor Leste	16–17	Upper Palaeolithic	Charred parenchyma, probably taro and yam	Oliveira 2012
Palawan, Philippines	11	Mesolithic	Charred seeds, nuts, parenchyma	Ochoa <i>et al.</i> 2014
<i>Australia & Pacific</i>				
Medjedbebe, Northern Territory, Australia	60–50	MSA	Charred seeds, tubers	Clarkson <i>et al.</i> 2017
Cuddie Springs, New South Wales, Australia	30	LSA	Micro-fossil grinding grass seed residues	Fullagar & Field 1997
Carpenter's Gap, Western Australia	40–24	MSA	Charred seeds and tubers	McConnell & O'Connor 1997
Kosipe Mission, Papua New Guinea	40–50	Palaeolithic	Charred pandanus nuts	Summerhayes <i>et al.</i> 2010
<i>Southwest Asia</i>				
Ohalo II, Israel	23	Upper Palaeolithic	Water-logged grass seeds, pistachio nuts, fruits	Kislev <i>et al.</i> 1992; Weiss & Kislev 2004; Weiss <i>et al.</i> 2004
Wadi Jilat, Jordan	19.5	Upper Palaeolithic	Desiccated seeds	Colledge 2013
Öküzini Cave, Anatolia, Turkey	18.2–11.8	Epipalaeolithic	Desiccated fruit, nuts, tubers, roots, bulbs	Martinoli 2004; Martinoli & Jacomet 2004
Wadi Kubbaniya, Egypt	20–12	Epipalaeolithic	Desiccated roots and tubers	Hillman 1989; Hillman <i>et al.</i> 1989b
Shubayqa I, Jordan	14.6–11.5	Natufian	Charred USOs, nutlets, grass seeds	Arranz-Otaegui <i>et al.</i> 2018
Wadi Hammeh 27, Pella, Jordan	12	Late Natufian	Charred seeds, starchy plant parts	Colledge 2013
Hayonim Cave, Western Galilee, Israel	12.3–12	Natufian	Charred wild barley, almonds, lupin seeds	Hopf & Bar-Yosef 1987
Abu Hureyra Phase I, Syria	12.5	Epipalaeolithic	Charred almonds, USOs, club-rush, wild wheats and ryes	Hillman <i>et al.</i> 1989a; Hillman 2000
<i>Europe</i>				
Dolní Věstonice, Czech Republic	30	Upper Palaeolithic	Charred parenchyma	Beresford-Jones 2006; Mason <i>et al.</i> 1994; Pryor <i>et al.</i> 2013
Hohle Fels Cave, Germany	40–15	Upper Palaeolithic	Charred seeds	Riehl <i>et al.</i> 2014
Mezhirich, Ukraine	22	Upper Palaeolithic	Charred seeds, berries	Soffer <i>et al.</i> 1997
Cova de les Cendres, Spain	14–14.5	Magdalenian	Charred seeds, fruits	Varea <i>et al.</i> 2018
Santa Maria, Spain	12–9	Epipalaeolithic	Charred fruits, seeds	Aura <i>et al.</i> 2005
Franchthi Cave, Greece		Palaeolithic–Mesolithic	Charred seeds, nuts	Hansen 1991
Calowanie, Poland	11.3–8.3	Mesolithic	Charred parenchyma	Kubiak Martens 1996

significantly increased energy costs, but fat would have provided buffers against periods of fasting when food was scarce (Aiello & Key 2002; Hardy *et*

al. 2015). More digestible starchy plant foods, along with meat, eggs and marine resources such as shellfish where possible, would have enabled greater invest-

Table 8.1. (Continued.)

Region	Age (millennia)	Period	Type of plant remain	References
<i>Canada & Americas</i>				
Pacific Northwest Coast, Canada	5.7–4.2	Late/Middle Component	Water-logged tubers	Hoffman <i>et al.</i> 2016
Dryden Cave, Great Basin, USA	8–6	Early Archaic	Semi-aquatic monocot tubers from coprolites	Neumann <i>et al.</i> 1989
Clauson Site, New York, USA	8	Late Archaic	Charred parenchyma	Levine 2004
LSP1 Rockshelter, South Central Oregon, USA	10–7.6	Early Archaic	Charred and uncharred seeds	Kennedy & Smith 2016
Shawnee Minisink, Pennsylvania	10.9	Archaic	Charred seeds	Dent 2007
Edwards Plateau & Post Oak Savannah, Texas, USA	8–9	pre-Columbian	Baked geophytes in ovens	Thoms 2008
Andes, Peru	12.4–11.5	Upper Palaeolithic	Charred parenchyma	Rademaker <i>et al.</i> 2014
Monte Verde, Chile	12.8–12.4	Upper Palaeolithic	Charred and dried tuber remains	Ugent <i>et al.</i> 1987; Ugent 1997
<i>Africa</i>				
Klasies River & Blombos Caves, South Africa	102–98	MSA	Starch granule in fossil dental calculus – grass seeds and USO	Henry <i>et al.</i> 2014
Sibudu, South Africa	77	MSA	Charred seeds and rhizomes	Sievers 2006; Sievers & Muthama Muasya 2011
Various sites, South Africa	11–110	MSA & LSA	Grass seeds, some roots and tubers	Nic Eoin 2016
Boomplaas, South Africa	43	LSA	Desiccated plant remains and fruits	Deacon 1995
Highlands Rockshelter, South Africa	30	LSA	Desiccated plant remains in cave	Deacon 1993
Strathalan B, South Africa	22	LSA	Charred and desiccated corms	Opperman & Haydenrych 1990
Grotte des Pigeons, Taforalt, Morocco	15–13.7	Epipalaeolithic	Charred acorns, pine nuts, legumes, wild grasses	Humphrey <i>et al.</i> 2014
Haua Fteah, Libya	12.6–7.9	Caspian	Charred large-seeded legumes, fruits, berries	Barker <i>et al.</i> 2010

ment in reproduction without compromising other activities (Pontzer 2012). Humans are the only altricial primate, giving birth to helpless infants that require significant parental investment until independence or maturity. Altriciality in humans is caused by the energetic demands of the large-brained foetus upon the mother, so that by nine months, the foetus' energy requirements exceed the mother's ability to meet both the baby's needs and her own and she must give birth (Dunsworth *et al.* 2012).

Human biological need for carbohydrates

Humans need glycaemic carbohydrate to support the healthy function of the brain, kidney medulla, red blood cells and reproductive tissues, as well as the daily energy requirement. The brain alone accounts for nearly 25 per cent of the adult basal metabolic expenditure (Hardy *et al.* 2015, 255). In the absence of dietary carbohydrates, or during periods of starvation,

the brain will use energy from the lipid metabolism instead, but this will only provide 80 per cent of the brain's energy requirement (Hardy *et al.* 2015, 256).

Diet in pregnancy and fat babies

Plant foods can provide a balanced diet that includes carbohydrates, essential fatty acids (EFAs) and proteins important for pregnant women. Increased gluconeogenesis is an early metabolic adaptation to pregnancy and by the last trimester there is high, almost entire, utilization of glucose by the foetus and placenta. This can be up to 50 per cent of the mother's total glucose; essentially insulin resistance develops to redirect glucose away from the mother toward the foetus (Butte 2000; Hardy *et al.* 2015; Herrera 2000). There is also a direct correlation between maternal glucose levels and infant size, with mothers requiring at least 70–130 g of carbohydrate per day (Hardy *et al.* 2015). For hunter-gatherers, these essential carbohydrates and EFAs would come from roots, tubers, seeds and

nuts. In the final stages of gestation, in preparation for breastfeeding, EFAs come from the mother to the newborn (Herrera 2000). Peak breastfeeding can require an additional 70 g of glucose per day for the synthesis of lactose, and the survival of infants is dependent upon the mother being able to meet the increased demand for glucose. This level of glucose demand can only be met by carbohydrate intake by the mother (Hardy *et al.* 2015). This maternal metabolism has evolved to meet the needs of fatter babies, and building fat reserves in both mother and baby had evolutionary significance. Human babies are the only terrestrial mammals to have evolved foetal body fat. Even newborn chimpanzees are born with no body fat, whereas a human full-term newborn is estimated to have at least 500 g of subcutaneous fat (Cunnane & Crawford 2003). The evolutionary hypothesis is that to produce bigger brains, it was first essential to have fatter babies (Cunnane & Crawford 2003; Leonard *et al.* 2003).

There are other benefits to increased infant body fat, however, most notably improved survival rates for mother and child. The nutritional buffer offered by the baby's fat layer both prior to the start of breastfeeding and at weaning, as well as during any periods of interrupted food supply, enhance the chances of infant survival (Cunnane & Crawford 2003; Kuzawa 1998). This is particularly important at weaning, when infants lose the mother's immune protection and are vulnerable to infections and disease. The energy required to build these fat reserves would mainly have come from carbohydrates. From the ethnographic research we see carbohydrates dominate the plant foraging, but archaeologically gendered foraging can only be inferred.

Where there are no carbohydrates – circum-Arctic populations

If carbohydrates are so critical to reproduction, how have populations with little access to carbohydrates been so successful? The communities of the circum-Arctic regions have diets that are high in protein and lipids and necessarily low in carbohydrates because of only brief seasonal access to plant foods. In latitudes above 60° N and in conditions of extreme cold, inland communities depend on reindeer/caribou herding (Kuhnlein & Soueida 1992; McCune & Kuhnlein 2011). In the prehistoric past, meat and fat would have come from following and hunting reindeer and woolly mammoth on their migrations (Nikolskiy & Pitulko 2013; Pitulko *et al.* 2004; 2015). Coastal populations were, and are, dependent on the meat and fat of marine mammals such as whales, seals and walrus (Bogoras 1901; Fediuk *et al.* 2002; Kuhnlein & Soueida 1992; Rabinowitch 1936).

Modern Inuit communities with a deep DNA lineage in this region have adapted to both the extreme cold and high fat/high protein diet by adaptive traits such as increased basal metabolic rate, low serum lipid levels and increased blood pressure (Cardona *et al.* 2014; Leonard *et al.* 2005). Many people within these communities have also undergone genetic adaptations to these environmental conditions. A mutation in the *CPT1A* gene, which normally regulates energy and blood glucose levels during periods of fasting, occurs with high frequency among Canadian and Greenland Inuit and at 68 per cent frequency among northeast Siberian communities (Clemente *et al.* 2014). However, the mutation of this gene blocks the normal function of the *CPT1A* gene, which can lead to high infant mortality. The Nunavut are the largest Inuit population in Canada and have a sudden infant death rate that is seven times higher than the Canadian national average (Collins *et al.* 2010). Despite the serious implications for infant mortality and general health, the *CPT1A* genetic mutation represents a strong genetic selective sweep, the advantage of which has been interpreted as a possible adaptation to a high-fat diet and/or protection from the cold environment that dates back to 6000–24,000 years ago (Clemente *et al.* 2014).

In the Dutch Hunger Winter of 1944–45, during the Second World War, a combination of food blockades by the Germans and a particularly severe winter saw the people of the Netherlands in famine conditions for seven months. Deprivation in pregnant women at all stages and those who became pregnant immediately after the relief of the famine produced conditions of glucose intolerance in all children in old age and a greater prevalence of Type II diabetes because of the impact on the glycaemic metabolism (Roseboom *et al.* 2006; Schulz 2010). Further studies have shown that deprivation of carbohydrates in women during pregnancy can increase body mass index in the children (Heijmans *et al.* 2008).

In general, deficiency in carbohydrate diets during gestation correlates strongly with higher levels of pre- and post-birth mortality and poorer-quality milk during breastfeeding (Hardy *et al.* 2015; Herrera 2000). The significance of carbohydrates in the human diet, particularly their role in reproduction, has been highlighted by recent genetic research (Hardy *et al.* 2015).

Genetic starch digestion *AMY* adaptation

The human ability to digest carbohydrates is controlled by amylase genes in the saliva (gene *AMY1*) and in the pancreas (*AMY2a* and *AMY2b*). These genes have undergone a significant adaptation and form the

largest area of genetic copy number variation (cnv) in the human genome (Carpenter *et al.* 2015). The gene *AMY1* expresses the protein amylase in human saliva that initiates the process of hydrolysing starch into disaccharides and trisaccharides (simple sugars); the process is then completed in the small intestine with *AMY2* amylase expressed in the pancreas (Hardy *et al.* 2015).

Whilst great apes and archaic human species such as Neanderthals and Denisovans have the diploid copy number of two *AMY1* genes (Prufer *et al.* 2014), in the human lineage, the amylase genes have expanded, with *AMY1* copy numbers varying between 2 and 20 (Lazaridis *et al.* 2014; Perry *et al.* 2007; Prufer *et al.* 2014). This selective sweep occurred around 300,000 years ago and post-dates human divergence from Neanderthals and Denisovans (Inchley *et al.* 2016). These duplicate starch digestion genes have been proven to be active in expressing the starch digesting enzyme amylase, meaning that starch acquired through plant carbohydrates would have formed an important part of the early human diet (Falchi *et al.* 2014).

It has been hypothesized that the advent of cooking increased the availability of digestible starches, which favoured the duplication of *AMY1* genes (Carmody *et al.* 2016; Wrangham 2013). However, this duplication happened only in humans and lags the advent of cooking by some 500,000 years. Therefore, whilst cooking improved the quality and energy availability of the human diet significantly, it only facilitated this adaptation. It may also be a dietary adaptation unique to the human lineage (Inchley *et al.* 2016), as opposed to the Neanderthal/Denisovan lineage.

Hardy and colleagues have also suggested that the need for multiple copies of the salivary amylase gene *AMY1* would have had great importance for infants prior to weaning, as they are dependent upon preformed glucose and have no pancreatic amylase at birth (Hardy *et al.* 2015, 259). And given the clear bias in female foraging for starchy foods, it is proposed here that the strong selective pressure that caused this selective sweep may be as a result of reproductive success offered by an improved carbohydrate diet.

Conclusion

Palaeolithic/Middle Stone Age hearths are often associated with food remains and the manufacture of stone tools, the place around which a family or communities gathered to cook and share food, make stone tools and weapons and, it can only be supposed, communicate plans for hunting and foraging trips. The cooking done in the small 30 cm diameter hearths of Klasies River is indicative of small food, not the big, meaty

food of the mega-faunal remains in some of the other, larger combustion features. Martin Jones discussed the important of feasting in providing bonding of communities over millennia, but the sharing of foraged plant foods provided (and continues to provide) something possibly as fundamental.

The ability of a woman to find food, especially carbohydrates, to feed herself and her children, to meet her own and their energy requirements and to forge relationships within a community by sharing plant food to ensure some kind of reciprocity when food becomes scarce, may have been key to human evolution. It was the basis of the transition of ecological intelligence, knowledge passed from a mother to her children about not just how to find food, but the right balance of nutrients at the right time of year, in the right place. The focus of our biological and genetic adaptations to carbohydrates has been on successful reproduction and children surviving to adulthood. Whether men protected women, or foraged with them, whatever the social structure of the community, this fundamental concept has enabled *Homo sapiens* to evolve and to colonize most biomes on the planet.

Acknowledgements

I would like to thank first and foremost Professor Martin Jones, who as my supervisor has taught me most how to think and was then extremely patient! Professor Dorian Fuller, Professor Xinyi Liu and Dr Emma Lightfoot for the honour of inviting me to contribute to this monograph; Professor Sarah Wurz, director of the Klasies River site, for her generosity in allowing me access to the site and her subsequent support; Dr Susan Mentzer for her generosity in the geoarchaeological interpretations of the Klasies River site; Professor Christopher Henshilwood for my introduction to the MSA sites of South Africa; AHRC of Great Britain for funding my PhD; and Dr Andrew Corbett.

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Chapter 9

Agriculture is a State of Mind: The Andean Potato's Social Domestication

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How far have we come in understanding agricultural origins and domestication? A long way in the past 30 years. We can now discuss both morphological and genetic relationships, intended and unintended processes (Fuller *et al.* 2014; Larson *et al.* 2014). We have learned that different plants had very different selection histories; we know that some wild and domestic interactions have continued over time, creating a diversity in domesticates that was not envisioned when this discipline began. As the book *Documenting Domestication* (Zeder *et al.* 2006) notes, there were/are many paths to domestication, some narrow, some broad, some fast, but most slow. It has been a long-entwined process that continues today, not just with genetically modified crops, but in many farmers' fields. With the multi-dimensional work of archaeologists through botanical and faunal morphological evidence, landscape and tool evidence and the genetic work on domesticates and their wild progenitors, we are rapidly expanding our data and insights on the dynamic temporal and spatial placement of domestication and agricultural origins in their cultural contexts.

It is in this context that I discuss here some ideas about the social, cultural and ontological points of view that accompanied the process of domestication and how both plants and people reacted to one another, each training the other to help them along in their life success. As people entered a new environment, they clearly sought out and engaged with plants and animals that they were familiar with, that were similar to those that they knew, those that tasted like and smelled like the plants or animals they were used to. They also would alter and construct the environment so that they could work with it in ways they understood. People moved across the landscape foraging on plants that they were familiar with on a daily basis. This activity was goal directed and innovative, as the knowledge of growth habits, yield, processing and all that it took to make the living things edible was transmitted throughout

the groups that roamed across the landscapes. This continual interaction with the world around them meant that, as in all ecology, people were altering and adjusting as they went, as were the plants and animals (Laland & Sterelny 2006). This continual process intensified as groups focused on specific locations and on specific resources. Part of people's success was cooperation and a sense of mutual responsibility, in that people did not live or move around alone, but worked together in small groups. Nor did they rage at the environment. As with all animals living in the wild, there is a give and take, a coping with the constraints and potential of the resources at hand, a sense of extracting as well as protecting. People were no different. As they increasingly returned to the same places, they learned more intimately about some specific plants and animals that they focused on, and in turn were a focus for the plants and animals. Over the generations, both the people and the ecological niches altered together. Certain resources were encouraged, others were diminished. Such foraging promoted general cooperation amongst people, evident still in communities around the world. This human agency in non-human evolution is seen most obviously in the process of domestication, as the plants and animals change enough for a co-dependence to develop that is often irresistible and irreversible. People have to care for the plants and/or animals and the plants and animals have to give yields to sustain their caretakers. The form of these interactive co-dependent histories varies by environmental setting.

Here I want to investigate this relationship of environmental maintenance and food production through one important and understudied domesticated crop, the potato tuber (*Solanum* spp.), domesticated in the South American highlands, well south of the Neotropical nexus where many plants were domesticated (Piperno & Pearsall 1998; Piperno *et al.* 2017). Focusing on this now globally important staple from the Andean region of South

America, the edible *Solanum* tuber-bearing species' difficult archaeological visibility and relatively poor preservation make them one of the least known staple crops in the archaeological record, although the genetics are helping us get a better sense of the timing and location of this plant–human interaction history. The macrobotanical record will never yield a detailed account of all root and tuber use, as what people harvest and eat is watery storage tissue that often lacks a preservable supportive structure. We can, however, surmise that geophytes in general were the focus of much gathering interest and engagement since their earliest encounter, perhaps even more so than grains, as they were harvestable throughout the year, whereas grains tend to mature once a year. Digging for roots is a very old food tradition, surely being one of the main forms of food gathering of our hominid scavenging/gathering ancestors as well as successful foragers (Veth *et al.* 2017). Cooking and the control of fire is a form of transformation that goes back to either around 1.9 million years ago, as Wrangham (2009) suggests, or 200,000–300,000 years ago, as Brace (1995, 578) proposes.

Once fire was harnessed and cooking could occur with gathered foods, bitter roots and tubers would have become even more important, as cooking can break down large compounds and detoxify some of the alkaloids in tubers, coordinating with the human stomach and tooth changes to keep an edible diet available (Johns 1990). This subterranean collection strategy, along with cooking, followed migrants out of Asia across the Pacific and the American continents. We should not be surprised that the earliest inhabitants of South America were seeking out edible roots and tubers to eat, engaging with these taxa quite intensively in all ecological niches where they were encountered. And what a collection of tubers they found in South America. We now know that there were many tuberous plants that have responded to human engagement across that continent, some having become global foods even before the Age of Exploration (Mann 2011), such as the sweet potato (*Ipomoea batatas* [L.] Lam.), and others at the start of it, as with the potato (*Solanum* spp.), manioc (*Manihot esculenta* Crantz) and arrowroot (*Canna indica* L.). There are also geophytes that were locally domesticated in the highlands of South America that only recently travelled outside South America, such as oca (*Oxalis tuberosa* Molina), ulluco (*Ullucus tuberosus* Caldas), mashua (*Tropaeolum tuberosum* Ruiz and Pavón) and maca (*Lepidium meyenii* Walp.). Why these domestic geophytes have been received differently by the world is an interesting cultural, symbolic, haptic, economic and even ontological question, but here I want to focus only on the potato

and how it was domesticated and spread throughout western South America, as a particularly productive example of ongoing geophyte domestication and the role that people's social relations have played in its success and expansion.

Today, landraces of potato range from Chile to Colombia, whereas their wild relatives have a much wider distribution throughout much of South America and north up to the southern US border (de Haan & Rodriguez 2016; Hawkes 1990; Spooner *et al.* 2004).

An explanatory framework proposed to address how and why potatoes became not just domesticated and farmed throughout the high Andean mountain regions, but became a staple crop there, is a complex but important question, weaving together biological and cultural processes. Morphological and genetic discussions of domestication are incomplete if our agricultural definitions do not include human engagement. Geophytes reproduce asexually through cloning or seed potatoes in this case, which either sprout during the new planting cycle from the tubers in the sediment, or are harvested, stored and replanted the following growing season. While sexual reproduction through seed planting is known today, it is very rare (de Haan & Rodriguez 2016). To model tuber domestication and the associated human decisions and agricultural processes that created it, in this paper I focus on the importance of *exchange* and *social relations* as a crucial element in the domestication process and the spread of potato production.

The potato has evolved the way it has due not only to the diverse Andean landscape and the wild species and genetic manipulation through pollination, but also through the actions of trading, sharing and exchanging the tubers between growers. If Andean people did not regularly carry and exchange the tubers, the plants would not have become as robust, and the tubers would not have become as varied or maintained their yields as much as they have. These results are reflected in the diverse variety of *Solanum* tubers present in the highlands today (Brush *et al.* 1980; 1992; de Haan & Rodriguez 2016; Hawkes 1990; Spooner *et al.* 2014; Zimmerer 1991).

There are debates as to how to classify the diversity of the potatoes growing throughout the Andes and beyond. Agronomists' and botanists' estimates of the number of cultivated species have ranged from one to eight. Many categorizations are in the literature, but I choose to follow the work of Huamán and de Haan of the International Potato Center and Spooner of the USDA. These scholars propose that there is one major domestic potato species: *Solanum tuberosum* L. They base this on several criteria, but mainly due to the ease of the different potato plants within this species'

abilities to interbreed with each other throughout the region, allowed by their genetic similarities. In addition, there have been a range of landraces categorized that carry the diversity of this food source throughout diverse geographies, climates and temperatures (de Haan *et al.* 2007; Huamán & Spooner 2002; Spooner *et al.* 2004; 2014). The two main domestic groups in *S. tuberosum*, the *S. tuberosum* Chilotanum group and the *S. tuberosum* Andigenum group (de Haan & Rodriguez 2016), and the three other cultivated species, *S. ajanhuiri* Juz. & Bukasov, *S. juzepcsukii* Bukasov and *S. curtilobum* Juz. & Bukasov, often called bitter potatoes, together contain over 5000 landraces (Brush 1980; de Haan *et al.* 2007). Additionally, c. 100 wild *Solanum* species are recognized and studied (Spooner *et al.* 2014).¹ Bitter potatoes are classed as such because they yield in much cooler and higher locations and require more processing to become consumable, due to their higher levels of alkaloids. These are the tubers that are freeze-dried and/or fermented for longer-term storage. Both modern hybrids and landraces are grown by farmers through the Andean region today, most often by small landholders.

For some time, there has been a debate as to the number of independent domestication locations of *Solanum tuberosum*, due to its widespread production. Recent genetic work by Spooner and colleagues, however, suggests there was only one domestication location for *S. tuberosum* from within the northern *S. brevicaulis* wild species complex (Spooner *et al.* 2014). Based on the genetics of field collections, they identified the root cultivar for the domesticate *S. tuberosum* Andigenum to have come out of stock from the northern Titicaca Basin. As the domesticate spread north and south over time, it continually hybridized with wild *Solanum* plants across the high central Andean mountains, creating a great diversity in the genetic stock via the landraces. This single origin location focuses our attention on the greater Titicaca region for the genetic origin of the potato and for the engagement with this species by the residents at least by Late Archaic times (6000–2000 BC: Rumold & Aldenderfer 2016).

This recent genetic work, in addition to assessing morphological and growth patterns, has allowed this team to identify the single origin of these domestic races. While it may have begun there, genetically the original stock stemming from the *S. brevicaulis* complex interbred with many wild *Solanum* plants and over 8000 years generated many varieties that have adapted to the diverse and different ecological conditions across western South America. This new model makes us focus more on the importance of trade than did the earlier domestication model of multiple

domestications throughout the highlands (Hawkes 1990). That model supported only local selection and engagement with different potatoes across the region. The new Huamán/Spooner model includes genetics and more clearly supports the agency of people moving and trading potatoes continuously east and west, north and south, actively creating new niches for the potato to prosper in.

Propagation is completed through planting curated seed potatoes, usually by opening up a small hole and dropping in one or two small healthy potatoes. This form of cropping has created the raw diversity we see still across the centre of origin and the robusticity of this now globally important geophyte. How did this happen and how was a clonal food plant maintained and even diversified over the past 6000 years of its domesticated life? – through informal and formal seed-potato exchange.

In the Andes, *movement of people and things—exchange* is a core tenet of social interaction, seen in inter-familial labour exchange (*ayni*), commonly called upon during most crop harvests. The movement of crops between different growing zones has long been seen as a vibrant, long-lived form of sustainability (Murra 1972; 1985). Another important related cultural tenet throughout the Andean region is reciprocity, reflected in the organization of moieties noted in many communities, where people, ideas and things are constantly moving back and forth, where balance between these two groups, like the marriage pair, keeps the community going, maintaining the responsibilities between groups and beings. Exchange and its cultural importance, I believe, has played a major role in the history of viable tuber farming, yield stability and the diverse existence of the Andean landraces.

Clone reproduction in farming narrows the gene pool and can make a crop very vulnerable to disease, as experienced in the Irish potato-blight tragedy of 1845–52, as the parasite (*Phytophthora infestans*) migrated out of Mexico into North America and then across Europe, attacking and killing field after field of plants brutally and quickly with no recourse (Kileany 1994; Messer 2000). At that time, there was only one member of the Chilotatum group present across this landscape, as one farmer after another ‘borrowed’ or purchased seed-potato clones from their landlords and neighbours, essentially reproducing the same plant across Ireland. Robusticity comes from diversity; because a cloned plant has increased vulnerability from new parasites, other activities must be enacted to sustain the crop yield, in addition to selecting seed tubers from the harvest. The main pressure is to avoid the late blight (*Phytophthora infestans*) and the potato

tuber moth (*Phthorimaea operculella*) (Giraldo *et al.* 2010). Farmers have to provide new varieties regularly into the farming system to maintain robusticity. This is brought about primarily by growing varieties in different locations as well as continually moving them around through exchange with other producers, thus maintaining and expanding diversity.

More so than for grain crops, this requirement of exchanging seed tubers between farmers is the state of mind I refer to in my title, as once there was a commitment to tending and harvesting potatoes, cultivators had to add new tubers into their fields regularly, lowering the capacity for pests to spread and thus increasing the capacity for viable yields. While the above-ground infestations are difficult enough to control, the parasites that attack subterranean storage tissues are much harder to deal with. Agricultural sustainability required more than hunters and herders carrying tubers to new places. With the commitment to regular potato consumption, farmers had to enhance the tuber's environment and increase clonal diversity. Encouraging diversity was accomplished by gathering first wild tubers and then landraces that people liked the taste of and planting them in new locations. As people moved around the landscape, this activity would have spread the landraces. Once people moved from cultivation to farming, territoriality and less regular movement transpired. A shift to exchange had to occur, as new territories were no longer as accessible. With dependence and commitment to eating potatoes, regular seed-potato movement and trade had to be socially encouraged to maintain diversity, as those who did not engage in such activities saw their yields diminish.

It is well known amongst highland farmers that good potato yields come from several actions: 1) planting potatoes after a fallow cycle of one to several years, hence their name, *la preciosa*—potatoes require more nutrients than other highland crops; 2) regularly trading for new seed potatoes from other zones, hoodwinking the local worms and bugs; 3) grazing their animals (camelids in the past, but today also sheep and cows) on the fields, or bringing their dung to the fields, so that these nutrients can be added to the soil; and 4) mimicking wild potato growth habitats by planting a range of different varieties in the same field (Brush *et al.* 1981). After a long fallow cycle when the nematodes in the soil have diminished, the conditions for tuber growth are again optimal through digging holes with a foot plough (*chakitaklla*), and plough or tractor to place several seed-tubers underground in the created holes, not by scattering.

Potato plants and their tubers are now incredibly diverse, with thousands of viable, edible landraces.

This variability is created through geography, climate, soil diversity, growing multiple races in one field and the wild species that exist across the highland landscape. Tuber exchange across the landscape was critical for the early propagators of the potato, as the traded tubers moved into new conditions, maintaining viability by escaping from local nematodes and other predators. To maintain potato yield and fertility, a regular replacement of seed-tuber stock is required.

Tuber exchange across the landscape that provides diverse varieties (landraces) continues today, and is a common way to maintain yields, while combatting local diseases and bugs. Andean farmers trade seed potatoes throughout their region informally, as well as constantly moving their own seed-potato stock from field to field (Thiele 1999). This constant re-configuration of varieties is augmented by cross-pollination, occasionally producing plants that are allowed to go to seed. When a farmer recognizes new productive or flavourful varieties, they will collect the tubers for seed potatoes. New varieties also occur through mutation and cross-breeding with the wild tuber-bearing potato plants that grow throughout the Andes (Spooner *et al.* 2004). But the most active and impactful method for retaining diversity and robusticity is what is called the informal seed system, the seed-potato exchange (de Haan & Rodriguez 2016; Thiele 1999). This is done across the highlands through trade of seed potatoes between farmers via family relations and trading partners and at tuber markets.

A self-sufficient farmer's fields in the Andes can hold up to 80 different varieties (Brush *et al.* 1981). Over the years, traits that have been selected for, stored, planted and traded include flavour, texture, colour, shorter stolons, more tubers per plant, lower glycoalkaloid levels, cooking qualities, storage capacities and yield maintenance, as well as frost resistance, drought tolerance, blight resistance and insect repelling (Brush *et al.* 1981, 81–2). The newer, 'improved', commercial varieties are much more vulnerable to yield loss if they are continuously planted in one place, whereas the landraces can be grown for many more years in the same region while retaining yield and viability.

From this agronomic evidence, we learn that potato production has regularly to be infused with new seed tubers to maintain yields, thus encouraging the spread and diversity of varieties over time. Tuber exchange across the landscape was therefore critical for the early gatherers and the later propagators of potato, as the traded tubers moved into new conditions, maintaining robusticity by escaping from local nematodes and other predators.

These requirements, as well as the genetics, inform us that early foragers carried potatoes throughout the landscape, planting them in new locations as they went, but also maintained social exchange relations across broad areas. This fits with the early archaeological evidence we have, suggesting that groups moved up- and downslope seasonally in the highlands until about roughly 4000–5000 years ago, when they began to settle on the landscape. Once people settled more permanently and farmed more locally, seed-potato trade had to increase to retain yields.

With these data, we now realize that it was the northern Titicaca Basin inhabitants who dug up patches of the potato's progenitors, creating soil disturbance while selectively replanting certain tubers that encouraged the crop in ever-new locations, ultimately becoming this important domesticate. The farmer's actions throughout the highlands created new microenvironments in a wider variety of field types and microenvironments, which is the heart of niche construction's role in domestication (Zeder 2015). But what it is important to emphasize, if models are to be constructed, is the core place of social interactions that had to be enacted regularly.

Solanum tuberosum L. existed throughout the highlands for thousands of years before we can identify it in the archaeological record. This was the time when there was a shift from mainly gathering and hunting to increasing commitment to farming and herding, when people decided to dedicate more time to helping the plants grow in specific places. These cultivation activities seemed to occur at the same time as the shift from hunting to herding camelids, as selective culling produced more useful herds in different landscapes (Kuznar 1993; Moore 2016; Pearsall 1989; 2008). Since camelids are territorial, in a way, they domesticated the people to stay put to manage and grow with them, which in turn channelled the focus on the encouragement of local root-tuber cultivation. Cultivating potatoes at the same time as the camelid domestication was not surprising.

Camelids, root tubers and people interacted symbiotically across the highland landscape after the glaciers retreated, as camelid dung helped enrich the soil for potatoes and camelid hooves aided in aerating their subterranean growth. As in Deborah Pearsall's model for a *Chenopodium* and camelid co-domestication process that occurred in early corrals, so too could *Solanum tuberosum* varieties have prospered from growing where llamas were herded, with the enriched soils encouraging increased yields (Kuznar 1993; Pearsall 1989; 2008). As camelid herds were increasingly managed, the plants were as well.

I therefore suggest that the potato participated in the highland pre-domestication cultivation trajectory along with camelids and chenopods.

Except for the genetic evidence, identifying the onset of farming and spread of the domesticated potato is essentially an archaeological issue. At this point, we can only 'see' produced tubers when we have dated archaeological field evidence, when we encounter identified domesticated animals or other domesticates like *Chenopodium*, or increased densities of parenchymous and potato starch grains. Visiting what archaeological data there is, we can say that wild potatoes were being collected and consumed by the earliest residents of South America. Wild *Solanum maglia* Schltdl. tubers were found on a use surface near a hearth at the Monte Verde site dating to 13,000 BP, located in a marshy wetland that would have yielded wild tubers available year-round (Dillehay 1989; Ugent *et al.* 1987). Several wild potato specimens also have been identified at Tres Ventanas cave in western mid-range Peruvian mountains by 5000 BC (7000 BP; Engel 1970; D. Pearsall pers. comm., 2000). Macrobotanical potato evidence at Huaynuná, on the well-preserved north-central Peruvian coast in the Casma valley, dates to between 2200 and 1200 BC (Ugent *et al.* 1982). These examples illustrate that *Solanum* tubers can be found and identified in the archaeological record. In this small Initial period (Late Archaic) ceremonial centre, potatoes were accompanied by sweet potatoes, manioc and *Canna*, suggesting a full range of tuber agriculture by that phase on the coast and therefore surely in the highlands as well (Ugent *et al.* 1981; 1984; 1986). This scant evidence exists in part due to the excavation and sampling strategies that have been applied in the Andean region, plus the difficulty in identifying tuber fragments, rather than the actual distribution of the *Solanum* tubers in archaeological sites across the Andes. The increasing study and identification of starch will help greatly (Perry *et al.* 2007). Starch grains tell of tuber grinding in northwestern Argentina at 2500 BC (4500 BP) identified by Babot (2006; Babot *et al.* 2014). Duncan and Pearsall have also found more tuber evidence just south of Huaynuná in the Chillón Valley at another Initial period site, Buena Vista, where a range of agricultural products have been identified by their starch grains, identifying *Solanum*, arrowroot and manioc that date to 2200 BC (Duncan *et al.* 2009). Rumold (2010) has identified diagnostic modifications to potato-starch grains, indicative of tuber freeze-drying and/or grinding, at the Titicaca Basin site of Jiskairumoko that dates to between 2000 and 1000 BC, further supporting a commitment to tuber consumption through processing and probable crop production by this point in the heartland of

potato domestication (Rumold & Aldenderfer 2016, 13674). This early evidence will continue to grow as archaeologists increasingly add more rigorous techniques to their excavation, collection and identification methodologies.

Turning to the models that might explain this history, first is the optimal foraging/diet breadth model, which suggests that it is all about collecting the highest-yielding plants first, adding less-productive foodstuffs as population grows (Gremillion *et al.* 2011; Hastorf 1993). Given the ubiquitous but low density of geophytes across the Andes for gatherers, underground storage organs would be added late in this food uptake model, linked to declining availability of other resources. I do not believe this model fits the Andean history of indigenous plant use, especially not tubers. We have evidence that a range of wild plants, tubers, fruits, nuts and animals were collected and consumed early on, at least by 7000 BC in the central Andes (Rossen *et al.* 1996) and much earlier in Chile at Monte Verde. No one plant or even plant form became dominant throughout the early plant use on the coast, as all food plants had to be brought in and then cultivated, providing a clear example of adopting the domestic package. This is where we have the best preservation and therefore the best history of plant use through time, but all were carried in as domesticates, primarily from the Amazon basin, as no real *in situ* domestication occurred on the coast (Hastorf 1999). The highlands are a different matter.

Niche construction theory, which stresses multi-directional engagement between the environment, the plants and the people, with each part affecting the others over the long-term, focuses our attention on the inhabitants and their interactions with the plants, their capacities to react, as well as the landscapes that these plants resided in (Fuller *et al.* 2014; Laland & Sterelny 2006; Langlie *et al.* 2014; Smith 2015). This dynamic strategy focuses on people's protracted engagement with plant species before, during and after clear domestic or farming evidence exists, tracking changes in the productive capacities of the land, as well as plant and cultural changes. This model fits better with what I am outlining for potato domestication: the long-lived, on-going human–potato interaction across the South American highlands and the commitment to steady social interaction and exchange, which escalated when people began settling across the upland valleys and mountainsides. Mainly, however, the niche-construction model allows for early and long-term engagement with the Andean tuber and root crops (ARTCs: de Haan & Juarez 2010). Even if these wild tubers were not hugely productive per plant 8000 years ago, they existed throughout the year

in the ground: they provided a stable year-round food source and therefore were part of the foraging package of the highlands. Clearly after many years of selection the range of tubers and roots increased their yields and eventually became a real focus of agricultural production. The archaeological record supports this second model in terms of human–tuber engagement.

These tuberous plants tell an intriguing tale: they speak of plants making themselves attractively visible to food seekers above ground, so that foragers could return to their patches, encouraging and allowing them to prosper. We can see this not only by the tubers found at Monte Verde, but also due to their spread across the region, as food seekers carried them across the landscape and helped the plants prosper in new places, lower down the valleys and eventually along to the west coast. We can therefore propose an early, dynamic engagement and expansion of the more edible, tuber-producing *Solanum* species with the coming of people into South America: as people followed the animals to rich microzones of lake and river shores, these plants dispersed and evolved. This was a directed, agentive engagement, encouraging both the plants and the people to adjust to the many environments.

Conclusions

Since the first peopling of the Andean regions where plants produced starch-rich tubers, people have been digging tubers up and modifying local environments to make them more amenable to yet more tuber growth. Through digging and disturbance, geophytes were encouraged to produce and thrive. I propose that this process of tuber domestication has been a long, dynamic, social process, as it continues today in the Andes, where new varieties are still being created and exchange is still a vibrant and essential part of potato sustainability.

Change in the plant during the domestication process was probably well under way by 6000 BC (7750 BP), with cultivation across most of the region by 2000 BC. In many ways potatoes still have control of themselves and are not fully domesticated. Tubers self-start if they are in soil, as they grow out of their own storage tissues in an unending process of renewal. Yet potatoes have changed and expanded over time through active propagation strategies, expanded field-niche construction and tuber exchange across the Andes, increasing the production of more tubers in more places, and allowed different textures, flavours, colours and climatic characteristics to develop and be maintained against field vermin. The actions that participated in this domestication process include field development and niche expansion.

Clonal potatoes and other Andean tubers also promote cooperative interactions between farming families, encouraging regular extra-community social interactions to keep the yields steady. The evidence we have today suggests that potatoes, along with camelids, participated in the highland pre-domestication cultivation trajectory, forming a synergy between plants, animals and people.

This geophyte production requires unique forms of social interaction, providing an unusual example of human agency operating within the domestication syndrome of the potato. The domestic potato and its domestication process therefore reflect the past state of mind of those who engaged with these tuberous plants; they had to maintain social relations with their neighbours and farther residents to maintain their crop. This archaeobotanical example displays the human agency in the evolution of the potato, through the power of exchange that created the diverse and genetically robust domestic potato we see and eat today as a staple food source throughout the Andean region, which has now spread around the world, to feed people in many different climates and cuisines.

Note

1. The potato that came to Europe is the common potato throughout Eurasia, the *S. tuberosum* Chilotanum group, today only propagated in western Chile. The Andigenum group is the more diverse and more common group throughout the Andean region, the origin of most of today's landraces.

Acknowledgements

I am honoured that the editors asked me to participate in this volume for Martin Jones. I want to thank Martin, who has been a great archaeobotanical colleague, providing an open space for debate and thus improvement in thinking about plant-human models, and how we best collect and present our data. I also want to thank Stephen Brush and Greg Scott, who, when I was a young graduate student, talked with me about potatoes and the complexity of their exchange, I have never forgotten the ideas we spoke of.

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Chapter 10

Archaeobotanical and Geographical Perspectives on Subsistence and Sedentism: The Case of Hallan Çemi (Turkey)

Manon Savard

Introduction

The questions *When?*, *Where?* and especially *How?* and *Why?* agriculture began in the Near East continue to fuel research. Several models have attempted to address these questions by trying to explain sedentism and shifts in subsistence strategies. This chapter revisits two of them from an archaeobotanical perspective illustrated by the archaeobotanical assemblage of Hallan Çemi (southeastern Turkey), in the spirit of the stimulating, outside-the-box discussions that Professor Martin K. Jones encouraged at the meetings and tea-breaks of the George Pitt-Rivers Laboratory of the McDonald Institute for Archaeological Research, University of Cambridge.

Developed by ecologists and zoologists in the 1960s, Optimal Foraging Theory became more widely used in archaeology and anthropology from the 1980s (Smith 1983). The theory ranks resources on the premise of cost-benefit considerations: resources such as small, fast-moving prey and small-seeded or low-yield plants are considered less desirable and thus ranked low. It is often associated with resource depression: lower-ranked resources would have been added to a diet only when preferred, higher-ranked food, such as large mammals, became scarce.

The Broad Spectrum Revolution is a model proposed by Flannery in 1968 at a London University symposium. It 'sets the cultural stage for domestication' and describes changes in subsistence patterns, from 'midway through the Upper Palaeolithic' to 'long after the cultivation had begun' (Flannery 1969). According to this model, subsistence strategies changed from 'a more narrow spectrum of environmental resources to a more broad spectrum of edible wild products' beginning with the addition to the diet of 'greater amounts of fish, crabs, water turtles, molluscs, land snails, partridges, migratory water

fowl (and possibly wild cereal grain in some areas?)' (Flannery 1969, 74, 79–80).

These models have been combined to describe shifts in subsistence strategies associated with sedentism, the latter being considered an important step toward the origins of agriculture (e.g. Stiner 2001; Stiner & Munro 2002; Stiner *et al.* 2000; Stutz *et al.* 2009). Instead of moving around to meet and hunt targeted high-ranked animals, hunter-gatherers who became sedentary would settle and adopt a more diverse diet that included lower-ranked resources available locally, in their catchment area. It is believed that the spectrum of wild plant species exploited later narrowed as agriculture began (Preece *et al.* 2015).

Both Optimal Foraging Theory and the Broad Spectrum Revolution are still widely debated, whether on their own or combined, particularly in recent years in zooarchaeology and archaeobotany (Jones 2016; see also Jones & Hurley 2017, for a review of literature on the Optimal Foraging Theory published in English between 1997 and 2017), as well as in research on the origins of agriculture (Smith 2014). Many publications have been critical of the negative push associated with the model and leading to sedentism and changes in subsistence strategies, or have underlined a lack of evidence for resource depletion or for a sudden, revolutionary broadening of the diet (e.g. Weiss 2004b).

The site of Hallan Çemi is a good case to test the combined models. Melinda Zeder (2012) has already challenged the Optimal Foraging Theory by reviewing numerous examples of permanent villages set in rich environments, including Hallan Çemi, where a wide variety of food resources was hunted with no sign of high-ranked food depletion. This paper will adopt an archaeobotanical perspective and focus on the plant remains of Hallan Çemi.

Table 10.1. Archaeobotanical results from Hallan Çemi.

Number of samples:		174			
Weight of 'flot' (excluding seeds)/weight of seeds = estimated charcoal/seed ratio		4889.15 g/48.64 g = 100.52			
Total sample size (in L):		19,393			
Family	Tribe/Species/sub-species/varieties	Absolute numbers	Numbers per 200L	Percentage	Ubiquity (percentage)
Aizoaceae	<i>Aizoon</i> type	2	0.02	0.02%	1%
Anacardiaceae	<i>Pistacia</i> cf. <i>khinjuk/atlantica</i> var. <i>kurdica</i>	47	0.49	0.36%	53%
Apiaceae	<i>Bupleurum</i> type	5	0.05	0.04%	3%
Boraginaceae	<i>Arnebia/Lithospermum</i>	1	0.01	0.01%	1%
	<i>Heliotropium europeum</i> type	13	0.13	0.10%	5%
	<i>Lithospermum</i> cf. <i>tenuiflorum</i>	2	0.02	0.02%	1%
	<i>Onosma albo-roseum</i> type	6	0.06	0.04%	3%
Capparaceae	<i>Capparis</i> sp.	4	0.04	0.21%	2%
	<i>Capparis</i> type	29	0.29	0.21%	11%
Caryophyllaceae	<i>Gypsophila pilosa</i> type	16	0.17	0.12%	6%
	<i>Silene</i> type	3	0.03	0.02%	2%
	<i>Vaccaria pyramidata</i>	1	0.01	0.01%	1%
	Indet. type 4	44	0.45	0.33%	14%
	Other indet.	65	0.67	0.48%	12%
Chenopodiaceae	Indet.	25	0.25	0.18%	11%
Compositae	<i>Centaurea</i> sp.	7	0.07	0.05%	3%
	<i>Gundelia tournefortii</i>	34	0.35	0.26%	11%
	<i>Lactuca</i> sp.	994	10.25	7.47%	38%
	Other indet.	12	0.12	0.09%	5%
Cruciferae	<i>Alyssum/Lepidium</i> type	74	0.76	0.56%	22%
	<i>Neslia paniculata/apiculata</i>	6	0.06	0.05%	5%
Cyperaceae	<i>Bolboschoenus glaucus</i>	4402	45.39	33.08%	75%
Euphorbiaceae	<i>Chrozophora tinctoria</i>	11	0.11	0.08%	3%
Fabaceae	<i>Lens</i> cf. <i>orientalis</i>	10	0.10	0.08%	6%
	<i>Pisum</i> type	59	0.61	0.44%	23%
	Trifolieae/ <i>Astragalus</i>	59	0.61	0.44%	22%
	<i>Vicia/Lathyrus</i>	650	6.71	4.89%	62%
	<i>Vicia ervilia</i>	25	0.26	0.19%	13%
	Vicieae	383	3.95	2.88%	63%
	Indet. type 1	25	0.25	0.18%	9%
	Other indet.	26	0.27	0.20%	6%
Fagaceae	<i>Quercus</i> cf. <i>brantii/boissieri/libani</i>	1	0.01	0.01%	2%

Hallan Çemi

The site of Hallan Çemi is located in southeast Turkey, near Batman. It belongs to the Taurus-Zagros Round House Horizon, as defined by Peasall (2000). In addition to available traditional radiocarbon dates (Rosenberg 1994; Rosenberg & Davis 1992; Rosenberg *et al.* 1995), 21 AMS dates obtained from charred seeds

indicate that it was occupied in the late eleventh to early tenth millennium BP (Higham *et al.* 2007).

Hallan Çemi has been described as 'the oldest fully settled village site known so far in eastern Anatolia' (Rosenberg & Redding 2000). A diversity of evidence supports year-round occupation: the excavations uncovered 4 levels of solidly built semi-subterranean round houses, organized around a central area. They

Table 10.1. (Continued.)

Number of samples:		174			
Weight of 'flot' (excluding seeds)/weight of seeds = estimated charcoal/seed ratio		4889.15 g/48.64 g = 100.52			
Total sample size (in L):		19,393			
Family	Tribe/Species/sub-species/varieties	Absolute numbers	Numbers per 200L	Percentage	Ubiquity (percentage)
Gramineae	<i>Bromus</i> sp.	3	0.03	0.02%	3%
	<i>Hordeum</i> cf. <i>spontaneum</i>	110	1.14	0.83%	28%
	<i>Hordeum murinum</i> complex	30	0.31	0.22%	20%
	<i>Hordeum</i> sp.	14	0.14	0.10%	6%
	<i>Hordeum</i> type	12	0.12	0.09%	11%
	<i>Lolium/Eremopoa</i> type	12	0.12	0.09%	3%
	<i>Lolium perenne/rigidum</i>	1	0.01	0.01%	1%
	<i>Lolium</i> type	4	0.04	0.03%	3%
	<i>Stipa</i> sp.	55	0.57	0.42%	23%
	<i>Taeniatherum caput-medusae</i>	65	0.67	0.49%	43%
	Triticeae	8	0.08	0.06%	5%
	<i>Triticum boeoticum/Secale</i>	17	0.18	0.13%	7%
	<i>Triticum</i> spp.	8	0.08	0.06%	5%
	Small-seeded indet.	171	1.76	1.28%	50%
	Labiatae	cf. <i>Teucrium</i>	7	0.07	0.05%
<i>Nepeta</i> type		29	0.30	0.20%	7%
<i>Ziziphora tenuior</i> type		455	4.69	3.42%	48%
Other indet.		37	0.38	0.26%	13%
Liliaceae	<i>Bellevalia</i> type	18	0.18	0.13%	10%
Papaveraceae	<i>Fumaria</i> sp.	11	0.11	0.08%	2%
Polygonaceae	<i>Polygonum</i> sp. (flat-seeded type)	10	0.10	0.07%	5%
	<i>Polygonum</i> sp. (triquerous-seeded type)	3710	38.26	27.88%	74%
	<i>Rumex</i> sp.	24	0.24	0.18%	7%
Ranunculaceae	<i>Adonis</i> cf. <i>flammea</i>	7	0.07	0.01%	4%
Rosaceae	<i>Amygdalus</i> sp.	113	1.16	0.85%	64%
Rubiaceae	<i>Galium</i> type	2	0.02	0.02%	1%
Scrophulariaceae	<i>Verbascum</i> sp.	1085	11.18	8.15%	35%
Solanaceae	<i>Lycium</i> type	113	1.17	0.85%	19%
Thymelaeaceae	<i>Thymelaea</i> type	4	0.04	0.03%	2%
Ulmaceae	<i>Celtis australis/tournefortii</i>	1	0.01	0.01%	1%
Other indet.	133	1.37	1.09%	24%	
Total	13306	137	100%	–	

yielded an impressive number of large immovable goods, such as large querns. There is also bioarchaeological evidence of multi-seasonality from seeds and molluscs. Most plants represented in the charred assemblage of Hallan Çemi bear fruits between April and September (Table 10.1), and most of the individual samples analysed contained remains of plants that fruit both early and late. High ubiquity figures of known

food plants that fruit only at a specific moment of the year suggest storage practices. Growth bands on freshwater mussels indicate that they were gathered in all seasons (Rosenberg *et al.* 1998, 34). Recent analyses of the bird assemblage of Hallan Çemi also support multi-seasonality of bird hunting (Zeder & Spitzer 2016).

Hallan Çemi's large bone assemblage has been studied by Zeder and Spitzer (2016), by Starkovich

and Stiner (2009) and by R.W. Redding (Rosenberg *et al.* 1995; 1998). It is dominated by ovicaprids, representing nearly half of the overall assemblage of identified bones, followed by deer and boar, each representing about a quarter of the overall assemblage (Zeder & Spitzer 2016). These studies suggest little or no pressure on the environment and no food depletion (Zeder 2012; Zeder & Spitzer 2016). Instead, they seem to indicate that the inhabitants of Hallan Çemi had access to a wide diversity of resources and a rich environment. Redding suggested the possibility of early pig husbandry, along with the hunting of wild boar (Rosenberg *et al.* 1998, 32–3).¹

Archaeobotanical analyses were conducted on 174 samples from Hallan Çemi (Savard 2005; Savard *et al.* 2006). According to the archaeologist M. Rosenberg (pers. comm., 2002), the 33 samples taken at different depths of a deep sounding in the central area of the site are most likely from a primary deposition. From the concentration of bone and fire-cracked stones, it was suggested that feasting might have taken place in this central area (Rosenberg & Redding 2000). One would expect a higher density of seeds in primary deposition contexts. The overall seed density is low, with 0.69 seeds per litre of sample. Such a low density is nonetheless not exceptional for sites from this period and for non-selective sampling. However, the seed density is even lower for the samples from the central area (0.23 seeds per litre). Even though it remains low, seed density is higher in samples taken near or within buildings (0.83 seeds per litre). If feasting did indeed take place, meat may have played a larger role, or maybe meat was prepared and shared in the central area while food plants might have been associated with everyday meals or household preparation. Among the 141 samples taken near or within buildings, 35 samples were hand-picked concentrations of seeds, mainly almond concentrations along with a few gundelia. Many others were described as fill of hearths, areas with ashes or traces of burning, as deposits within floors or associated with floors, or deposits within features such as a stone platform. However, by studying the field notes and by looking at the composition and density of the assemblage, it was not possible to confirm that they were from primary depositions.

More than 13,000 seeds were identified, belonging to 63 different taxa. Only 5 taxa account for 5 per cent or more of the overall assemblage, which was overwhelmingly dominated by club-rush nutlets (*Bolboschoenus glaucus*)² (33%) and a triquetrous knotgrass (*Polygonum* sp.) (28%), followed by mullein (*Verbascum* sp.) (8%), wild lettuce (*Lactuca* sp.) (7%) and *Vicia/Lathyrus* (5%). Club-rush and knotgrass were each found

in nearly 75 per cent of the samples. Large-seeded legumes also show high ubiquity figures: they are present in over 60 per cent of the sample, while mullein and wild lettuce are each found in 35 per cent and 38 per cent of the samples, respectively (Table 10.1). Other taxa with high ubiquity include *Amygdalus* sp. (present in 64 per cent of the samples, including hand-picked samples of almond concentrations), *Pistacia* cf. *khinjuk/atlantica* var. *kurdica* Zohary (present in 53 per cent of the samples) and small-seeded grasses (present in over 50 per cent of the samples). While other uses are not excluded, the bulk of the most common plants of the assemblage, in both percentages and ubiquity, were considered food plants, including club-rush and knotgrass (see justifications below).

No morphological evidence of domestication was found. However, the assemblage comprises as many taxa of obligatory weeds (arable weeds not known outside cultivation) (see also Stevens & Fuller, this volume) as those of slightly later sites where plant domestication is well attested or where pre-domestic cultivation was suggested (Willcox 2012). Because the wild progenitors of pulses are much more abundant at Hallan Çemi than those of cereals, Willcox (2012) suggested a pre-domestic cultivation of pulses.

An archaeobotanical perspective

Diversity

Many sites not affected by a strong preservation bias have yielded highly diverse archaeobotanical assemblages from early on, including the Acheulian site of Geshert Benot Ya'aqov (Melamed *et al.* 2016), Kebara cave dated to 60,000–48,000 BP (uncal.: Lev *et al.* 2005) and Ohalo II dated to 23,000 BP (uncal.: Weiss *et al.* 2004a,b). Whether archaeobotanical assemblages become significantly broader or more diverse with sedentism is thus questionable, and they do not seem to support the notion of a 'revolution' in the spectrum of food resources. Archaeobotany itself may even have underestimated the range of the food plants included in the assemblages.

Ranking food plants

In archaeobotany, individual food plants have not explicitly been labelled as high- or low-ranked, but a more subtle categorization has been applied and has resulted in differential research efforts. Any clues that could help foresee the origin of agriculture have been sought by archaeologists and archaeo-environmentalists. Sites slightly earlier than the beginnings of agriculture have most often been studied for what they were potentially to become, rather for what they were or for what they could teach us of hunter-

gatherer's subsistence strategies. When studying the archaeobotanical assemblages of Epipalaeolithic village sites, the focus was therefore on wild progenitors, on morphological signs of their domestication, or on an increase in weeds. Small-seeded plants that are not known agricultural weeds and that have never been domesticated were often overlooked.

Wild cereals at the centre of attention

Several reasons can explain why cereals and their wild progenitors have been, and still are, the main focus of archaeobotanists and archaeologists interested in the origins of agriculture in the Near East: 1) the first Natufian village sites discovered in the early 1960s were found in rich stands of wild grasses, which led to the suggestion that wild grasses had been the staple food-plant of sedentary hunter-gatherers, particularly large-seeded grasses, the wild progenitors of cereals (Cauvin 1999, 180; 2000, 15; Henry 1989, 19, 35). The domestication of cereals was then considered to be a continuity of hunter-gatherers' subsistence strategies; 2) cereals are the dominant component of archaeobotanical assemblages of most agricultural sites; and 3) unlike other plants, cereals can show clear morphological evidence of domestication, such as a tough rachis and an increase in grain size (Willcox 2004).

A review of the published results of archaeobotanical assemblages from the Fertile Crescent (Savard *et al.* 2006) has demonstrated that the wild progenitors of cereals most often represent a very small proportion, in number and percentages, of the archaeobotanical assemblages of sedentary hunter-gatherer sites. Wild small-seeded grasses are most often more abundant than wild progenitors of cereals. More importantly, most assemblages show diversity, suggesting that Epipalaeolithic to Early Neolithic hunter-gatherers took advantage of the variety of plant resources available locally and enjoyed a diversified diet.

The other plants of archaeobotanical assemblages

Except for nuts and obligatory weeds, much less attention has been given to plants that are not the wild progenitors of crops.

Nuts: From early on, nuts have been more readily accepted as a potentially valuable wild food, except maybe for those that need detoxification to be edible (Martinoli & Jacomet 2004; Mason & Nesbitt 2009). Except maybe for acorn, their shells preserve well, so they are most often well represented in charred archaeobotanical assemblages. It is also the case at Hallan Çemi in terms of ubiquity. In small Palaeolithic assemblages affected by preservation bias, nuts are often the main charred taxa found, such as in the ear-

liest layers of Çayönü (van Zeist & de Roller 1991–92; 2003). Because of their size, nuts were also among the first charred plant remains collected on archaeological sites before flotation became widespread and hand-collecting was still the main recovery method.

Weeds: Obligatory weeds have recently been given more attention. They have proved useful in the identification of tilling and 'pre-domestic cultivation', or cultivation before morphological transformation can be detected, such as suggested at Hallan Çemi (Willcox 2012; Wilcox *et al.* 2008).

The rest of the archaeobotanical assemblages: Other plants are more rarely discussed. When they are, it is mostly with regard to site formation: whether they were introduced voluntarily or incidentally with an economic plant, or as part of dung (e.g. Hillman *et al.* 1997; Miller 1996; 1997), or for their possible use other than as food (fuel, medicine, dyeing, thatching, mat-making, etc.). Their role as food is often questioned, even if they are known to be edible. For instance, Spengler (2018) mentions that '[...] it is safer to assume that seeds from wild plants in archaeological sites represent animal foraging, rather than human foraging, although disentangling these signatures is often impossible.' The burden of proof then falls on the food hypothesis against all other possible uses. Furthermore, when wild plants have served as famine food in recent times, it is often assumed that they had a similar role in the more distant past; that they were only valuable when crops failed. Many publications have highlighted the potential and value of such underestimated wild food plants, mainly by documenting ethnographic cases and results of food-processing experiments (e.g. Hillman 2000, for the various wild food plants found at Abu Hureyra; Mason & Nesbitt 2009, for acorn; Martinoli & Jacomet 2004, for wild almond; Wollstonecroft & Erkal 1999 and Wollstonecroft *et al.* 2008, for club-rush tuber and seeds).

Hallan Çemi's wild food plants

The plant diet of Hallan Çemi seems both broad and narrow: broad because of the large number of taxa present in the assemblage, narrow because only a few dominate the assemblage in terms of abundance or ubiquity. Club-rush and knotgrass were most likely collected as food. Dung burning at Hallan Çemi is unlikely. Samuel (2001) compiled criteria to help identify the use of dung as fuel. The most obvious evidence is the presence of dung itself within the archaeobotanical assemblage; evidence suggesting a possible scarcity of wood in the vicinity of the site or heavy pressure

on wood resources is also an important factor. In the case of sites with no domestic animals, the presence of animals that leave piles of dung, such as gazelle, would have facilitated dung collecting, making it more likely. The seed:charcoal ratio and the composition of the assemblage can also give a hint: the importance of 'non-crop' plant remains (or rather non-useful plants in the case of hunter-gatherer sites) and the relative high proportion of chaff are other indicators. Spengler (2018) adds that the presence of spherulites is another reliable means of identifying a dung signature in sediments. Among wild seeds, *Chenopodium* are highly over-represented (Spengler 2018).

At Hallan Çemi, no dung or chaff were found. There is no evidence of domestication, except perhaps for the possibility of early pig husbandry. The weight of 'flots' (that comprised mainly charred plant remains) were recorded before and after sorting to estimate the charcoal:seed ratio. Charcoal remains were found to be much more abundant than seeds, about 100 g of charcoal per gramme of seeds (Table 10.1). Indeterminate *Chenopodiaceae* specimens represent less than 1 per cent of the assemblage and were found in 11 per cent of the samples. Gale (1998) also reports that the use of wood for fuel remained similar throughout the occupation of the site, which suggests a persistent woodland structure within the natural environment, and the site shows no evidence of wood scarcity.

Club-rush and knotgrass could indeed have been used as building material, for matting and thatching, or as mud-brick temper. Burnt wattle and daub was found at Hallan Çemi, but a preliminary examination of samples, including casts of its botanical components, did not yield any evidence of seeds. Moreover, no building structures were found in the central area of Hallan Çemi, where club-rush and knotgrass were as important as at other parts of the site. In most samples, club-rush and knotgrass occur with other food plants, in percentages and ubiquity scores that are most often higher than any other known food plants. The bulk of the club-rush and knotgrass seeds were thus most likely brought to the site as food, rather than incidentally introduced with building material. Indeed, their seeds and bulbs are edible and their use as food is well documented in numerous instances, from ethnography to human faeces (Hillman 2000, 354–8; Wollstonecroft & Erkal 1999; Wollstonecroft *et al.* 2011).

Valley-bottom plants were also considered important food resources at Mureybet (van Zeist & Bakker-Heeres 1984) and at Abu Hureyra. While Miller (1996; 1997) considers that wild seed plants derived from dung burning, this proposition was rejected by Hillman *et al.* (1997). Because these valley-bottom resources declined in the assemblages after the

Younger Dryas, it was suggested that they were some kind of famine food (Hillman *et al.* 2001; Willcox *et al.* 2009). However, valley-bottom plants were also the main component of the archaeobotanical assemblage during the initial occupation of Abu Hureyra, shortly before the onset of the Younger Dryas (Hillman 2000). At Hallan Çemi, the numerous radiocarbon dates available indicate that the site was occupied towards the end of the Younger Dryas, a time associated with improving climatic conditions. Moreover, charcoal, charred seeds (Savard 2005) and faunal remains (Zeder 2012) do not suggest any depletion; on the contrary, they suggest that Hallan Çemi had a rich and diverse environment.

Starkovich and Stiner (2009, 44) consider the plant remains of Hallan Çemi to be 'low-return plant resources'. They thus see a contradiction between the 'image of plenty' provided by the bone assemblage dominated by high-rank animal resource and the intensive plant processing. Their view does not take into account the abundance and the reliability of resources and the advantages of a diversified diet. The abundant stands of valley-bottom food-plants were the resources that the people of Hallan Çemi could rely on, as did the people of Abu Hureyra, Mureybet and Demirköy, and they continued to play an important role at later sites (Wollstonecroft *et al.* 2011).

Moreover, they were not famine foods; on the contrary, they represent abundant and reliable staples. The presence of such resources may even have influenced the location of Hallan Çemi and other early permanent villages. In other words, valley-bottom plants may have been the resources that made sedentism possible.

Sedentism and the origin of agriculture

Sedentism is often considered an important step toward the origin of agriculture. Optimal Foraging Theory and the Broad Spectrum Revolution have been combined to explain the changes in subsistence strategies associated with sedentism. They picture sedentism and the change of subsistence strategies that it commands as the results of a negative push: archaeologists working on this transition period have been looking for material evidence of population growth or for pressure on the environment associated with sedentism. While criteria to detect sedentism have evolved to become more stringent, even bioarchaeological evidence is now being challenged because of the low resolution offered by most archaeological sites.

The Early Natufian is often 'regarded as the original case of sedentism in non-agricultural societies' (Boyd 2006, 165). The major labour investment required

for building solid round structures, the presence of several of these structures, often organized around a central area interpreted as a midden or as a communal space, along with storage facilities, were often taken as satisfactory evidence of sedentism. With the development of archaeological sciences, such evidence became insufficient: 'well-built structures and storage facilities alone do not indicate sedentism without supportive bio-archaeological evidence' (Bar-Yosef & Belfer-Cohen 1992, 24). A new set of evidence was then proposed: in addition to round architecture and storage facilities, it included multi-seasonality of hunting and gathering inferred from zooarchaeological and archaeobotanical evidence, abundant immovable goods, commensal fauna, cemeteries, evidence of rebuilding and a high density of archaeological deposits. While each of these can individually be challenged (Boyd 2006), multi-seasonality of hunting and gathering combined with solidly built architecture were generally accepted as the two main pieces of evidence required. Additional evidence just made the case for sedentism stronger, the notion of sedentism being applied to the settlements themselves and, by extension, to their inhabitants. This led to much research effort trying to define concepts such as semi-sedentism or semi-nomadism, and to estimate various degrees of mobility or sedentism based on bioarchaeological evidence.

Multi-seasonality of hunting and gathering as evidence for sedentism is now, in turn, being challenged: Asouti and Fuller (2013, 314) have suggested that they might simply indicate periodic returns at different moments of the year, by the same group or by different groups, rather than continuous, year-round occupation. Permanent sites could have been inhabited periodically by hunter-gatherers that remained mobile. They could also represent stages in an annual cycle of mobility. Ascertaining one or the other would be difficult from archaeological evidence. Nonetheless, Asouti and Fuller's (2013) proposition opens up a new perspective, one that is less anthropological and more geographical. Sedentism could be seen as a new perception of, and relation to, geographical space. Rather than focusing on the modalities or temporalities of the occupation of a site, one may consider the human investment into a specific geographic location to turn it into a permanent, man-made *locus*.

Conclusion

Club rush and knotgrass have been overlooked by archaeologists and archaeobotanists interested in the origin of agriculture. The archaeobotanical assemblage of Hallan Çemi offers an insight on the role played by such underestimated plants, suggesting that they

might have been the reliable staple that made sedentism possible. Wetlands or disturbed floodplains, particularly areas with regular overbank flooding favourable to club-rush and knotgrass, would thus have been a good choice for the establishment of these villages. Such locations may have also been the first choice of early farmers: Flannery (1969, 81) writes that '[a]t Ali Kosh on the lowland steppe of south-East Iran, early farmers planted their cereals so near swamp margins that seeds of club-rush (*Scirpus*) were mixed in the carbonized grain samples' and that '[t]his is analogous to the practices of early farmers in parts of arid highland Mesoamerica, who also utilized permanently-humid bottomlands and high-water table zones'. The proximity of another type of environment, or ecotone, is another desirable aspect. These locations provided both diversity and security.

In his paper 'Cheating at musical chairs', Rosenberg (1998) has suggested that sedentism was driven by territoriality. Valley-bottom environments with a nearby ecotone might have been the more productive areas that groups of hunter-gatherers sought to keep for themselves. At the other end of the spectrum, if hunter-gatherers using these sites remained mobile, the exploitation of valley-bottom food-plants could have provided a node in a cycle of annual migration that translated into a meeting place, a 'stop-over', so rich with this abundant and reliable resource that it was worth investing time and effort to build permanent structures. It transformed these places into some sort of caravanserais, open to those passing by and invested by them. Distinguishing one or the other through archaeology would be challenging and most archaeological sites would probably not offer the resolution to do so. Nonetheless, these permanent villages represent the first man-made *loci* made to last. It undoubtedly reveals a changing perception and a changing relation to geographical space and landscape.

Notes

1. M. Zeder is currently conducting further analyses on faunal remains from Hallan Çemi (Zeder pers. comm., 2017).
2. Following a re-examination of Near Eastern club-rush specimens from various archaeobotanical assemblages (Wollstonecroft *et al.* 2011), club-rush nutlets previously identified as *B. maritimus* (Savard 2005; Savard *et al.* 2006) are now identified as *B. glaucus*.

Acknowledgements

This reflection emerged during my PhD, during meetings with my supervisors, Martin K. Jones and Mark Nesbitt. I wish to thank them warmly for their time

and inspiration. The reflection was deepened during research sabbaticals at the McDonald Institute, under the direction of Martin K. Jones, and at the Smithsonian's National Museum of Natural History, under the sponsorship of Melinda Zeder and Rick Torben. I wish to thank them for their hospitality.

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Chapter 11

Rice and the Formation of Complex Society in East Asia: Reconstruction of Cooking through Pot Soot- and Carbon- deposit Pattern Analysis

Leo Aoi Hosoya, Masashi Kobayashi, Shinji Kubota & Guoping Sun

Introduction: cooking and society

This article examines the possibility of reconstructing ancient cooking methods to interpret structural shifts in society, focusing on the formation of rice farming-based complex societies in East Asia. Recently, diverse methods of reconstructing ancient cooking have developed remarkably (e.g. Heron *et al.* 2016a,b). This article uses cooking pot soot- and carbon-deposits analysis (Kobayashi 2011a): cooking traces left on pots, mainly soot- and carbon-deposits, are systematically analysed to reconstruct the preparation of daily meals.

In the archaeological study of the history of human subsistence, research has focused predominantly on farming and animal husbandry techniques and the introduction, dispersal and development of domesticated plants and animals. This approach was rooted in the concept that societies before and after farming or animal husbandry were in clearly different stages of human history. This idea stems from the work of Childe (1936), wherein the origin of farming and animal husbandry is the most significant issue in history. However, recent archaeobotanical research has demonstrated that even after the introduction of farming, basic subsistence strategies did not greatly change for hundreds to thousands of years. This is the case both in Near Eastern wheat farming (Tanno & Willcox 2006) and in East Asian rice farming (Fuller *et al.* 2009; Nakamura 2010). Archaeobotanical and archaeofaunal evidence from early rice farmers' sites on the Yangtze indicate that these communities continued to practice broad-spectrum subsistence strategies, including hunting, gathering and fishing, rice cultivation being only a small part of the food-procurement system (Fuller *et al.* 2009; Kohmoto 2001; Nakamura 2002). Moreover, this broad-spectrum economy remained stable for hundreds of years. These new insights have led to the growth of research in the reconstruction of food-processing activities, includ-

ing cooking, to learn how various types of food were managed in daily meals.

Food processing to make plant and animal tissue edible is as vital for human living as food procurement such as gathering and cultivation. Without processing, the nutrition of most natural resources is inaccessible to humans. Furthermore, food processing is a research scope which can be applied both to societies without farming and those with it, with the same standard. Therefore, societies with broad-spectrum subsistence strategies, which cannot be clearly defined to be either before or after farming, can still be effectively studied within this scope. Many processing activities (crop dehusking and cooking) likely took place within settlements. Thus, food-processing activities, work areas and scheduling must have been incorporated into the domestic cycle. It may therefore be possible to reconstruct routine food processing among ancient people by synthesizing what we already know about their processing facilities, tools and work areas, as well as the organic debris found within a site. If we identify distinct food-processing stages within a settlement, we can better interpret the scale and frequency of each group of activities, how they were organized on a daily basis, and chronological shifts and regional diversities in these activities. Within the study of the archaeobotany of macro plant remains, a methodology to reconstruct stages in crop processing and its contexts at an archaeological site was previously established (Hillman 1981; Jones 1985), but it lacked detailed discussion of the stage of cooking. Subsequently, however, remarkable developments in analytical techniques, such as ancient starch analyses (Fullagar 1998), carbon and nitrogen isotope analyses of food residue (Mason & Hather 2002) and analyses of cooking-pot soot and carbon deposits (Kobayashi 1996) enabled more detailed studies of ancient cooking.

The study of cooking, although until recently underestimated partly due to gender bias (Hastorf

1991), is an effective way of studying past culture and society, because cooking is the basis of daily living and thus reflects cultural and social frameworks. Fuller and Rowlands (2011) claimed that although ethnographers had examined culinary systems as bearing the cultural schema of their communities, built up within rich symbolic systems, their viewpoint was not adopted in the study of long-term history. They noted that although archaeological studies had discussed the social significance of culinary culture, they tended to focus on special occasions, such as feasting, rather than on quotidian food consumption; alternatively, they investigated food itself, not prime movers in driving subsistence and increasing food production. As an effective starting point for the consideration of long-term connections between food and cultural tradition, Fuller and Rowlands (2011) studied techniques of food preparation in prehistoric eastern and western Eurasia. They found that the culinary cultures of eastern and western Eurasia were based on boiling and grinding (baking), respectively. Thus, not only 'powerful forces of technological and subsistence conservatism' but also 'the combination of technological traditions engrained within cosmological frameworks' characterize food culture. Their work showcases the potential of archaeological culinary study as social study.

As acknowledged by Fuller and Rowlands (2011), especially in the rice-farming areas of East and Southeast Asia, cooking rice plays a remarkably significant role in daily life. Characteristically, in those areas, rice is distinctly categorized as the staple, and it is clearly distinguished, conceptually, from side dishes. The heavy dependence on one type of crop as the main food, both from a practical and a conceptual viewpoint, means that the use of rice and how to manage its production and consumption may have been the core of social organization. For example, in Japan, rice was both the practical basis of governmental organization and a symbolically important food at latest by the seventh to eighth centuries AD (Hosoya 2012) and has since this time been deeply connected with Japanese identity (Ohnuki-Tierney 1994). Accordingly, shortages of rice, such as after a poor harvest, have caused severe social disturbances, so-called 'rice riots', a number of times throughout Japanese history (Kanazawa *et al.* 2016). The most recent of these occurrences took place as recently as 1993, and it is clear that the problem was not any actual shortage of food, as there were other types of food in abundance, but entirely due to mental uneasiness. Interestingly, Japanese culinary culture had already been largely Westernized at that time; in fact, government statistics show that consumption of rice per person had been decreasing since

1962 (Ministry of Agriculture, Forestry and Fisheries 2017). Nevertheless, a rice riot occurred. This indicates rice's remarkable symbolic power to influence society even today, beyond its practical significance. Exploration of when and how this power of rice began is vital for understanding the social history of East Asian rice-based societies. Moreover, within this scope, we may be able to construct social formation models constructed only on East Asian evidence, rather than applying Western models.

The reconstruction of ancient rice cooking is the most useful initial step for this discussion. The methods of rice cooking are particularly diverse and complicated compared to the preparation of other food plants/animals (Kubota *et al.* 2017). Rice can be cooked by being boiled, steamed, parched and powdered to make bread, dumplings or noodles (Nakao 1972). Furthermore, there are several variations on boiling, such as *yutori* (boil-and-steam), *takiboshi* (letting the water be absorbed up into rice), pasta-like boiling and frying before boiling (Nakao 1972; Okada 1998). The most common way of preparing rice in modern Japan is the *takiboshi* boiling, while *yutori* boil-and-steam is broadly used in Southeast Asia (Kobayashi 2011a). Rice-cooking methods differ not only regionally, but also within and between households, where different methods may be used for different occasions. In modern Japan, rice is boiled for daily meals, but for New Year's Day, rice cakes made by steaming and pounding rice are served specially, and the pounding action is considered part of the New Year's celebration. In Bali, which is also traditionally a rice-centred society, not only cooking methods, but also types of rice are thoroughly regulated and used for various occasions (Hosoya 2008). Analyses of cooking-pot soot and carbon deposits bear directly on issues of complex rice cooking and will open a window on East Asian social history in its unique framework.

For the last couple of decades, this direction of research has been actively pursued in the study of Japanese prehistory to the medieval period, mainly led by Kobayashi, and it has also been applied recently to a Neolithic case for the first time in China. In this article, the results of research in Japan and China are compared to determine the role of rice in the formation of complex society.

Establishment of rice farming-based complex society in China and Japan

The discovery of the Hemudu site (5000–3300 BC), Zhejiang, China, in 1973 sparked the interest of global researchers due to its remarkable preservation of waterlogged organic material, indicating the exist-

ence of rice farming-based civilization in south China (Nakamura 2002). Later, the lower Yangtze River region including the Hemudu site was claimed to be one of the origins of rice cultivation (Yen 1982). The Yangtze River and the southern region of China have been rice based since then.

At present, the beginning of rice farming is considered to lie in the Kuahuqiao culture (6000 BC). Subsequently, the first rice-farming culture was established in the Ningshao Plain and Taihu Lake Plain. Systematic interdisciplinary research has recently been conducted by international research teams at the Tianluoshan (TLS) site (5000–3500 BC) of the Hemudu culture, on the Ningshao Plain, and it has been discovered that rice cultivation was only a part of subsistence, judging from the variety and quantity of plant remains (Fuller *et al.* 2009). The introduction of agriculture did not drastically shift the subsistence system, and hunting, fishing and gathering wild plants continued to form a broad-spectrum economy (Nakamura 2002). The intensification of paddy rice farming, with the introduction of new techniques such as irrigation (Fuller & Qin 2009; Nakamura 2002), eventually occurred between the Songze culture (3800–3200 BC) and the Liangzhu culture (3400–2200 BC) periods, approximately 2000–3000 years after the beginning of rice farming. In the Liangzhu culture, a complex urban civilization with a social hierarchy and work specialization formed (Xu 1998). Thus, it is clear that complex societies based on intensive farming are not merely a natural and inevitable outcome occurring immediately after the introduction of cultivation and domestication. Instead, complex societies emerge from specific shifts in the social organization of the group in question. It remains to be determined what kind of shifts they were and what were the prime movers.

In Japan, rice farming started late, introduced from continental Asia. The first rice-farming culture in Japan is called Yayoi and had its centre in western Japan. The starting date of the Yayoi period has been under discussion for the last couple of decades. The results of dating, depending on the interpretation of AMS, range from the latter half of the tenth century BC to 600 BC, but its ending is generally agreed to fall in the third century AD (Fujio 2017). Subsequently, the Kofun period, with its systematic social hierarchy, began and continued till the seventh century AD. Complex society appears to have formed during the Yayoi period, and approximately 1200 years after the beginning of agricultural society, if the earliest possible starting date of Yayoi is taken. This time span is much shorter than the one for the Yangtze area, which may be because the whole system based on irrigated-paddy rice farming, including the culture, was introduced

at once to western Japan (Yamada 2017). It remains unclear what the system was like. In and after the middle Yayoi period, this system was also introduced into the eastern parts of Japan (Yamada 2017).

Although originally Yayoi was defined as a farming culture, in contrast with the previous Jomon hunter-gatherer culture (13,000–1000 BC), for a long time, there has been discussion of the possibility that the Jomon people also cultivated plants (Shitara 2014, 14–29). Based on the results of a series of remarkable developments of analyses of plant imprints on pottery called the replica method, it is believed that dry-field cultivated legumes and millet were a substantial part of Jomon subsistence (Obata 2015). If this is the case, while the Yayoi culture is still distinguished from Jomon by its irrigated rice paddies (it has been discovered that dry-field cultivation was also used regularly in settlements of the Yayoi culture, on a larger scale than previously expected: Kohmoto 2004), the change in subsistence strategies from Jomon to Yayoi was not drastic. Accordingly, it is believed that the system associated with paddy rice farming more significantly characterizes Yayoi culture and played a bigger part in the formation of the complex society that followed than the rice-paddy technique itself.

To examine the prime mover, or the system, functioning behind the formation of complex society based on rice farming in China and Japan, we must study the historical sequence of social meanings of rice. As already discussed, rice in East Asia had remarkable power to influence society as a practical and perceived staple, and it may be that it was a fundamental factor in the formation of complex society. In previous archaeological research, the examination of whether rice was the staple at different times was conducted largely through the reconstruction of the annual yield of rice to determine whether it was enough to sustain the given population (Hosoya 2001). This quantitative approach, however, may be misleading, because being a staple relates to practical and perceived regularity in meals, rather than quantity. In ethnography, the significance of rice in the perception of Japanese people has been used as a clue to the Japanese identity and their culture (Tsuboi 1982); however, this perspective has seldom been applied to the study of extended history. We must develop new methodologies to deal with the social meanings of rice in extended histories. The most effective way of approaching that question may be to reconstruct how people actually ate rice in daily life, as reflected in their processing and cooking.¹ Hosoya (2009; 2014) studied macro plant remains from the Ikegami Sone site in Osaka (middle–late Yayoi) and determined how contemporary community leaders in the latter half of the Yayoi period in western



Figure 11.1. Burn mark above the waterline after experimental cooking of liquid-rich food.

Japan extended their centralizing power using rice-processing cycles eventually to establish a classed society. However, this approach, using macro plant remains, is insufficient for reconstructing in detail how rice was eaten as the daily meal. Here, analyses of soot and carbon deposits on cooking pots are introduced as the most effective method of examining that aspect.

Method of analysis of soot and carbon deposits

The study of pottery use beyond typology began to receive research attention in the late 1980s as a direction developing from Processual Archaeology (Nishida 2000). In Japan, research on pottery usage began to be developed in the 1980s, but was rather independent of Processual Archaeology, and it characteristically focuses on the traces of cooking (Nishida 2000). For example, K. Kobayashi (1978) found that clear patterning could be recognized in soot and carbon deposits on Jomon pottery, and a reconstruction

of the typical cooking method of the investigated community was made possible. Kawanishi (1982) explored the transformation of cooking from the Yayoi to the Kofun periods, based on transformations in styles, manufacturing techniques and heating traces on cooking pots. In line with those studies, M. Kobayashi has developed analyses of soot and carbon deposits on cooking pots (Kobayashi 1993; 1996; 2011a; 2016).

The basic method of the analyses of soot and carbon deposits on pottery is as follows: 1) the pottery styles are analysed to reconstruct what kind of cooking the pottery makers intended each type of cooking pot for; and 2) the patterns of soot and carbon deposits left on cooking pots are analysed to reconstruct the cooking methods (Kobayashi 2011a). To obtain information on which cooking method leaves which kind of soot or carbon deposits, as a fundamental part of the study, ethnographic research is conducted in communities whose daily practice includes traditional cooking with pottery; such groups are mainly found in Southeast

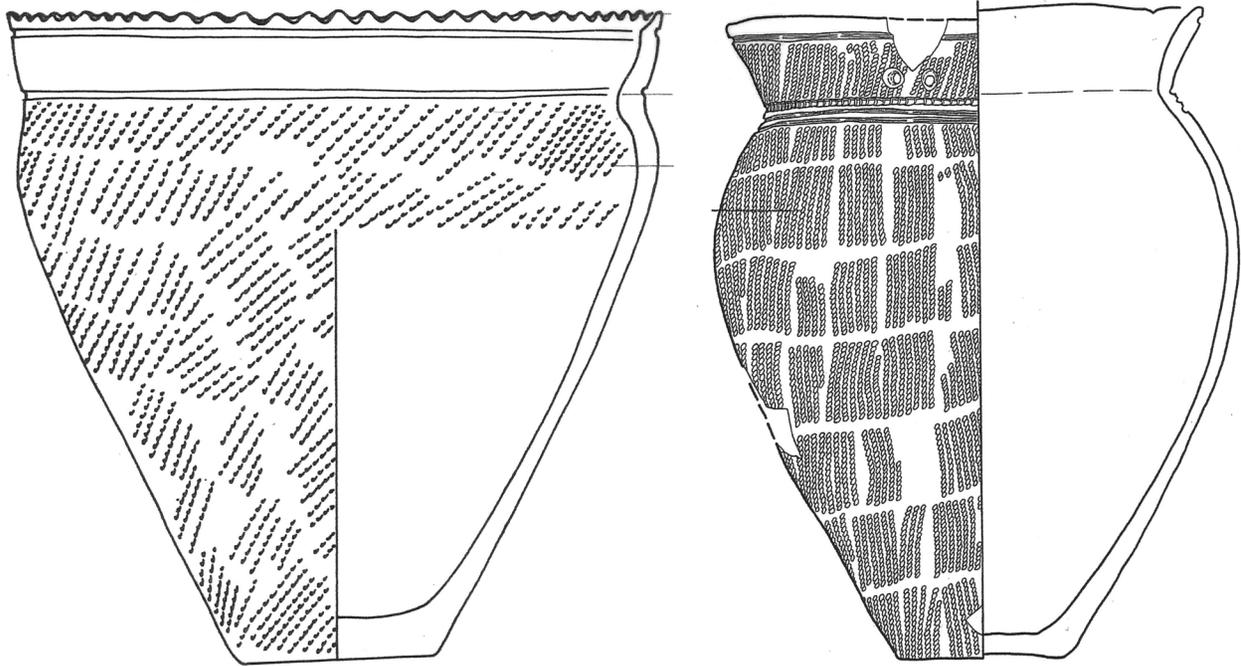


Figure 11.2. The style of Jomon and Yayoi major cooking pots: (left) Jomon pot (deep bowl, 10 litres) (Kitakami City Education Committee 1988); (right) Yayoi pot (jar, 7 litres) (Aomori Prefecture Education Committee 1985).

Asia, where there is an emphasis on rice as the staple (Kobayashi 1993). As soot and carbon deposits are the remnants of several different activities, and other complicating factors may be involved, Kobayashi stressed the importance of collecting a broad range of ethnographic examples and introducing experiments in various controlled settings to test hypotheses (Kobayashi 2011a).

Commonly observable soot- and carbon-deposit patterns are as below (Horaguchi *et al.* 2011; Kobayashi 2011a).

Soot: Carbon from the firing material, usually firewood, adheres to the outer wall of the pot. When the soot is touched by high heat, it is oxidized and whitens.

Carbon deposits: The cooked material adheres to or is absorbed into the inner wall of the pot and is carbonized. To analyse patterns of carbon deposits properly, a cross-section of the pottery wall must be observed in addition to the surface. Layered carbon deposits are formed when cooked content eventually loses its liquid and is burnt, for example in rice cooking and simmering a thick stew. Normally, as pots are used, thick carbon deposits are washed out. This means that if they remain for archaeology, they are likely from the final use before it was discarded. In general, liquid-rich cooking leaves carbon deposits

above the waterline (Fig. 11.1) and, when the cooking eventually loses liquid, below the waterline.

Stain: Thin, not carbonized, traces of cooked content are observable on the inner walls.

Overflow lines: Traces of cooked material boiled over the rim of a pot and drip onto the outer face. When pots are then later heated after a boiling-over event, the drip becomes carbonized and blackens. Otherwise, the marks are white.

When the patterns in those traces are observed, such as their position, shape, range and thickness, and with reference to ethnographic and experimental examples, various factors can be reconstructed,² including the lengths of cooking times, the direction and strength of fires, sequences of cooking, use of stoves or hearths and characteristics of the cooked material. To understand the patterns, sherds are insufficient: pots excavated in mostly complete forms must be analysed. In such analyses, observed soot- or carbon-deposit patterns are recorded on figures drawn from four views (two halves each of the inside and the outside of the pot). Cross-sections of pot walls are also observed as much as possible.

Analyses of soot or carbon deposits can help determine how food was cooked in different contexts, and thus they are particularly well suited for studying rice-centred societies, as ways of cooking rice are vari-

ous and complex, and the choice of the way of cooking rice often reflects social backgrounds (Section 1). In East Asia, the typology of pottery is remarkably well established (Ohnuki 1997) and archaeologists are well trained to draw detailed figures of artefacts, including pottery (Kobayashi 2011a), which is an advantage in conducting analyses in East Asia. Therefore, there is a high potentiality that this method can open the way to constructing East Asia's own models of social formation.

Case study 1: Japanese Jomon–Yayoi–Kofun pottery

Kobayashi and colleagues have been conducting soot- and carbon-deposit pattern analyses on cooking pots from all over Japan from prehistoric to medieval times. In this article, we review the results of their research from the Jomon, Yayoi and Kofun periods; the timing, from the introduction of rice farming to the formation of complex society, is discussed. The reference throughout this section is Kobayashi (2011a), if not otherwise indicated.

Shifts in cooking pottery styles and soot- and carbon-deposit patterns: Jomon to Yayoi

In the Jomon Period, the main cooking pot was a style of pottery called the deep bowl 深鉢, and in the Yayoi period, a type called the jar 甕 predominated (Kobayashi 1993; Fig. 11.2). However, those traditional archaeological terms are misleading and prejudice the observer against their real usage, so Kobayashi calls both styles of pottery pots 鍋 (Kobayashi 2011b). Following this policy, all cooking pots are called 'pot' in this chapter.

Pots with cooking traces found in 25 Jomon sites all over Japan were analysed to show the characteristics of Jomon cooking pots: 1) their walls are thick; 2) lids are rarely found; and 3) large pots (more than 10 litre capacity) are relatively more prevalent (more than 40 per cent of cooking pots). They exhibit the following patterns of soot and carbon deposits: 1) waterline traces of cooked material are comparatively low down in the body of the pot; 2) carbon deposits can be recognized in the lower part of the inside of body of the pot in more than 75 per cent of all examples, and most of these are above the waterline; 3) soot oxidation is obvious in the lower part of the outside of the pottery, and this position accords with that of the inner carbon deposits; and 4) blackened overflow lines are commonly observed. Furthermore, several cooking pots show post-cooking heating over a low fire, possibly the residual heat of carbonized firewood, in a standing or lying position (Kitano *et*

al. 2011). Such characteristics are generally shared by all Jomon cooking pots, regardless of region or phase.

There are few pots which are suitable for soot- and carbon-deposit analyses in the earliest phase of Yayoi (c. 1000–800 BC), so the cooking style of this phase is not known; while, from the early phase of Yayoi (c. 800–400 BC), Yayoi pots show characteristics that are completely at odds with those shown by Jomon pots (Kanegae 2011). Yayoi pots, according to analyses of more than 30 Yayoi sites, have the following pottery style characteristics: 1) large pots are dramatically fewer in number, and medium-sized (4–7 litre capacity) and small (3–4 litre capacity) pots dominate; 2) pot walls were thinner, their bodies rounder and the neck narrower than those of Jomon; 3) the necks were particularly robust; and 4) lids were commonly found. The soot- and carbon-deposit patterns have the following characteristics: 1) the waterline of the cooked material is comparatively high; 2) carbon deposits can be recognized in the lower part of the inside of pottery, but, unlike Jomon pots, the deposits are mostly observed beneath the waterline and in patches; 3) soot oxidation is not obvious on the lower part of the outside of the pot, but round patches are seen on the upper part; 4) the traces of the boiling over of a cooked meal are not blackened, but white; and 5) no traces of post-cooking heating are found (Kitano *et al.* 2011). It should be noted that such characteristics in soot- and carbon-deposit patterns are particularly obvious in medium-sized pots and less in smaller pots.

In general, the Yayoi characteristics noted above are more obvious in western Japan, which was the centre of Yayoi culture. In northeast Japan, from the middle phase of Yayoi, the Yayoi characteristics of cooking pots are recognized, but showing somewhat longer and higher-temperature heating than western Japanese cases (Kobayashi 2016).

Insofar as Kobayashi's ethnographic and experimental research is accurate (Kobayashi 2011a), the characteristics of Jomon pots indicate that the major meal cooked was a simmered stew-like meal. The thick wall of the pottery is suitable for prolonged simmering and retaining heat after cooking. The heavy soot oxidation on the outside of the pots also indicates prolonged heating, as do the blackened overflow lines, which show that meals that had boiled over were heated further. The low waterline may indicate that Jomon people did not use the full capacity of their pots in cooking meals to avoid boiling over. Further, the lack of carbon deposits beneath the waterline suggests that meals contained a great deal of liquid up until the final stage of cooking, supporting the contention that the meal was stew-like. The lack of

lids or lid-rests at the rim indicates that the content was frequently stirred rather than being covered by a lid to steam, and this is well-suited for making stew.

Furthermore, the traces of the heating of pots after cooking on a low fire are not observed in Yayoi cooking pots, only with Jomon pots. This can be a clue to the ingredients. With reference to cooking experiments (Kitano 2009), it is likely that the purpose of post-cooking heating was to burn the food residue clinging to the pot wall to make it easier to wash out and to prevent mould. Sticky food residues are usually produced from mixtures of starchy food and oil (Kitano 2009). The Jomon stew was probably made of starches (wild nuts) and proteins (animal and fish meat). It has been concluded that for common Jomon meals, all food procured was stewed together (Kitano *et al.* 2011). The large proportion of larger pots accords well with the proposal that everything was cooked in one pot.³ When starch and protein are cooked separately, no sticky food residue is usually produced, so the lack of post-cooking heating traces on Yayoi cooking pots indicates that exclusively starchy food was cooked, as discussed below.

With regard to typical Yayoi cooking pots, particularly the medium-sized ones, their thinner wall indicate that quicker and more efficient heating was preferred to prolonged simmering. Both the round body of the pot and the commonality of lids show that efficient heat circulation was a desideratum. In addition, the high waterline shown by carbon deposits indicates that boiling over was not as much of a concern as in the Jomon period. Accordingly, prolonged simmering did not occur, and cooking times were shorter. The fact that boiled-over contents are not blackened also indicates that they could not be carbonized, due to the short cooking time. The carbon deposits beneath the waterline inside the pot typically consist of a series of round burnt patches, showing that the cooked material had lost liquid by the end of cooking, and organic material touched the pot wall and burnt.

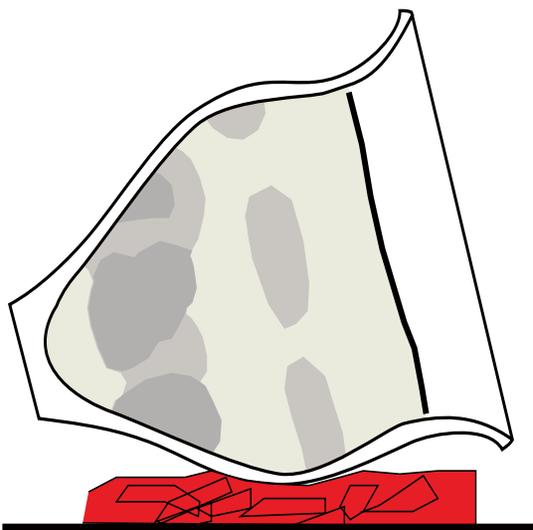
The characteristics of Yayoi cooking pot noted above accord well with rice cooking. In cooking rice, the duration is generally much shorter than that required to simmer a dish, so less boiling-over of contents is expected and the waterline can be high. In addition, heat circulation is more significant to cook rice evenly than to simmer stew, and the round shape of the pots, their narrow mouths and lids and their moderate size are ideal. In some cases, food residues are well preserved in cooking pots, such as at the Joto site, Okayama (late Yayoi), and carbonized rice is often recognized in that (Kobayashi & Yanase 2002). In addition, that those characteristics are more obvious

with a particular size of pots, namely, medium-sized ones, suggests that they were specialized rice cookers. Further, the lack of post-cooking traces of heating on Yayoi pots, which may well indicate that starches and proteins were cooked separately, supports the idea of a distinction to be drawn between rice cookers and cooking pots for side-dishes of proteins.

If this is the conclusion, the characteristic round patches of soot oxidation observed on the upper side of the outer wall of mainly medium-sized pots suggest that the method of rice cooking was *yutori*, or boil-and-steam, which is commonly used in modern Southeast Asia. Ethnography from Thailand, Laos, Philippines and Bangladesh (Kobayashi 2011a), where this method is commonly used, tells us that the rice is first boiled with plenty of water and then the pot is removed from the fire and the excess water is taken out (Fig. 11.3). The rice is then steamed on a low fire to be cooked. The final steaming is done through side heating, that is, the covered pot is laid down or inclined and the side is heated (Fig. 11.4). In this way, the upper side of rice, which is not yet cooked through being boiled from the bottom, can be heated as well, and the rice is eventually cooked evenly. Side heating leaves soot oxidation patches on the outer side of a pot similar to those observed on Yayoi pots. In addition, the robust neck of the Yayoi pots accords well with this hypothesis, because in the boil-and-steam method, pots are always removed from the fire by the neck, which needs to be robust enough to sustain the weight of the pot and its contents. In this method, most water is removed after boiling, and the remaining water is entirely absorbed by the rice during steaming, which is likely to leave carbon deposits in patches beneath the waterline, as is observed in the Yayoi pots. Furthermore, it has recently been recognized that in many cases of Yayoi pots, white overflow lines change angle in the middle; straight down first, then going at an angle (Kobayashi 2016). The trace is interpreted to show the pot was tilted to drain water (see Fig. 11.3) just after boiling-over of the meal began, further supporting that the boil-and-steam method was used with Yayoi pots (Kobayashi 2016). Thus, typical cooking methods in Jomon and Yayoi were entirely different, although the shift in subsistence strategy itself may not have been drastic (Section 2). The standard way of cooking rice (the boil-and-steam method) among Yayoi people and its specialized cooking vessel were already established from the earliest part of the Yayoi period. This suggests that rice as a staple began at the same time as the Yayoi culture, so the shift between Jomon and Yayoi was much clearer in perceptions of meals than in proportions of food.



Figure 11.3. Removing excess water after boiling rice (Central Thailand). (Photograph: Masashi Kobayashi.)



Shifts in cooking pottery styles and soot- and carbon-deposit patterns: Yayoi to Kofun

Ten Kofun sites were analysed for soot- and carbon deposit patterns on cooking pots. Up through the early Kofun period (third to fourth centuries AD), the basic structure of cooking pots was the same as it had been during the Yayoi period: medium-sized (3–4 litres) and small (1–2 litres) pots are the majority, and the carbon deposits beneath the waterline in a series of round patches are particularly observed on the medium-sized pots. This is evidence that the same rice-cooking method continued. From the latter half of the early Kofun to the middle Kofun periods (the late fourth to

Figure 11.4. Steaming stage of the yutori boil-and-steam rice-cooking method reconstructed with Yayoi pots.

the early fifth centuries AD), cooking pots became larger and longer both in western and eastern Japan: pots with more than 5–6 litre capacities became the majority, but the rice-cooking method remained the same.

However, during the middle Kofun period, cooking stoves were introduced from continental Asia and cooking styles appear to have changed. At fifth-century AD sites in western Japan, cooking pots consisted of long-body pots (approx. 5–10 litre capacity), large, medium-sized and small round-body pots, shallow pots and steaming baskets. A similar composition of cooking pots is also found at contemporary sites in eastern Japan, so although western Japan appears to have been where new items from continental Asia were first received, these spread to eastern Japan quite quickly. A difference can be found in the shape of cooking stoves between western and eastern Japanese: western Japanese ones have only one hole where pots can be placed and eastern ones have two. It appears that in eastern Japan, long-body pots were fixed to the stoves. In both cases, long-body pots were probably used mainly for cooking. Thin stain is observed at the bottom of the inside of these pots in a 4–6 cm band, but no carbon deposits are recognized. It can thus be concluded that these pots were used to boil clear water without any organic material. Considering the emergence of the steaming basket, it appears that in the middle Kofun period, steaming became a common method of cooking both for rice and side-dishes in both western and eastern Japan, replacing the boil-and-steam method.

Throughout the Jomon, Yayoi and Kofun periods, common cooking methods shifted according to cultural background, and rice was a staple from the beginning of the Yayoi period. Let us compare the cooking methods of early Chinese rice-farming society.

Case study 2: Chinese Neolithic pottery

Pottery soot- and carbon-deposit analyses were performed on Hemudu culture (5000–4500 BC) pottery from TLS, in Zhejiang, from 2015 to 2016 (Kubota *et al.* 2017).⁴

Hemudu culture emerged in the Late Neolithic, spreading along the southern coast of the Hangzhou Bay, bordering the eastern part of the Ningshao Plain. The base site is the Hemudu site.

TLS (5000–3500 BC) is located 7 km northeast from the Hemudu site. Eight archaeological layers have been recognized there, and those from Layer 8 to 3⁵ are identified as of the Hemudu culture (Zhejiang Archaeological Institute *et al.* 2007). The dating runs approximately: Layers 8–7: 7000–6500 BP; Layers 6–5: 6500–6000 BP; and Layers 4–3: 6000–5500 BP (Naka-

mura 2010). These layers contain archaeological material that is as rich as that found at the Hemudu site; in particular, Layers 8–5 are waterlogged, and organic remains deposited here are well preserved (Fuller *et al.* 2010). These remains include a broad range of food plants and animals, mainly from the freshwater habitat, including bones of carp, crucian carp, wild geese and the seeds from wild nuts, as well as rice remains, showing subsistence on a broad-spectrum economy (Fuller *et al.* 2010; Nakamura 2002). The majority of plant remains are wild nuts, particularly acorns and water chestnuts, and rice forms 18 per cent of remains in Layer 8–7 and 24 per cent in Layers 6–5 (Fuller *et al.* 2009). Thus, rice does not appear to be the central food source for the Hemudu culture community of the TLS, at least quantitatively. The question arises whether rice was also qualitatively insignificant. To answer it, soot- and carbon-deposit analyses were applied to the pottery found.

Shifts of pottery styles

Four types of cooking-vessel pots 釜 have been recognized at TLS: the slant-rim type (whose mouth's rim sharply slants to the outside), the wide-mouth type, the round-body type and the two-sectioned-body type (the body of this type is cut by two ridges: Fig. 11.5). The slant-rim and wide-mouth pots can be further classified by size: large (with a more than 8 litre capacity), middle (4–8 litres) and small (less than 4 litres). Round-body pots only occur as medium-sized and small, and among two-sectioned-body pots, only medium-sized ones of an approximately 5-litre capacity have been catalogued. Considering its basic shape and late emergence, the two-sectioned-body type is thought to be a transformation of the slant-rim type. From the Hemudu culture layers, approximately 120 pots whose size and shape could be clearly identified were analysed for soot- and carbon-deposit patterns.

The chronological shifts observed in the relative proportions of pot types are given in Figure 11.6. In Layer 8, the oldest, slant-rim pots are more than half of all pots surveyed, and wide-mouth and round-body pots also exist in lower amounts. However, the relative amounts of slant-rim pots decrease later layers, particularly drastically in Layer 5. More round-body and wide-mouth pots are found at this level, and round-body ones are the majority in Layer 5. However, round-body pots are fewer in Layer 3. Two-sectioned-body pots emerge in Layer 6, and their numbers gradually increase in Layer 5–3, which follows Layer 6. Similar shifts in pot types have been observed at the Hemudu site (Fig. 11.6), with the first phase roughly corresponding to TLS Layer 8–6 and second phase to TLS Layer 5.

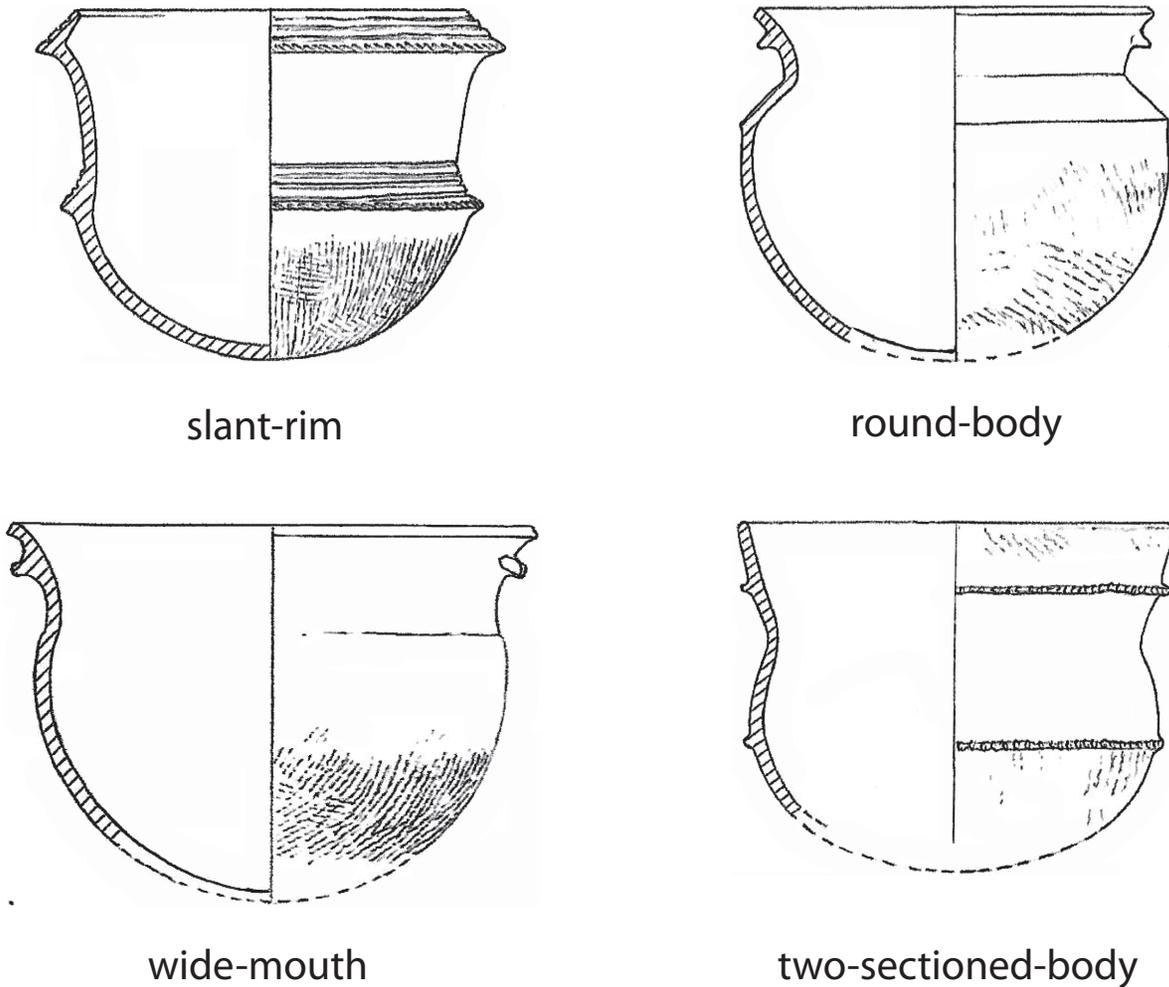


Figure 11.5. *Cooking-pot styles of the Tianluoshan Site (Kubota et al. 2017).*

Do those shifts reflect changes in cooking styles that took place at the different layers or merely changes in tools for a kind of cooking that remained the same?

Soot- and carbon-deposit patterns

Analyses revealed that each type of pot shows a characteristic soot- and carbon-deposit pattern. It is thus quite possible that those patterns are evidence of cooking styles rather than being taphonomic factors, such as burning after being discarded.

On the inner side of the slant-rim pots, 1–2 mm thick layered carbon deposits are generally found at the bottom and just above these, a burn-trace band is observed. Outside the pot, in the same position as the inner carbon deposits, heavy soot oxidation is observed. Evidence of the use of pot stands in heating is also found. The soot oxidation indicates that the pots were exposed to heavy fire, considering that heavy carbon deposits can be formed by the loss of

liquid by the object being cooked and its subsequent carbonization.

Round-body pots generally show the same pattern as slant-rim pots: at the bottom, round soot oxidization is observed on the outside, and at the same position on the inside, layered carbon deposits are found. However, neither the soot oxidization nor the layered carbon deposits are as heavy as those found in the slant-rim pots, so it appears that in the round-body pots, food contents also eventually lost liquid and burnt, but did so on a weaker fire. Soot oxidization patches, unique characteristics of round-body pots, are observed in the middle of the outer body (Fig. 11.7). This means that they were not just heated from the bottom as slant-rim pots were; round-body pots were also heated from the side during a different phase of cooking.

The wide-mouth pots from TLS were generally not clear of soot- and carbon-deposit patterns, but some show only slight carbon deposits at the bottom

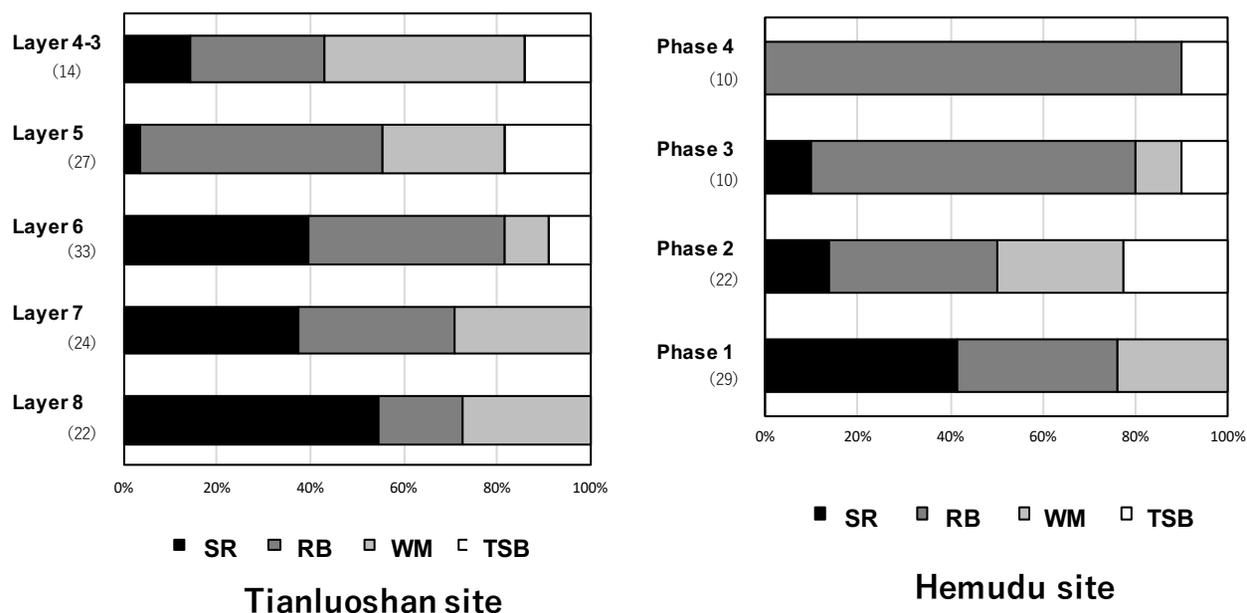


Figure 11.6. Shift of proportions of cooking-pot styles in Hemudu culture (Kubota et al. 2017). SR: Slant-rim; RB: Round-body; WM: Wide-mouth; TSB: Two-sectioned-body.

of the inside and oxidized soot on the outside. It is obvious that their use was different from that of the slant-rim or round-body pots, because the layered carbon deposits and soot oxidation patches characteristic of these types are not found in the wide-mouth type. Judging from their wide-mouthed shape, this type was likely to have been used for boiling, and its contents were kept liquid throughout the cooking operation, so they did not burn.

On two-sectioned-body pots, which appeared only in the latter half of the Hemudu layers, round-shaped soot oxidation is generally observed at the bottom of the outside, as is the case for the slant-rim and round-body pots. However, a clear difference from those two types can be found in that no layered carbon deposits are found at the bottom of the inside. This indicates that with two-sectioned-body pots, things that contained a great deal of liquid, such as soups or stews, were cooked, and the liquid was retained in the dish until cooking was completed. The widened mouths of these pots are also suitable for frequent stirring, helpful in cooking liquid-heavy food.

As above, it can be seen that each type of pot shows a characteristic soot- or carbon-deposit pattern, indicating that different pot types were associated with different modes of cooking and different ingredients. Next, a more detailed reconstruction of the cooking is attempted.

The common factor in soot- and carbon-deposit patterns between slant-rim and round-body pots is the layered deposits of carbon, though the thicknesses



Figure 11.7. TLS round-body pots characteristic soot and burn mark: (above) soot oxidation patch on the outside; (below) burn mark on the inside (same position as the upper). (Photographs: Masashi Kobayashi.)



Figure 11.8. Layered burn deposits formed after experimental porridge cooking. (Photograph: Masashi Kobayashi.)

of the layers vary. In previous studies, these layered deposits of carbon were without due consideration supposed to be the remains of rice cooking. To determine whether this is indeed the case, the deposits were closely observed. A certain amount of material similar to rice husks was indeed recognized in the deposits in certain amounts. It is believed that rice was dehusked before it was cooked, but when dehusking is done manually, it is difficult to perform perfectly, and some husks likely adhere to the rice grains and are cooked together with them (as Hosoya observed in Bali in 2006–2011). Furthermore, the authors (Kobayashi & Kubota) experimented by cooking rice with the husks, and it was found that, while rice grains were burnt, the husks kept their shape in the layered carbon deposits. Therefore, given that the remains of husks found in the TLS pots were well mixed into the layered carbon deposits, the rice husks were probably parts of cooked material, rather than being a later contamination, and the layered carbon deposits were indeed the remnants of rice cooking. Lipid-residue analyses of those layered carbon deposits also supported this conclusion (Kubota *et al.* 2017). Accordingly, there is a significant possibility that slant-rim and round-body

pots were both used to cook rice, at least as part of the ingredients. The difference between the soot- and carbon-deposit patterns between those two types of pots suggests different cooking methods.

It is clear from a close observation of the section of layered carbon deposits of slant-rim pots that the centre is the thickest. Further, the division between the burnt and non-burnt parts on the interior wall is quite clear. Those facts indicate that with this type of pot, rice was cooked with plenty of water, something like porridge. When porridge is cooked, no carbon deposit is generally formed, thanks to the plentiful water, but if the pot is left on the heat before it is served, the amount of water eventually lessens and the porridge on the bottom is burnt, forming a layered carbon deposit thickest at the centre. Furthermore, a band of carbon deposits can be left at the original water line and beneath, although the rest of the pot is clean. Indeed, the results of experimental porridge cooking (a proportion of rice to water of 1:5) in a pottery pot by the authors (Kobayashi & Kubota) showed almost identical soot- and carbon-deposit patterns as that of the slant-rim pots from TLS (Fig. 11.8; Kubota *et al.* 2017). It was suggested by lipid-residue analyses

(Kubota *et al.* 2017) that terrestrial animal meat was cooked within the porridge.

However, with round-body pots, layered carbon deposits have been found, but these are not as thick as those of slant-rim pots; additionally, soot oxidation patches are observed in the middle of the outer body, a unique pattern for this type of pot. That layered carbon deposits are found only at the bottom indicates that rice was cooked in plenty of water at first, but the water was lost, as in the case of the slant-rim pots. However, the thin wall of the round-body pots suggests that they were not left for long on the heat, leading to the conclusion that the loss of water was not the result of vaporization, but was for some other reason. The soot oxidation patches are probably the marks of heating from the side. This pattern is similar to that observed in Japanese Yayoi pots. It may be that the round-body pots were used exclusively as rice cookers for the boil-and-steam method. Round-body pots had already existed at Layer 8, though slant-rim pots were the most commonly found during this time; thus, it is likely that in the early Hemudu phase, rice was cooked as porridge mixed with protein, but also with the boil-and-steam method. Subsequently, in Layers 6–5, rice was commonly cooked separated from other ingredients by the boil-and-steam method.

Interpretation: shifts of cooking styles and the significance of rice

The results of the soot- and carbon-deposit analyses of TLS pots show the following: 1) slant-rim and round-body pots were used for cooking rice; 2) it is likely that slant-rim pots were used to cook rice porridge mixed with terrestrial animal protein, whereas there is a significant possibility that round-body pots were exclusively rice cookers; 3) it is possible that wide-mouth pots were used for boiling food, but the evidence of cooking is not quite clear; and 4) two-sectioned-body pots, which had a late appearance, were used for cooking food like soups or stews.

Combining these results with the facts of the chronological shifts in the relative proportions of pot types (Fig. 11.6), we can create the interpretation below.

During the oldest phase of the Hemudu culture at TLS, namely Layer 8, slant-rim pots are in the majority, indicating that porridge made of rice and protein was the main food. This accords well with the broad-spectrum subsistence strategy reconstructed for this time period from macro plant and faunal remains; food from several sources was eaten together. However, slant-rim pots gradually decreased, and by Layer 5, round-body pots were the majority. It is likely that round-body pots were specialized rice cookers,

so it may well be that by the middle of the Hemudu phases at TLS, it became common for rice to be cooked separately from other types of food; at the same time, the method of rice cooking was standardized to boil-and-steam. The dominance of round-body pots indicates that boiled rice was the major food. Wide-mouthed pots were present in the second-greatest numbers. Supposing that this type of pot was used to boil foods other than rice (judging from the lack of layered carbon deposits), it can be concluded that the pots were for cooking side-dishes to accompany rice. In other words, the concept of rice as the staple food might have already been established during the middle of Hemudu culture at TLS. It must be admitted that rice remains are still not a large percentage of food-plant remains even in this phase (Fuller *et al.* 2009), but quantities of macro plant remains can be misleading, as discussed in Section 2. Cooking-pot analyses indicate the established regularity of rice cooking and its distinction from other types of food, regardless of quantity, and thus the change of perception required to give rice special significance over other types of food. A related shift of pottery style also happened at the Hemudu site, as shown above, which may have been the turning point for the entire Hemudu food culture. In Layer 6, two-sectioned-body pots were found to be a likely transformation of the previously existing slant-rim pots, possibly succeeding them in their food-boiling function, but rice may have vanished from among the ingredients used, due to the lack of layered carbon deposits. Therefore, alongside another boiling vessel, namely wide-mouth pots, two-sectioned-body pots may well have been developed to cook side-dishes.

In Layers 4–3, the matrix soil is not waterlogged and the preservation of organic remains is much worse than in Layers 8–5, so detailed soot- and carbon-deposit analyses are impossible. However, it can be recognized that the relative numbers of round-body pots decreased in these layers, whereas wide-mouth pots increased. If rice was already a staple in Layers 6–5, the decrease in round-body pots would be more likely there: the presence of specialized rice cookers indicates a shift in the way rice was cooked, rather than any decrease in rice eating. Indeed, in the Songtze to Liangzhu culture, which chronologically follows, it is highly possible to find a common rice-cooking method of steaming rather than boiling, as indicated by the spread of the set of a steaming basket and vessel (Nakamura 2002). Although this is still speculation at present, it may be that wide-mouth pots were used as a steaming vessel in Layers 4–3, showing that rice steaming was introduced there at the TLS. Matching steaming-basket-like artefacts have not been found in

the TLS, but they could have been made of perishable materials, such as leaves. If this is the case, it can be concluded that during the Hemudu culture phases in TLS, rice was first mainly cooked as porridge mixed with other types of food; then, in the middle of the phase, the method of rice cooking was standardized to the boil-and-steam method, as rice became a staple, distinguished from other types of food. Finally, the standard method of rice cooking shifted to steaming in the final phases of Hemudu. Even if the wide-mouth pots of Layers 4–3 were not steaming vessels, it is certain that at the latest, the shift to steaming happened before the end of Hemudu culture.

Discussion

The above shows the results of analyses of soot- and carbon-deposits on cooking pots applied to a Chinese Neolithic case as a first trial. When the results were compared to results of Japanese cases, two main issues are raised, as below.

1) Rice was the staple food

In Japan, particularly in the west, the shift in cooking from the Jomon to Yayoi periods was rather drastic both in methods and vessels, and a standardized rice-cooking method (boil-and-steam) and a specialized vessel were already common at the early phase of Yayoi. Therefore, rice was already clearly established as a staple from the early stage of the establishment of Yayoi society.

On the other hand, the Chinese case at TLS shows rice becoming the staple food in a gradual process. In the early phases of Hemudu culture, the cooking pot soot- and carbon-deposit patterns show that rice was largely cooked mixed with protein foods, indicating that it was introduced as a part of a broad-spectrum subsistence strategy. During the middle phases of the Hemudu culture, rice was more commonly cooked independently of other foods, and the method of cooking (boil-and-steam) and its specialized vessel were established; thus, it probably was a staple at that point. This means that the process went on for hundreds of years.

This conclusion leads to the hypothesis that the clear contrast observable between the Jomon to Yayoi culture in Japan implies that the technique of paddy rice farming and the perception of rice as a staple, along with its proper method of cooking, was introduced from continental Asia to western Japan, rather than that perception being locally developed. It is also likely that the acceptance of the perception of rice as a staple may well have triggered the establishment of the Yayoi society, because it was discovered

that total food composition did not drastically change from Jomon to Yayoi (above): the shift in cooking is the most obvious archaeological factor distinguishing the Yayoi culture. If this is found to be true, it is immaterial whether rice itself or the technique of its cultivation was introduced into Japan during the Jomon period, as the shift of perception of rice was the key.

It is intriguing that in both China and Japan, the shift in rice cooking towards becoming a staple happened before the establishment of complex society, rather than after it. This indicates that rice as a staple was a vital factor for the formation of complex society in those areas. Furthermore, it may be that because the social significance of rice had been established, the power centralization necessary to form a complex society could emerge through control of rice production and distribution. Accordingly, if it is supposed that the establishment of the Yayoi culture was marked by the acceptance of perception that rice is a staple, rather than the introduction of the cultivation technique itself, a shorter-term time for the formation of complex society than the Chinese case would be rather natural.

If this is the case, the next question is how and when rice production and consumption came to be controlled by centralized power during the formation of complex society.

2) The change in rice cooking from boiling to steaming

As the cases of China and Japan that we have examined are compared, it is noticeable that in both cases, at a certain point after the boil-and-steam method was established, the method of rice cooking seems to have shifted from boiling to steaming. In the TLS Hemudu culture, this possibly happened in the final phase, certainly before the end. In the Japanese case, this transition happened in the middle Kofun period. If the timing of the shift is examined in both cases, it is possible to conclude that it may have been connected with the control of the production and consumption of rice.

Kobayashi (2011a) once raised the possibility that cultivated rice changed, at the time of the shift in cooking from boiling to steaming, from non-glutinous to glutinous rice, for which steaming is more suitable than boiling. Kobayashi (2011a) noted the greater efficiency of production of glutinous rice than non-glutinous rice to explain the shift in types of rice. However, he and Toyama later contradicted this hypothesis, presenting the evidence that non-glutinous rice had nevertheless been eaten throughout the Kofun period and in the following historical ages (Kobayashi & Toyama 2016). These researchers instead supplied the hypothesis that centralized control of rice circulation was the reason for the shift, as below:

Although non-glutinous japonica rice was the major rice cultivated in Japan, beginning with the introduction of the cultivation of rice, it has been found in morphology and ancient DNA analyses of carbonized rice remains (Ishikawa *et al.* 2015; Sato 1999) and phytolith analyses (Udatsu 2008) that during the Yayoi to the medieval period there was a shift in the primary rice cultivated and eaten from tropical japonica to temperate japonica. The Kofun period occurs right in the middle of this time of the shift; thus it may be that both types of japonica, and possibly a hybrid, co-existed in whatever proportions.

Still, it is not likely that one household could cultivate different types of rice together, so types of rice may possibly have varied among households or communities. Tropical japonica grains contain more amylose than temperate japonica does, making them less sticky. Using the ethnographic example of the Oy tribe, Laos (Kobayashi & Toyama 2015), it can be seen that when grains of rice that have different amounts of amylose are boiled together, the adjustment of water is quite difficult: if the water is adjusted to the standard of the high-amylose rice, low-amylose rice will melt, but if the water is adjusted for the low-amylose rice, the high-amylose rice will remain uncooked. However, when the rice is steamed, no such challenge occurs with the mixing of high- and low-amylose rice, as the grains of rice do not directly touch water. It is suggested here that in the middle Kofun, people shifted their method of rice cooking from boiling to steaming, because they were eating the rice harvests of other households, not their own alone, which was likely uniform rice type, forcing them to cook rice of mixed origins and mixed types. This indicates that rulers may have controlled rice circulation, collecting harvests from all farmers ruled and redistributing it to them (Kobayashi & Toyama 2016, 71–2, translated by Hosoya)

This hypothesis should be noted, though it remains a speculation until more substantial supporting data, such as greater archaeological information and botanical remains, are collected. In addition, we need to discuss other possibilities why Kofun people started using mixed types of rice, such as for preference of more diverse dishes or for risk-management of crop failure. Still, this hypothesis at least shows the possibility of discussing the issue of the shifting management of rice circulation from a new and clearer viewpoint, namely, in reference to the daily meal, a more substantial level than the previous discussion, which remained merely notional. In combination with reconstruction of the how rice became perceived as a staple, which is hard to discuss while restricting oneself entirely to the analysis of plant remains, the cooking pot soot- and carbon-deposit analyses can open up new vistas for the study of the unique role of

rice in the formation of complex society in East Asia, on its own methodological terms. Through the development of these analyses and by synthesising other necessary data, in particular, the chemical analyses of food residue adhering to pots, it will be possible to develop tangible results illuminating the history of rice-based civilization.

Conclusion

It has been examined from multiple viewpoints how dependence on paddy rice influenced the formation of society and worldviews. The classical historian and sinologist Wittfogel (1957) promoted the theory of Oriental despotism, claiming that the bureaucratic structures of the East Asian society are rooted in the organization of the irrigation system for the paddies, calling it the Hydraulic Empire. Recently, Talhelm and colleagues (2014), using the tools and methods of psychology, examined people living in rice cultures, concluding that they are more interdependent and holistic in their thinking than individuals in wheat culture, using respondents from north and south China.

While room remains in these issues for more discussion, it can certainly be agreed that rice, as a staple food, is both physically and symbolically a core factor in the rice-farming societies of East Asia. To understand East Asian society and culture, it is necessary to understand the long-term history of rice in society: when and how it became a staple, over and above other foods, its production and consumption in their political management. However, although technical aspects of rice cultivation, such as the origin and diffusion of cultivation techniques and the breeding sequences, have been exhaustively studied in archaeology, the social aspects of rice are insufficiently examined.

Archaeobotany and archaeozoology, particularly in northwest Europe, have been highlighting since the 1980s–90s that human meals have been a social activity from the earliest stage of human history instead of just a means of obtaining nutrition, and thus they must be studied within the scope of social archaeology. Many researchers have attempted to reconstruct different meanings for food in past societies beyond mere reconstruction of subsistence (Jones 2007). The most effective method for this type of research is to reconstruct food-processing and cooking activities for each archaeological site; in this way, it is possible to reconstruct the social organization and cultural context of those activities (whether they are mundane, ritual or other), and eventually, as a goal, the social meanings of each food. In studying macro plant remains, methods of reconstructing food processing

were intensively developed, introducing ethnoarchaeological approaches, and they were applied to several crops in various cases, mainly in Europe (Butler 1992; Hillman 1984; Jones 1985; Reddy 1994) in the 1980s and 1990s, but this research perspective did not find a foothold in East Asia. However, thanks in part to recent progress in analytical techniques, particularly chemical analyses, the goal of determining the meanings of different foods began finally to be sought in Chinese and Japanese cases, with the introduction of those techniques. Currently, intriguing research achievements are being published quite rapidly; for example, a new outlook on Jomon food-processing management and food valuation using analyses of ancient lipids has been published by Heron and colleagues (2016a) and Lucquin and colleagues (2016). It is promising that such new directions of research on archaeological subsistence are leading to a more profound understanding of all of East Asian social history. Still, particularly in Japan, the focus of research is centred on Jomon hunter-gatherer society, and study of the meaning requires extensive further development.

This chapter has attempted to reconstruct the meanings of rice in the formation of complex society in China and Japan, based on analyses of soot and carbon deposits on cooking pots. Although this research is still in a preliminary stage, especially in China, it was clearly shown to be feasible with this method to reconstruct how rice became a staple, following shifts in methods of rice cooking in connection with the transformation of the social background. It was also suggested that the use of rice in daily meals in a community is surely a good indicator of social transformation. The concept of a staple is itself unique to eastern Eurasia; rice, as a staple, can be efficiently studied to construct social formation models belonging to East Asia.

Acknowledgement

Professor Martin K. Jones was the supervisor of Leo Aoi Hosoya's PhD dissertation at the University of Cambridge, and Leo heartily appreciates his support with her developing interests in the research on East Asian ancient foodways, not only for the dissertation, but also for her future research.

Notes

1. Recently it has been generally accepted that ecological characteristics of rice contributed to its becoming the major food. Yet even if so, the process and timing of rice to become a staple are issues of social history; thus historical approaches are needed for the discussion.

2. It must be noted that the soot- and carbon-deposit patterns generally show the last use of the pot. However, if a section of the wall of the pot can be properly analysed, the regular use of the pot can be reconstructed.
3. There is a possibility that especially large pots (larger than 20 litres) were used for blanching wild nuts (Kobayashi 2011a).
4. This study was supported by a JSPS Grant-in-Aid for Scientific Research on Innovative Areas 'Rice Farming and Chinese Civilisation' (FY 2015–2019, No. 1701).
5. In Chinese archaeology, layers are numbered from the latest (upper) to oldest (lower).

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Chapter 12

Food as Heritage

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Introductory reflections on food, culture and heritage

Food is culture; supremely so. It not only makes and nourishes our bodies, but it also partakes in the building of sociability and in the performance of identities. Through food we make ourselves, and exercise and experience social qualities such as communality and exclusions. Commensality, the process of eating together, may be seen as both a central social glue and a stage-setting of social relations, including differences within and between groups. It is also common for the making and processing of food to reference earlier events and traditions, whether the meal is a feast or an everyday activity. Food is also materiality, and its various elements have been, and are, objects of manipulation ranging from the long-term genetic story of modifications and mutations to the short-term daily processes of food making.

The recognition of the cultural dimension of food is not new. Studies of food as part of social settings have long pedigrees, but from a socio-cultural point of view the second half of the twentieth century saw a particularly novel and more socially orientated manner of appreciating the significance of food. Anthropology and sociology provided core arguments, with scholars such as Mary Douglas (1966) and Jack Goody (1982) developing structuralist-inspired arguments about the patterns and regularities that are expressed within and through food. They, and others, argued convincingly for the strongly symbolic dimensions of food. On this background, wider aspects and impacts of food have been increasingly recognized. Within this, the importance of food as part of our heritage has also become a distinct area of appreciation. This focus emerged 'naturally', as food making in itself is strongly conscious of its history (in the form of recipes dictating the special way of selecting and treating ingredients)—in other words there exists a value linked to culturally prescribed ways of doing things, and food is regularly performed within a strong sense of 'past tense' (this is how it has always been done).

In turn, this reflexivity about tradition means that food is often integral to the formation, as well as the performance, of personal and group identities, and in particular to notions of inherited practices. Moreover, food is also a strongly mnemonic device: the taste or smell of food may recall, for example, a memory or a scene from childhood or a special event, and through such memory recall food is used to confirm identity and social belonging. Marcel Proust's famous description in *À la Recherche du Temps Perdu* of how tasting a madeleine dipped in tea ignites a journey of memory has been widely cited to capture this capacity of food, resulting in the idea of 'the Proustian moment' or 'the Proust Effect'.¹

Food as 'home' is further linked to the tangible site of food making, the hearth. Tastes and smells, often remembrances of childhood as in the Proustian case, become a sensorial home to which the mind returns, motivating efforts to recreate it. This dimension becomes especially salient in the context of the movement of people, forced or otherwise. People on the move take with them recipes, know-how and their memories related to food. When their displacement is forced or motivated by economic necessity, then the acts of cooking, sharing and, of course, eating the dishes of the lost home can become an important gesture of resisting loss and attempting to recover that space of belonging. In the refugee camps in Greece, for instance, up-rooted Yazidi and Syrian families fleeing violence have tried against extraordinary odds to recreate some of the flavours of home and maintain daily routines revolving around food (see Figure 12.1a–d).

Food is, therefore, part of heritage at different scales—from the microhistories of individual lives, the personal variations on recipes and the predilections of palates to a diachronic perspective on a regional and even global scale reflecting the transformation of social systems and mobility of populations with their food know-how and taste preferences. These dimensions of food have increasingly become recognized within heritage policies and practices of different kinds.



Figure 12.1. Photographs taken at the Refugee Camp in Idomeni, Greece, March/April 2016: (a) A Yazidi woman prepares a sweet breakfast of roasted raisins for her family; (b) A Yazidi family from Iraq gather to eat breakfast; (c) An older Syrian woman makes rice pudding for her grandchildren. Supplies are limited and the food on offer is often unappealing and stale. Small reminders of home can help face the difficult and often depressing living conditions; (d) A group of people queue for chai at the Solidari-Tea tent, in Idomeni. Access to hot sweet chai was a small source of comfort for residents of the camp and the tea tent remained open 24/7 to accommodate needs. (Photographs: Alkisti Alevropoulou-Malli, reproduced with her kind permission.)

In this brief chapter celebrating Martin Jones and his career in plants and food, we provide an outline of two main approaches to food heritage. One is the global valorization through instruments developed by the United Nations Education, Scientific and Cultural Organization (UNESCO) and the tensions that sit therein; the other is the exploration of a particular case in which food has become part of a regional reflection over—and deflection of—a difficult part of twentieth-century history. Both of these levels at which food as heritage operate exemplify official and public understandings as well as issues about the appropriations of food heritage. Although brief, the examples illustrate something about how food matters and how that mattering can be used, enhanced and possibly manipulated, as well as also what food brings to the social conversation about history, places and ways of doing things.

International recognition—food as Intangible Cultural Heritage

In 2002 UNESCO officially launched the concept of the world's Intangible Cultural Heritage (ICH) through the 'Convention for the Safeguarding of Intangible Cultural Heritage' to create a system of official appreciation for a range of cultural practices that are distinct from monuments and sites—'the oral and intangible treasures of humankind worldwide'—with the aim 'to raise awareness of intangible heritage and provide recognition to communities' traditions and know-how that reflect their diversity'.² The convention took effect from 2003, and in 2008 a derived list had been established. By 2016 there were 429 ICH elements listed. Through this, the contribution of crafts and skilled knowledge has been up-graded in value and recog-



Figure 12.2. An example of a 'Mediterranean Diet' meal. (Photograph: Dacia Viejo Rose.)

nition, but also (potentially) reified and consolidated into types potentially resulting in fossilized versions of, for example, food practices. However, our interests here are the motivations and ideas that influence how we conceive of food as intangible³ cultural practice.

In the details provided for the different food traditions listed on the 'Representative List of the Intangible Cultural Heritage of Humanity', it is possible to discern a number of preoccupations. First, there are case studies that focus directly on food, in particular specificities of its preparation and consumption; we shall discuss some of these further below. Second, there are cases that focus on particular production practices, where a procedure and traditional knowledge and skills are the concern rather than the food that is produced. Example of this are the *Mibu no Hana Taue* ritual of transplanting rice in Mibu, Hiroshima, Japan, or the shrimp fishing on horseback in Oostduinkerke, Belgium. Third are those cases in which food plays a central role, but where it is not the main object of the ICH practice being listed, such as the *Qiang New Year Festival* in China, the Winegrowers' Festival of Vevey in Switzerland, or the *Makishi Masquerade* in Zambia.

The first group is the one that interests us most here, as it includes cases that are about intangible heritage in the form of the production of food out of various ingredients and using particular practices and tools. Within these cases there is a distinct focus on commensality and communality. The cases presented for the 'Mediterranean Diet' (Greece, Italy, Morocco, Spain; see Figure 12.2) and the '*Oshi palav*' [pilaf] in Tajikistan express this respectively as follows:

Hence, the cultural practice transcends the boundaries of food and acts as a cornerstone for cultural practices which involves eating together [...] and stresses on hospitality and neighbourliness. These community meals in turn have given rise to a large amount of art being produced—in the form of music, legends and tales. (www.gounesco.com/intangible-cultural-heritage-food-edition, accessed 16 September 2018)

Otherwise known as the 'King of meals', it is based on a recipe using vegetables, rice, meat and spices but up to 200 varieties of the dish exist. Considered an inclusive practice that aims to bring people of different backgrounds together, oshi palav is prepared to be enjoyed at regular mealtimes, as well as social gatherings, celebrations and rituals. The importance of the dish to communities in Tajikistan is indicative in sayings such as 'No Osh, no acquaintance' or 'If you have eaten Osh from somebody, you must respect them for 40 years.' (<https://ich.unesco.org/en/RL/oshi-palav-a-traditional-meal-and-its-social-and-cultural-contexts-in-tajikistan-01191#identification>, accessed 16 September 2018)

Another strong focus is the food being produced as a result of a particular process or celebrated due to its social and cultural significance. These range from specific beverages with traditional forms of production and contexts of consumption, such as 'Turkish coffee culture and tradition' and 'Arabic coffee, a symbol of generosity', to the community-building and celebratory aspects of the 'gastronomic meal of the French' or the 'beer culture' in Belgium. In some cases one

can detect a tendency to claim that the ‘essence’ of a culture can be found in its food-ways, or that its symbolic character is explicit and widely recognized. Japanese cooking is, for instance, described as ‘very sincere’, whereas Croatian gingerbread is claimed to be ‘One of the most commonly recognized symbols of Croatian identity’.⁴ Yet even in these celebrations of communal sharing there are rifts that indicate the ubiquitously political nature of UNESCO and its listing mechanisms. Perhaps this is most evident in the case of kimchi, listed in 2013 as ‘Kimjang, making and sharing kimchi in the Republic of Korea’, and in 2015 as the ‘Tradition of kimchi-making in the Democratic People’s Republic of Korea’, despite their obvious similarities and the irony that descriptions of both emphasize the fact that the process of kimchi making boosts cooperation and social cohesion. This is without going into the tensions that broke out between Japan and the Republic of Korea over kimchi in 1996, which led to the latter petitioning the World Health Organization and the Food and Agriculture Organization to establish international standards for kimchi (Lahrichi 2014).

Within the explicit focus on food as ICH, we recognize the topics brought out by anthropologists in the late twentieth century—food is about sustenance, but its importance goes far beyond this and it is its role as a social medium that we truly want to celebrate and preserve. This, in turn, is what gives food cultural values, and makes it an important part of many different kinds of heritages.

Local usage and significance—food and the narration of war and occupation in the Channel Islands

Food-as-heritage can even play an important role in museums dedicated to the subject of war. The display of daily rations, narratives of rationing, of food scarcity for some groups and unequal access to food resources by others can be used to communicate daily life and inflicted suffering, and can provide clear insight into the character of the enemy and their actions.

A disproportionately high number of museums dedicated to the German occupation of 1940–45 are found throughout the British Channel Islands. The occupation has been the single most important historical event in living memory and is a crucial element of identity creation today (Carr 2014). These occupation museums started in the Islands in 1946, and are principally private venues used for the display of personal collections of militaria, usually arranged around certain themes (Carr 2016).

One feature that unites all of these museums is the display of food and food-related artefacts. These

include ersatz food; home-made tools and instruments created to turn one type of (relatively) more plentiful food into another which was in short supply; tools for making on a domestic level that which had long since become mechanized and mass produced; and home-made food containers and cookware.

Such items include 75-year-old jam-jars containing dried seaweed to use as blancmange; dried and ground parsnips and acorns used as a coffee substitute; and various leaves dried for use as tea. Potato graters (to turn potatoes into bread flour) and sugar-beet presses (to make substitute sugar) are among other items displayed with pride. Small (and illegal) butter churns for creating small amounts of butter for the household are among commonly displayed objects. Finally, the most ubiquitous of all food-related items in occupation museums are the pots and pans made from recycled Red Cross tins. A Red Cross relief ship came to the Islands monthly from December 1944 onwards and saved the population from starvation. The food tins in the parcels, once their contents were consumed, were recycled and used to replace the cookware long since vanished from the local shops. Nowhere are all of these food-related items of heritage displayed more clearly than in a recreated occupation-period kitchen at the German Occupation Museum in Guernsey—an iconic image of the occupation (Figure 12.3). These objects are exhibited for the public as ‘mnemonic devices’, as Macdonald calls them; objects capable of ‘carrying’ the past into the present and, through younger museum-goers, into the future (Macdonald 2013, 152). Through these items, younger generations learn the occupation narrative.

This obsession with food—or rather, with a need to display a historical preoccupation with food at a time when mass hunger and, indeed, starvation was rife—is indicative of how important this time period was for the Islanders, and indeed how important the hunger was, and is, as part of the narrative of the German occupation. In fact, the display of food-as-heritage is used as an instrument and, sometimes, a metaphor for narrating the story of the German occupation to museum-going audiences.

The narrative presented is a selective one, however, albeit a not untruthful one. While the wartime experience of the Channel Islands was closer to that of continental Europe—comprising resistance, persecution of Jews, deportation of political prisoners and other sectors of society, and the importation of forced labour—the war narrative displayed adheres instead to that of Britain (Carr 2012). This has been termed the ‘Churchillian paradigm’ by Paul Sanders, who has characterized the narrative as one of “‘blood, toil and tears” of sublime and unwavering



Figure 12.3. A Guernsey occupation-era kitchen, complete with food-related objects, at the German Occupation Museum, Guernsey. (Photograph: Gilly Carr.)

steadfastness in the face of adversity' (2012, 25). This narrative of endurance until final victory has a focus on victory rather than the darker side of what was stoically endured. The most palatable, least dark and least controversial way of narrating what was endured is to focus on hunger rather than, say, on the persecution of Jews and deportations of political prisoners, which the local government—who stayed in power after the occupation—failed even to try to prevent. We can suggest that narrating occupation through the 'safe' topic of food has formed a special version of what Laurajane Smith calls the 'Authorised Heritage Discourse' in the Channel Islands, whereby food-as-heritage is something that is 'innately valuable' and that 'current generations "must" care for, protect and revere so that they may be passed to nebulous future generations for their "education", and to forge a sense of common identity based on the past' (Smith 2006, 29).

Thus, a focus on food represents an untroubled representation of the occupation devoid of any of the complexities of the occupation experience. A focus on food avoids the topic of collaboration (although veers dangerously into black-market territory). In truth, narrating the experience of occupation through food is an accurate way of representing a common denominator—something that everybody experienced. It is an uncontested narrative of war. Nobody is to blame for hunger but the occupiers; and the civilians and local authorities were entirely innocent of any blame at all. Food is used as a metaphor to speak of innocent suffering of all at the hands of the enemy and of the blamelessness of the local political leaders, who did their best for the civilian population. By the same token, the display of a number of wooden bread bowls, engraved with mottos and messages by German soldiers, speaks of the perceived ubiquity of food in the possession of the occupiers. They are presented

as greedy, as growing fat while the Islanders starved; indeed, as the very agents of Islander starvation.

However, is this the only narrative concerning food in occupation museums? Is there any sign that the Churchillian paradigm is weakening its grip and allowing alternative narratives to come to the fore? Certainly we can see new displays erected since the turn of the millennium which are allowing other voices to tell alternative stories. In the 'Prisoner Room' of the German Occupation Museum in Guernsey, for example, a bowl and spoon found at the concentration camp in the Channel Island of Alderney is displayed. In another exhibit erected at the same time, plates, cups and food trays recycled from Red Cross tins, made by deported Channel Islander civilian internees in German camps, make a mute statement about their experience. These internees were kept alive by weekly Red Cross parcels, and recycling the metal food tins were a way of preventing the guards taking them away to give to the German armament industry. These objects thus speak not only of the loyalty of the deportees to the Allied cause, but also of their experience of hunger in camps relieved through aid.

The Occupation Tapestry Gallery in Jersey depicts the German occupation in a series of 12 panels inspired not only by the Bayeux Tapestry, but also by the Operation Overlord tapestry at the D-Day Museum in Portsmouth. It was put on display in 1995, on the occasion of the 50th anniversary of Liberation. The third panel depicts a scene remarkably similar to the wartime kitchen displayed at the German Occupation Museum in Guernsey (Figure 12.3). The penultimate panel shows the arrival of the Red Cross ship that saved the Islands from starvation. And yet the fifth panel, in addition to depicting long queues for food, also shows a woman trading a pearl necklace on the black market for a package of tea. It also includes a vignette of somebody hiding a pig in a bed in order to avoid its confiscation by the occupiers—a clear example of civilian resistance.

In short, food is an emotive part of heritage. As an artefact of war, it can be used (and abused) to narrate any number of alternative and competing versions of the same story, but few museums have room for all versions. Through the selective display of different food-related artefacts, similarly selective versions of the past, voices, and discrepant experiences can be chosen to educate an audience about what the experience was like for 'everybody'. National narratives are built on such displays. And yet narratives can and do change with time. New exhibitions increasingly seek to tell different stories and to bring marginalized narratives centre stage. It is incumbent upon archaeologists and heritage professionals who curate such

exhibitions, and who choose food-related artefacts to tell stories of the past, most especially those which are controversial, contested or sensitive, to make sure that these stories are plural and do not privilege the same old 'safe' and seemingly uncontroversial narratives.

Afterthought

Preparing, presenting and consuming food, then, is about much more than providing nutrition. These acts represent a range of human activity replete with social, cultural and symbolic meaning that may be related to every aspect of the food cycle. Above we have seen both the heritagization of food by an international organization and the use of food in displays of difficult pasts as a, deceptively, 'safe' heritage narrative.

So does this heritage interest in food matter; does it have any repercussions? One obvious impact is that the heritagization process can lead to the reification and commodification of its subject. This in turn can lead to tensions internationally that make food seem a little bit less 'safe' and innocent. Combine trade negotiations, geographical indicators (e.g. Champagne and Bordeaux), intellectual property, competition, sprinkle in some nationalism, and the results are conflicts over champagne, feta and hummus, to name but a few. Those seeking to protect the particular food, or drink, emphasize the sense of authenticity, the links to land and community, and make a point of this being linked to a set of traditions tied into a territory and ultimately being about identity: 'Much like the nation, champagne and its *terroir* are believed to possess eternal, natural qualities. The wine can be seen as an objective manifestation of the French "soul," the guardian of supreme spiritual values' (Guy 2003, 2). This strength of feeling can be evidenced in part by the Champagne Wars that can be traced back to the 1950s between France and Canada and only ended in 2003, but France fought similar battles with the US, Spain and, more recently, Ukraine. In the case of hummus, tensions gradually mounted between Israel and Lebanon, and in 2008 they led the Association of Lebanese Industrialists to launch a lawsuit against Israel for infringement of food copyright laws and sparked one observer to write: 'Lebanon and Israel are currently engaged in a two-pronged battle over the national identity of hummus' (Ariel 2012, 34). In reflecting on the dynamics that have led to this conflict, Ariel further remarks:

In the age of globalization and international travel, migration foodways have become increasingly hybrid. Dishes travel and are adopted and indigenized by groups of people outside of their 'original'

homes. This produces anxiety in those who once considered these foods 'theirs'. The trademarking of foods is a reaction to this process. (Ariel 2012, 34)

The commodification of food heritage is also found in the growing trend of 'food tourism', defined by the World Food Travel Association as 'The pursuit and enjoyment of unique and memorable food and drink experiences, both far and near.'⁵ Such tourism, together with heritage labelling, tends to follow an expectation of a loyalty to the original and authentic, thus potentially resulting in a reification of 'traditional food'. This is in contrast to the intention of the intangible heritage convention, which aims at the preservation of live traditions. In the UNESCO convention it is stressed that intangible heritage is alive, transmitted through generations and confirmed, potentially even slightly altered, through its various performances, but also that in some ways it nonetheless stays true to the original. Another international movement, in this case a non-governmental one, that equally works to valorize and protect these authentic dimensions of foodways is the Slow Food organization created in 1986 and the movement around it. This tension within intangible heritage between, on one hand, permanence and authenticity and on the other, the common tendency for shifts and transformations is not distinct to food, but food expresses it very clearly due to its presence in so many contexts and its continuous performance and reimagining.

At the same time, however, food cultures also have ways of overcoming such apparent changes, and ability of resistance and reconstitution. Haboucha's study of how Afghan women refugees in London used food to reconcile the memory of home with their lived experiences in a new place is indicative of the ways in which food can simultaneously resist and absorb change (Haboucha 2015). In this case, through various processes of social conformity the women gradually came to the agreement that leek could replace the *Gandana* (wild leek) traditionally used for many dishes—and through this appropriation a new version of the authentic Afghan meal was produced. And so we come to the particular strength of food as heritage—its ability at once to reflect and to recreate the most intimate of home environments and personal remembrances, while at the same time slicing through national borders linking regional communities and indeed creating international ones, to be both resilient and malleable.

Notes

1. The Proust effect refers to the vivid reliving of events from the past through sensory stimuli (van Campen 2014).
2. <http://www.gounesco.com/intangible-cultural-heritage-food-edition> (accessed 15 September 2018).
3. The potential irony of the convention approaching food as intangible when most of us experience it as a physical matter is not lost on the authors, but a critique of the fundamental conceptualization of intangible heritage is not the topic here.
4. <http://www.gounesco.com/intangible-cultural-heritage-food-edition> (accessed 15 September 2018).
5. The association, founded in 2001, <https://www.worldfoodtravel.org/cpages/what-is-food-tourism> (accessed 15 September 2018), aims to support people interested in engaging in food tourism. Searching Google for 'food tourism' reveals how big the concept has become within a few years, including a substantial academic involvement with its analysis.

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Part IV
Between Fertile Crescents

Chapter 13

From a Fertile Idea to a Fertile Arc: The Origins of Broomcorn Millet 15 Years On

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'I've always thought the best thing to do with festschrifts was to air something too speculative to get in a refereed journal, so that one worked well.'

(Martin K. Jones)

Introduction

In 2004, in a chapter contributed to Colin Renfrew's festschrift, which Martin Jones edited, he drew attention to the relationship between research projects and research questions: 'Research projects typically proceed by posing a question, and working in a systemic manner towards finding its answer. Collectively, however, the whole constellation of research projects within a discipline depends upon a converse process. Some scholars begin with a tentative answer, drawn from a wealth of experience, insight and guesswork, and pressing questions, which go on to drive research' (Jones 2004, 127). In the past decades, Martin Jones has played that role in asking new questions that offered opportunities to generate diverse research projects and to steer the direction of future archaeological enquires. This is particularly the case for the broomcorn millet (*Panicum miliaceum*) question (Jones 2004): whether it was domesticated once in North China, or multiple times across Eurasia.

The millet question first arose in the 1970s when Jones was surveying British crops between 500 BC and AD 500 (Jones 1981). A noteworthy feature was that the British record lacked a crop, broomcorn millet, that recurred on the neighbouring countries of the European mainland. At that period, the absence from Britain was the exceptional feature, rather than its presence in Europe. In the next few decades the presence of millet in much earlier European records emerged, provoking the key question that Jones spelled out in the seminal 2004 paper: 'Any western domestication of broomcorn millet would presumably have been very early, and comparable in age certainly with the date from the eastern Fertile Crescent [c. 6000–5000 BC], and possibly the western Fertile Crescent [c. 10000–8000

BC]. It may indeed be that the two regions begin to join up' (Jones 2004, 132). By 'eastern fertile crescent', he meant the Early Neolithic sites in the Yellow River region. It became clear later that a series of foothill locations along the eastern edge of the Loess Plateau played a key role in early millet cultivation, forming 'China's Fertile Arc' (Liu *et al.* 2009; Ren *et al.* 2016).

The context in 2004

Early discussions on East–West interconnections in prehistoric Eurasia focused primarily on the inter-continental exchange of material cultures. By 2004, much had been debated about the dispersal of metallurgical technologies, the horse and horse management, among other material traditions, from the West to East Asia (Levine 1999; Mei 2003; Mei & Shell 1998; Olsen 2003). It was suggested that the cultural separation of East and West began to break down around the middle of the second millennium BC (Sherratt 2006). Before this date, societies in the eastern and western parts of Eurasia were largely mutually isolated. Meanwhile, scholarly attention was drawn to a number of published early western records of two crops principally associated with China, broomcorn millet and foxtail millet (*Setaria italica*). Their significance was that at the apparent time period (pre-5000 BC) of these European millet records, no material culture context explained the dispersal of eastern crops. This elevated minor cereals, which had hitherto been rather overlooked, to a conspicuous position in relation to questions of origins and spread within Old World prehistory, and provide a unique example (possibly the oldest) of how eastern agriculture had an influence on the western system from an early stage.

At that time, the archaeobotanical patterning of minor crops with apparently widely dispersed early records in East and West came against a background of archaeogenetic debate on single *versus* multiple origins of domesticated plants and animals. The driving question in archaeogenetic research in the late 1990s



Figure 13.1. Locations of key millet sites across Eurasia. (Map generated by ArcMap v. 10.2.) (1) Xinglonggou; (2) Xinle; (3) Zhangmatun; (4) Yuezhuang; (5) Xihe; (6) Nanzhuangtou; (7) Donghulin; (8) Cishan 9; (9) Peiligang; (10) Shatvoli; (11) Wuluozi; (12) Zhuzhai; (13) Dadituan; (14) Baligang; (15) Krounooka 1; (16) Dongpan; (17) Beiqian; (18) Yuhua; (19) Xinjie; (20) Yangguanzhai; (21) Xishaping; (22) Buziping; (23) Gaomuxudi; (24) Hurere; (25) Luowalimchang; (26) Gayixiangjing; (27) Nanshan; (28) Yuchisi; (29) Chengtoushan; (30) Nanke; (31) Yingpanshan; (32) Tongsandong; (33) Gahyeon-ri and Saongjeori; (34) Zhaojiazhuang; (35) Taosi; (36) Zhouyuan; (37) Wangchenggang; (38) Erlitou; (39) Daxinzhuang; (40) Liangchengzhen; (41) Jiaochangpu; (42) Xihetan; (43) Huoshiliang; (44) Ganggangwa; (45) Huoshao; (46) Donghuishan; (47) Xichengji; (48) Shaguoliang; (49) Mozuizi; (50) Huangniangniangtai; (51) Mogou; (52) Jinchankou; (53) Lajia; (54) Guangtaoyuan; (55) Baodun; (56) Haimenkou (early phase); (57) Non Pa Wai; (58) Gonur Tepe; (59) Ojaky; (60) T211/1219; (61) Begash (Ia); (62) Xiaohe; (63) Karuo; (64) Changguogou; (65) Kweemo-Kartli sites; (66) Jubabat al-Iuruf; (67) Haftaani; (68) Kilise; (69) Gordion; (70) Mägura-Buduiasca; (71) Liubcova; (72) Sacarocca; (73) Ratnio-2; (74) Zánka; (75) Fajsz 18; (76) Bylany; (77) Moheinic; (78) Bruchenbrucken-Friedberg; (79) Sammardenchia; (80) Mandalo; (81) Mimirching; (82) Skala Sotiros; (83) Kastanas; (84) Sanghol; (85) Lahuraderwa; (86) Daimabad; (87) Harappa; (88) Pirak; (89) Surkooda; (90) Rojdi; (91) Kammer; (92) Oriyo-Timbo; (93) Babar Kot; (94) Ojijana.

and early 2000s was whether domesticated plants and animals had evolved in and dispersed from those discrete centres of agricultural origin inferred from archaeology, or whether domestication was a much more geographically diffuse process. The principal toolkit, phylogeographic analysis of domesticated animal breeds and crop-plant landraces, together with their wild ancestral species where these were known and still extant, necessarily produced bifurcating evolutionary trees from which the monophyly (indicating a single origin) and/or rates of evolutionary change of the domesticate, in relation to geography, could be inferred. By 2004, all the major domesticates had been subjected to phylogeographic analysis, and an intriguingly broad picture had emerged of multiple, geographically widespread domestications of livestock species, in contrast to single, localized domestications of each of the principal crops (Larson *et al.* 2005; MacHugh & Bradley 2001; Matsuoka *et al.* 2002; Salamini *et al.* 2002).

In the years following Jones' 2004 paper, the gathering of novel archaeobotanical evidence intensified across the Eurasian continent. In the same year that Jones raised the millet question, a major recovery of millet grains from the Neolithic site of Xinglonggou in China was published (Zhao 2004). This study marked the advent of systematic archaeobotanical research in China, with more than 1200 flotation samples taken at the site. In contrast to solitary finds in Europe, over 1400 charred millet grains were recovered at Xinglonggou (predominantly broomcorn, but also some foxtail millet) dated back to 6000 BC. Xinglonggou is only one example of the many archaeobotanical investigations in East, South and Central Asia in the past 15 years or so, which vastly increased the database of millet sites (Ren *et al.* 2016; Zhao 2011). Stable isotopic studies have complemented archaeobotany in directly evidencing the role of millet in the human and animal diet, with more than 50 publications featuring isotopic results in China alone during the past decade (Lightfoot *et al.* 2013). Archeogenetic research on the processes that shaped patterns of intraspecific genetic diversity in *P. miliaceum* is inherently bound up with the wider evolutionary context (Hunt *et al.* 2014). In this chapter we will review recent advances in our understanding of broomcorn millet origins and spread, focusing on three areas: genetic work on the origins and spread of broomcorn millet; the earliest archaeological evidence of cultivation and consumption of the crop in China; and new advances in Central Asia and Europe. By doing so, we will revisit the questions of where broomcorn millet was first cultivated and consumed, and its spread across Eurasia (see Figure 13.1 for locations of key millet sites across Eurasia).

Genetic data and the origins of broomcorn millet

From a genetic perspective, research on the processes that shaped patterns of intraspecific genetic diversity in *P. miliaceum* is inherently bound up with the wider evolutionary context. Furthest back in evolutionary time, this means the evolution of its genome composition, which was followed in the relatively recent past by the differentiation, imposed by human selection, from a wild ancestral taxon to the phenotypically domesticated form. These issues have been partly clarified since 2004. Patterns of sequence diversity in our exploratory studies of genetic markers were strongly suggestive that broomcorn millet is an allotetraploid or amphidiploid, that is, its genome of 36 chromosomes comprises two distinct sets of 18 chromosomes combined from two wild species in a polyploidization event. This is comparable to the genomes of the better-understood tetraploid wheats, emmer (*Triticum turgidum* subsp. *dicoccum*) and durum (*T. turgidum* subsp. *durum*). This led to a collaborative cytogenetics project with Pat Heslop-Harrison in Leicester, in which DNA sequence and genomic *in situ* hybridization analyses of *P. miliaceum* and available wild *Panicum* species confirmed the allotetraploid nature of *P. miliaceum* and indicated that one of the two wild genome donors was the diploid *P. capillare*, or a genetically very similar species. The other genome in *P. miliaceum* appears to have some identity with one of the two genomes in a wild allotetraploid species, *P. repens* (Hunt *et al.* 2014). These findings themselves pose new biogeographical conundrums, as *P. capillare* is thought to be a New World native.

We can speculate that, as in the tetraploid wheats, allopolyploidization preceded domestication and thus that the direct wild ancestor of *P. miliaceum* is also allotetraploid. Little progress has been made to date on evaluating the weedy-type forms of *P. miliaceum* (*P. miliaceum* subsp. *ruderales*) that have been reported from a wide geographical range from central Europe to northeastern China. Miller and colleagues (2016) suggest that we have 'simply written off the range of this wild progenitor as somewhere in the vast terra incognita of Central Eurasia'. The difficulties here have proved twofold. First, in contrast to the large-grained cereals, such as Triticeae, existing herbarium or germplasm collections of *P. miliaceum* subsp. *ruderales* are very few in number, lacking in clearly stated morphological criteria for their identification, and lacking provenance or passport data. *De novo* field collections with adequate coverage of the Eurasian range are a challenging proposition within the timespan of any research project. Second, the genetic and genomic resources available for *P. miliaceum* have made study of its intraspecific diversity unusually challenging.



Figure 13.2. Harriet Hunt visiting the Vavilov Herbarium, St Petersburg in 2011, collecting millet accessions. (Photograph: courtesy of Harriet Hunt.)

Miller and colleagues (2016) incorrectly state that the genome of broomcorn millet has been sequenced; although a number of other Panicoid cereals and wild relatives have been the subject of genome sequencing projects in the last decade, including foxtail millet (*Setaria italica*), green foxtail (*S. viridis*) and switchgrass (*Panicum virgatum*), the large polyploid genome and low global economic importance of *P. miliaceum* (in contrast to the bioenergy crop *P. virgatum*), have left it lagging in the priority list for genome sequencing. In consequence, in relative terms, the paucity of known genetic sequence for broomcorn millet (Saha *et al.* 2016) is even more strongly true than it was in 2004. From the markers that are available, intraspecific genetic diversity in *P. miliaceum* appears to be unusually low, and is in stark contrast to the high morphological diversity (Hunt *et al.* 2011; 2013). This presumably results from the fact that polyploidization and domestication have both imposed genetic bottlenecks, narrowing the gene pool.

Nonetheless, the geographic picture that emerged from microsatellite markers (the state-of-the-art technique for most plant-population genetic studies prior to the 2010s) is strongly illuminating regarding the

patterning of broomcorn millet diversity. Initial studies showed that domesticated *P. miliaceum* is divided into two major gene-pools with distinct eastern and western distributions, which both subdivide further into a total of six or seven clades whose distribution shows clear geographical structuring (Hunt *et al.* 2011; 2013; see Figure 13.2, for Harriet Hunt visiting the Vavilov Institute). A number of considerations from the genetic diversity statistics, let alone evidence from other proxies, were more suggestive of a single centre of domestication of broomcorn millet in China (Hunt *et al.* 2011; 2013). This is supported by an updated analysis of genetic data that included many additional Chinese samples, based on a simple model of population expansion. Further, these analyses suggest that the centre of origin may lie in western China, at the western end of the Loess Plateau (Hunt *et al.* 2018).

With the growth of functional genetics and genomics since 2004, the role of selection alongside demography in shaping patterns of crop variation has also come to prominence. Broomcorn millet has apparently undergone selection for starch quality, specifically for a high frequency of varieties with waxy or glutinous starch in those areas of East Asia (central-eastern China, Korea and Japan) where this trait is valued in the cuisine (Fuller & Rowlands 2009). The evolution of waxy grain starch in the polyploid genome of *P. miliaceum* was non-trivial, requiring mutations at two parallel loci followed by their combination in a single plant (Hunt *et al.* 2010; 2013). As part of the ‘constellation of research projects’ on broomcorn millet, the distribution of the waxy-starch genotypes poses new questions on culinary choice and its cultural boundaries (Hunt *et al.* 2013).

Earliest evidence for cultivation and consumption of broomcorn millet in China—an updated picture

Since 2004, archaeological investigations on Pleistocene and early Holocene sites have transformed knowledge about hunter-gatherers in north China. A few Pleistocene sites in Shanxi province have provided residue and tool use-wear evidence for pre-agricultural plant processing, including grinding implements and the use of Panicoid grasses (Liu & Chen 2012; Liu *et al.* 2013). Macrofossil remains reported from one of these (Shizitan: 10,700–9600 BC) suggest the existence of Paniceae grains (Bestel *et al.* 2014). None of these data provide direct evidence for millet cultivation, but they nevertheless indicate the use of post-harvest processing techniques that would incorporate grains in the diet.

Evidence from phytoliths and starch granules places the first use of broomcorn and foxtail millet in the early Holocene. In the case of foxtail millet, the



Figure 13.3. Martin Jones at a broomcorn millet field near Lanzhou, Gansu Province, western China, September 2007. (Photograph: Xinyi Liu.)



Figure 13.4. Visiting millet sites in Gansu Province, western China, September 2007: from left to right, Xinyi Liu, Giedre Motuzaitė Matuzeviciute, Dustin White and Martin Jones. (Photograph: courtesy of Giedre Motuzaitė Matuzeviciute.)

oldest claim—inferred from starch granules—is from Nanzhuangtou (c. 9500 BC), followed by Donghulin (c. 7500 BC) (Yang *et al.* 2012a); and in the case of broomcorn millet, the earliest claim related to phytoliths is from Cishan (c. 8000 BC: Lu *et al.* 2009; Yang *et al.* 2012b). However, there are considerable disagreements among scholars regarding both the lack of species-specificity from starch grains and phytoliths (Liu *et al.* 2013) and the radiocarbon dates from Cishan (Zhao 2011).

Compared with microfossil evidence, macrofossil identification in the early Holocene is less controversial. The earliest charred grains of broomcorn and/or foxtail millet in archaeological contexts date to the turn of

the seventh/sixth millennia BC. Seven localities report charred broomcorn and foxtail millet grains prior to 5000 cal. BC (Liu *et al.* 2009; Ren *et al.* 2016; see Figures 13.3 & 13.4, for fieldtrips to China).

Considering domestication as a plant evolutionary process, data on the loss of seed dispersal, a key domestication trait, are lacking for broomcorn millet. This is partly because the millet rachis is delicate and does not normally survive the charring process, in contrast to rice, wheat and barley. In some seed crops an increase in grain size evolved alongside the non-shattering trait (e.g. Fuller *et al.* 2014), a proxy for domestication that has potential to be used for broomcorn and

foxtail millets. It has been noticed that broomcorn and foxtail millet grains show a gradual increase in size and change in shape over the Neolithic period. This has led some scholars to speculate that the broomcorn millet from Early Neolithic sites such as Xinglonggou had undergone some selection for caryopsis size and shape (e.g. Zhao 2004), with grains from later sites showing a more pronounced morphological change. However, multiple factors, such as sowing depth and culinary choices, may also influence the grain shapes of seed crops; grain size alone cannot be used as the sole indicator of the domestication process (Harlan *et al.* 1973; Liu *et al.* 2016a).

Turning to the consumption of millet, there has been a rapid increase in the past decade of palaeodietary studies using stable isotopes across Eurasia, particularly in China (see Lightfoot *et al.* 2013, for a review of the isotopic evidence). This isotopic research shows that human consumption of millet at a significant scale is surprisingly old in north China, but variable both among sites and among individual consumers. Human skeletal remains have been analysed isotopically from five northern sites pre-dating 5000 BC. Isotope values from one site are consistent with no millet consumption (Jiahu) and two are consistent with a mix of C₃ and C₄ consumption (Guowan and Xiaojingshan: Hu *et al.* 2006; 2008). The remaining two—Xinglonggou and Xinglongwa—have carbon isotope values indicating millet consumption on a significant scale (Liu *et al.* 2012). Therefore, the Xiliao River region (where the Xinglongwa culture is situated) provides evidence for both the oldest directly dated millet grain as well as the oldest millet consumers. After 5000 BC, almost all northern populations are consistent with C₄ diets and they also produced enough millet to provision their animals, particularly pigs (Barton *et al.* 2009; Chen *et al.* 2012; Guo *et al.* 2011; Pechenkina *et al.* 2005).

There are, however, some marked gaps in our understanding regarding millet uptake through food chains. For example, conventional isotopic analysis of bulk collagen alone stops short of answering questions such as to what extent did Neolithic humans consume millet directly, and what proportion of their diets consisted of meat or dairy from animals fed on millet? When dietary reconstruction is based on bulk collagen isotopic determinations, informative variation at the molecular level is masked. Carbon isotope analyses of individual amino acids show that collagen amino acid carbon isotope ($\delta^{13}\text{C}$) values can differ by up to 27‰ (Hare *et al.* 1991; Tuross *et al.* 1988). Future research to analyse single amino acids will be plausible and timely. Furthermore, the assumption that the C₄ signal detected in human skeletal remains reflects human and animal consumption of major C₄ crops/millets

should be further tested (see Chapter 14, this volume, for further discussion).

The early millet sites in north China are concentrated along a chain of low mountains broadly running northeast–southwest, extending along a 2500 km boundary between the Loess Plateau and eastern China floodplains, a pattern echoing the ‘hilly flanks of the Fertile Crescent’ in southwest Asia (Liu *et al.* 2009; Ren *et al.* 2016). This early association of millet sites with foothill locations is also helpful to understand the geography of the later dispersal of millet cultivation. In Central Asia, the earliest archaeological sites with millet remains are restricted to a narrow foothill zone between 800 and 2000 m a.s.l., where summer precipitation is relatively high (Miller *et al.* 2016).

Chronology of broomcorn millet in Europe

Very early records of broomcorn millet in Europe have puzzled scholars since macrobotanical remains of millet were found in strata dated to as early as the seventh millennium BC (reviewed in Hunt *et al.* 2008). Some twenty sites dated to pre-5000 BC in Europe and the Caucasus were reported, mostly containing a few remains of broomcorn millet (Hunt *et al.* 2008; Jones 2004). Direct radiocarbon dates obtained on some of those broomcorn millet grains (10 sites in total), reported from pre-5000 BC sites in Europe, resulted in a very different age than the archaeological chronology. The earliest directly dated broomcorn millet grain was placed at only c. 1600 cal BC (Motuzaite Matuzeviciute *et al.* 2013). The AMS dates of the early millet records in Europe have indicated that at least some, and possibly all, of these ‘early’ records are doubtful and could well be intrusions of recent-age seeds into Neolithic layers. There is also a series of early indirect dates from grain impressions in Neolithic pottery from east Europe (Hunt *et al.* 2008). These are dependent upon the reliability of identification of casts from impressions, largely conducted and published prior to the possibilities of electron microscopy.

The beginning of millet cultivation in Europe more likely began sometime during the Middle Bronze Age (c. 1500 BC). Along with the earliest directly dated grain, it is during this period that many sites across Europe report broomcorn millet seeds in large quantities, providing clear evidence of its cultivation (Kneisel *et al.* 2015). In some places in Europe millet remains can be found in ubiquities of up to 65 per cent of samples (e.g. Rosch 1998; Szeverényi *et al.* 2015). The dietary changes associated with C₄ plant consumption can also be seen in Europe only starting from the Middle Bronze Age (e.g. Varalli *et al.* 2016). Lightfoot and colleagues (2013) noted that during the

Bronze Age, C₄ consumers outside China are often individuals within communities where the majority of people are C₃ eaters. In a different study by Lightfoot and colleagues (2015), only individuals buried in simple pits seemed to consume millet in prehistoric Croatia, while Ananyevskaya *et al.* (2017) have noted the opposite in Central Kazakhstan, where individuals with elevated $\delta^{13}\text{C}$ values belong to exceptionally rich male burials. Therefore, millet status as a food seems to be culture driven and differ across the region, at least in the pioneering stage of its dispersal.

It has been suggested that millet in the Mid–Late Bronze Age contributed to the ‘third food revolution’ in Europe, associated with changes in crop-production strategies and increased diversity of cultivated crops (Kneisel *et al.* 2015). At the northern limit of its distribution in Europe, in Latvia and Lithuania millet became one of the dominant crops at the end of the Bronze Age (800–600 BC; Grikpēdis & Motuzaite Matuzeviciute 2017; Pollmann 2014). Its cultivation coincided with population increase and the formation of fortified hillfort sites in this region. Furthermore, the increase in ubiquity of millet records in Europe coincides with the evidence of highly increased human mobility during the Bronze Age.

Globalization of millet crops

The accumulated data for China and Europe now suggest that broomcorn millet was cultivated at least 4000 years earlier in the east than in the west, overturning the maps of Jones (2004) and Hunt *et al.* (2008). The route of the implied east–west spread of millet has therefore been debated (see Figure 13.1 for locations of key millet sites across Eurasia). Jones (2004) proposed the steppe pathway, following the northern grassland route from China to Europe. The steppe has been often proposed as a ‘highway’ across Eurasia that allowed innovations to advance rapidly, given the lack of geographical obstacles (e.g. Middleton 2015). Despite the sporadic nature of archaeobotanical investigations in northern Eurasian steppe, macrobotanical evidence of millet is absent from the region before the mid second millennium BC. Recent stable isotope studies show that C₄ human consumers appeared in Minusinsk Basin during the Late Bronze Age, c. 1400 BC (Svyatko *et al.* 2013). In this period, C₄ consumers also appeared in southern and central Kazakhstan, but not northern Kazakhstan (Ananyevskaya *et al.* 2017; Lightfoot *et al.* 2014; Motuzaite Matuzeviciute *et al.* 2015). Millet may still have moved westward along the steppe pathway at a later period, as indicated by macrobotanical evidence from Early Iron Age Scythian graves in Siberia and Charasmian Steppe in Central Asia (Brite *et al.*

2017; Hunt *et al.* 2018; Spengler *et al.* 2016), but the focus of research on the first wave of westward expansion has now shifted south, to Central Asia.

Archaeobotanical research has now been conducted at multiple sites across Central Asia, embracing a wide variety of geographical zones including grasslands, mountain piedmont, high mountain valleys and riverbeds. The earliest evidence of broomcorn millet comes from Begash, located on the piedmont of the Tian Shan mountains in southeastern Kazakhstan. Direct radiocarbon dates from broomcorn millet placed its arrival in this region at the end of the third millennium BC (Frachetti *et al.* 2010). There is evidence for the expansion of broomcorn millet westwards from Begash along the northern slopes of the Inner Asian mountains during the first half of the second millennium BC, with records at sites in Afghanistan, Turkmenistan and Uzbekistan (Rouse & Cerasetti 2014; Spengler 2015; Spengler *et al.* 2014; 2016).

In South Asia, both broomcorn and foxtail millet are common in late Harappan sites in the early second millennium BC, although the precise dates are open to radiocarbon scrutiny (Pokharia *et al.* 2014; Weber 1998). Broomcorn millet is also reported in Yemen dated to the mid second millennium BC and there is evidence for its spread into Sudan in the same period (Boivin & Fuller 2009; Fuller *et al.* 2011). In Southeast Asia, foxtail millet is reported from Thailand at around c. 2000 BC (Weber *et al.* 2010).

The 2004 title ‘Between fertile crescents’ was not intended to suggest that broomcorn and foxtail millet themselves might link the eastern (north China) and western (southwest Asia) Fertile Crescents. Archaeobotanical data at the time (Nesbitt & Summers 1988) indicated that these crops were late arrivals among the crops grown in southwest Asia. Subsequent work has supported this chronology and clarified its geography and seasonality. In the second millennium BC, Asian millets are found in central Turkey and northwest Iran; they become more widespread across Anatolia, Iran, Iraq and northern Syria during the first millennium BC (Hunt *et al.* 2008; Lightfoot *et al.* 2013; Miller *et al.* 2016).

In 2004 the pattern was enigmatic; the western records of eastern millet are older than any material cultural evidence. This archaeobotanical patterning of minor crops with apparently widely dispersed early records in East Asia and Europe stimulated archaeobotanical, isotopic and genetic research across the continent. Archaeobotanical research since 2004 has secured and extended the evidence base for broomcorn millet in multiple regions of north China prior to 5000 BC. In contrast, re-evaluation of the solitary early *Panicum* records from Europe and the Caucasus has shown that their chronology was incorrect, and

therefore fails to substantiate the presence of millet in the west at this early date. The isotopic and genetic evidence are also consistent with a single early focus of millet agriculture in China. The documentation of broomcorn millet in eastern Kazakhstan from the late third millennium BC marks the first step on a Bronze Age pathway westward that followed the Inner Asian Mountains towards the Caucasus and Europe, although many details of this pathway remain to be explored. By the second millennium BC, archaeobotanical evidence of broomcorn millet are reasonably established in Afghanistan, Turkmenistan and Turkey in Central Asia; Greece, Romania and Hungary in Europe; India and Pakistan in South Asia; and Yemen and Sudan in North Africa. From isotope studies, there is evidence for C₄ consumption in at least 12 sites outside China. An emerging theme of the early millet agricultural sites is their location in the soft foothill spurs, shifting the focus away from the river-valley bottoms. This growing emphasis upon foothill locations, and the exploitation of slope runoff as opposed to valley-bottom water, also resonates with the locations of important new millet sites in Central Asia.

Conclusion

It was not so long ago that the idea of a single centre of the origin of civilization was a popular and widespread narrative. One consequence of recent discoveries in East Asian agricultural origins has been to undermine this notion. Studies into Asian millets have a significant agenda in this process. In terms of the spatial, the western and southern expansions of broomcorn and foxtail millet provide a unique example (and possibly the oldest) of how East Asian agriculture had an influence on the global system from a very early stage. This can encourage us to reflect on assumptions we have held in a western context, which include the assumptions about what agriculture actually is. Turning to the temporal, the gradual temporal change in millet consumption, as well as the slow dispersal of its cultivation, can be considered by contrasting the perpetual needs of the poor with the more ephemeral cultural choices of the powerful. The former may endure for centuries and millennia, whereas the latter, as the word 'choice' indicates, are to some extent biographically situated and more open to constant reconfiguration (Liu & Jones 2014). The dates available so far indicate a process spanning millennia. While this does not in itself exclude a cultural choice trigger, it would require a separate and more lengthy driver to sustain it over these much longer periods.

Over 10 years, the Asian millets have moved from a poorly understood peripheral resource to a

well-charted core feature of Old World prehistoric agriculture and its globalization. This greatly changed status has not only transformed our understanding of the past, but also our appreciation of the present, and its invaluable crop resources, whose diversity is continuously in danger. The research into the past of Asian millets has dramatically changed the profile of the Asian millet heartlands today. In 2012, the United Nations Food and Agriculture Organisation (FAO) designated the Aohan district of Inner Mongolia (the region in which Xinglonggou is situated) a Globally Important Agricultural Heritage System. This designation, explicitly acknowledging the role of archaeology in establishing its importance, has already impacted visibly upon the lives of Asian millet farmers.

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Chapter 14

A World of C₄ Pathways: On the Use of δ¹³C Values to Identify the Consumption of C₄ Plants in the Archaeological Record

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Introduction

Most palaeodietary isotope studies, our own included, rely on the assumption that the C₄ signal detected in human skeletal remains reflects human and animal consumption of one or two major C₄ crops—usually millets (a group of small-grained taxa including *Setaria* and *Panicum*) in Eurasia or maize (*Zea mays*) in the Americas—rather than other C₄ or CAM plant species. This assumption is problematic, as stable isotope analysis can only distinguish between photosynthetic pathways; it does not comment on the species consumed. Nevertheless, many studies (again, our own included) have not adequately considered whether or not C₄ or CAM plants other than the major crop species may have been available for human and/or animal consumption. This paper calls for greater consideration in palaeodietary analysis of the potential for C₄ and CAM plant consumption beyond these major crops through an assessment of edible C₄ and CAM plants that are currently available in the region. Importantly, this requires assessing which C₄ or CAM plants are edible not only to humans, but also to any animals which may themselves have entered the human food chain. While the question of human consumption may be approached by paleoethnobotanical survey, determining the possibility of animal consumption is conceptually more challenging.

To build our case, we provide three regional case studies where we consider C₄ and CAM plant availability: Sicily, Italy; Haryana, India; and the south coast of Peru. These case studies have been selected to represent different environmental conditions, which are likely to have different proportions of C₃, C₄ and CAM plants available for human and animal consumption. They have also been selected to illustrate different methodological approaches to the problem of C₄ plant consumption, with the former two drawing on literature reviews undertaken by the authors,

while the third, taken from the published literature, uses direct isotopic analysis of plants collected in the field. Armed with this knowledge, we then consider how best one can use human and animal δ¹³C values to identify and evaluate C₄ consumption in the archaeological record.

Background

Photosynthetic pathways

Photosynthesis is the process by which plants convert light energy to chemical energy by synthesizing sugars from carbon dioxide and water. There are three main types of photosynthesis, C₃, C₄ and CAM, which use different mechanisms to take in carbon dioxide from the atmosphere. Palaeodietary stable isotope analysis relies on the fact that these mechanisms discriminate to different degrees against isotopically heavy carbon dioxide (that is, carbon dioxide that incorporates carbon-13, ¹³C; e.g. O'Leary 1981). This means that the resulting plant tissues have stable isotope ratios that are different (i.e. fractionated) both from the isotopic ratio of the source carbon dioxide and from each other.

The mechanisms and differences between C₃, C₄ and CAM photosynthesis have been discussed in detail elsewhere and the reader is referred to Farquhar and colleagues (1982), Farquhar (1983), Osborne and Beerling (2006) and Sage and colleagues (2011) for a full discussion. In brief, the carbon-isotope value of C₃ plants is largely controlled by the diffusion of carbon dioxide through the stomata and the action of various enzymes, including Rubisco (Farquhar *et al.* 1982). C₄ photosynthesis evolved multiple times as a mechanism to increase the efficiency of Rubisco at higher temperatures by using a carbon-dioxide pump to concentrate the carbon dioxide around Rubisco before C₃ photosynthesis occurs (Farquhar 1983; Osborne & Beerling 2006). In contrast to C₃ and C₄ plants, CAM plants primarily take up carbon dioxide

at night, which reduces the rate of transpiration and allows them to live in some of the most water-stressed environments on Earth (Heyduk *et al.* 2016).

The vast majority of plants in the world use the C₃ photosynthetic pathway. C₃ plants represent 95 per cent of the world's plant biomass (Still *et al.* 2003), including most human and animal plant foods such as wheat, barley, rice, potatoes, fruits and vegetables. C₄ plants are mainly tropical grasses, but this group includes a small number of important food crops: most notably the millets, maize, sugarcane and sorghum (Sage *et al.* 1999). CAM plants are mainly succulents such as cacti (Silvera *et al.* 2010) and are hence rarely considered in the archaeological literature; nevertheless some CAM plants (such as pineapple) can be consumed.

Because the three different photosynthetic pathways discriminate against heavy carbon dioxide to different degrees, plants belonging to each pathway can be identified based on their carbon-isotope ratios (expressed as $\delta^{13}\text{C}$ values in units of per thousand: ‰). C₃ plants have $\delta^{13}\text{C}$ values between -35 and -21 ‰, C₄ plants between -20 and -6 ‰, and CAM plants between -33 and -14 ‰ (Bender *et al.* 1973; O'Leary 1988; Smith & Epstein 1971). By analysing the carbon isotope ratios of plant tissues, it is therefore straightforward to distinguish between C₃ and C₄ photosynthetic pathways—although identifying CAM plants in this way can be problematic due to their wide range, which overlaps with both C₃ and C₄ plants. Where assessing a plant's photosynthetic pathway based on its isotopic signature alone is not feasible or appropriate, an alternative approach is to identify photosynthetic pathways based on the anatomical features associated with C₄ and CAM photosynthesis.

Photosynthesis and archaeology

Identifying the photosynthetic pathways of plants in the human food chain has long been a concern of archaeologists. This interest stems in part from the importance of C₄ plants and their introduction to the food chain to some key transitions in human history: most notably the emergence of agriculture in the Americas (maize: e.g. Vogel & van der Merwe 1977), parts of China (foxtail and broomcorn millet: e.g. Zhao 2011), parts of Africa (sorghum, finger millet and pearl millet, *Sorghum bicolor*, *Eleusine coracana* and *Pennisetum glaucum*, respectively: e.g. Giblin & Fuller 2011; Manning *et al.* 2011), and parts of India (bristly foxtail, yellow foxtail, little, kodo and browntop millet, *Setaria verticillata*, *Setaria pumila*, *Panicum sumatrense*, *Paspalum scrobiculatum* and *Brachiaria ramosa*: e.g. Fuller 2006). In other contexts, there are also interesting archaeological questions to be asked about the social, cultural and economic roles of these C₄ crops

where they were adopted into pre-existing agricultural systems: for example, in the context of millets' spread into Europe, and the later expansion of maize.

Fortunately, the isotopic differences in C₄ plants compared to C₃ plants discussed above are passed on to the people and animals who consume them (Schwarz 1991). People and animals who consume large quantities of C₄ plants thus have a heavier (less negative) isotopic signature than those who consume solely C₃ plants. Intermediate quantities (or proportions) of C₄ plants in the diet will lead to intermediate isotopic signatures. This isotopic food-chain effect allows C₄ plant consumption to be identified and (semi-) quantified in skeletal remains in the archaeological record (Hedges 2004).

While this basic principle supports a wide range of palaeodietary applications, identifying—and in particular, quantifying—the consumption of C₄ plants is not always straightforward. One problem is that isotope scientists do not have a reliable estimate of the proportion and/or quantity of C₄ foodstuffs that need to be consumed in order for it to be identifiable in skeletal stable carbon isotope values. Addressing this issue is complex because the majority of palaeodietary isotope studies are carried out on bone collagen, which is the primary protein in bone. The body mainly builds protein from amino acids taken directly from protein in the diet; however, some amino acids can be constructed using carbon from non-protein dietary sources (Schwarz 1991). Consequently, bone collagen is biased towards, but not solely reflective of, the protein component of the diet. Isotope scientists tend to estimate that 20 per cent of the protein in the diet needs to originate from a different isotopic source (i.e. 20 per cent C₄ protein in an otherwise C₃ diet) in order for it to be identifiable in bone-collagen isotope ratios (Hedges 2004); however, it is likely that the proportion required to be visible isotopically depends upon a wide range of variables, including health and physiological status; the proportion of protein in the diet; the quality (in terms of amino acid distribution) of that protein; and the amount of food being consumed (Ambrose & Norr 1993; Jim *et al.* 2006; Podlesak & McWilliams 2006). Overall, however, given that plants tend to contain relatively little protein compared to animal products, small amounts of C₄ plant consumption within an omnivorous human diet may be difficult to identify.

Having said that, when C₄ plants are grown or gathered, it is likely that human diets will contain a mixture of C₄ plants and animal products from animals that themselves consumed (varying quantities of) C₄ plants. In this scenario, the consumption of C₄-fed animal products may mask or confound any

evidence of direct C₄ plant consumption (assuming that the latter is the primary interest). It is therefore necessary to analyse both human and animal bone collagen carbon isotope ratios in order to disentangle direct human C₄ plant consumption, animal C₄ plant consumption and a mixture of the two. This relies on comparing the difference in $\delta^{13}\text{C}$ values between consumer and consumed, and determining whether the difference is notably greater or lesser than would be expected for a trophic level enrichment (i.e. the expected difference in carbon isotope values between consumer and consumed, a value which is itself poorly defined and likely variable).

Alternatively, archaeological scientists can minimize some of the problems inherent in analysing bone collagen by instead analysing the carbon stable isotope ratios of bioapatite (the mineral component of bones and teeth). Bioapatite is in many ways better suited to the identification of C₄ plant consumption, because the carbon in bioapatite reflects the whole diet and includes a higher proportion of carbon from dietary carbohydrate than collagen and other proteins (Ambrose & Norr 1993; Tieszen & Fagre 1993). Because this tissue is not biased towards the protein component of the diet, it is more likely to provide evidence for the consumption of C₄ plants by humans and other omnivores. However, compared with bone collagen, bone apatite is more prone to diagenetic alteration, and for that reason the assessment of carbon in bone apatite is more difficult and contentious. Enamel apatite is less subject to diagenetic alteration, but reflects childhood diet rather than the last years of life. Depending on the archaeological context, a childhood dietary signature may or may not be of archaeological interest. If one does analyse bone or tooth apatite, it is still necessary to analyse animal samples for comparison in order to determine the proportion of C₄ plants and C₄-fed animals in the diet. Where time, samples and finances permit, both bone collagen and (preferably enamel) bioapatite should be analysed in order to provide a complete picture of past diets.

Combining isotopic and archaeobotanical evidence

Both bone collagen and bone bioapatite samples reflect food consumed over a period of years and thus provide an 'averaged' picture of diet (Budd *et al.* 2004; Hedges *et al.* 2007; Stenhouse & Baxter 1979). Their isotopic composition therefore primarily reflects foods that were consumed consistently and in significant quantities over the time represented by the tissue. For this reason, stable isotope scientists often consider only the major crop species (i.e. wheat, barley, rice, the millets, maize, etc.) found archaeobotanically (or assumed based on context) and give less consideration

to edible taxa that are not thought to be major calorific resources in a given diet.

While this approach is not entirely without rationale, the biases associated with archaeological data mean that we have a fragmentary picture of past diets. Even where both archaeobotanical and stable isotope analyses have been carried out, given that both techniques are insensitive to minor dietary components, it is entirely possible that plant species were consumed for which we have little or no archaeological evidence. For example, archaeobotanical preservation of plants consumed by animals is unlikely in contexts where animals were foddered away from the site; any evidence for fodder plants would, in this case, only be present in dung, either because the animal returned to the site within a few days of consumption, or because dung was collected and returned to site to be used as fuel. Similarly, archaeobotanical preservation of human plant foods is unlikely when said species were prepared and eaten beyond the reach of fires. Furthermore, it is difficult to integrate stable isotope and archaeobotanical data directly, as they are biased towards different stages of the subsistence quest; isotopic data reflect food consumption, while archaeobotanical remains are generally thought to reflect food production (e.g. processing remains), although some argue that charred plant remains primarily reflect consumption via fuel—either dung or peat (e.g. Miller 1984; Spengler *et al.* 2013). It is therefore important for the stable isotope scientist to consider all the possible edible C₄ and CAM plants that could have been consumed *by humans or animals* before assuming that any C₄ signal represents only one or two well-known C₄ crops, such as maize and millet. They must also consider that these 'other' C₄ plants could be a single species consumed in relatively high amounts, or a diverse range of species consumed in small quantities by humans and animals, and are likely consumed in conjunction with any available C₄ major crop plants.

The identification of edible C₄ plants for palaeodietary analysis

We argue here for more consideration of the modern edible C₄ and CAM plant species available in the region under study in isotopic palaeodietary analyses: either via a review of previous research or via botanical and/or ethnobotanical surveys if no such work has previously been carried out in the region. Ideally, such studies would centre on the site in question and cover an area large enough to encompass the area exploited by the population of site. In reality, studies' geographical extents will likely be determined by previous botanical research and other such practicalities: this need not preclude useful information being gathered, given that

the aim of such studies is to inform the isotope scientist as to the extent to which they need to consider such plants in their interpretations, rather than to provide an accurate and complete list of the plants consumed.

The two key questions that such studies must address in order to provide a useful platform for palaeodietary analysis are: first, which plants are edible to humans and/or animals; and second, which of those plants use the C₄ or CAM photosynthetic pathway? In the context of a palaeodietary isotope study, where the excavation may well have been completed many years previously and the isotope scientist may never see the site under study, the time and money available for investing in answering these questions is likely limited. Nevertheless, useful data can be derived with minimal effort where ethnobotanical and botanical research has already been undertaken. Where such studies have not been carried out, a more substantial research input may be required, but again we seek to show that this need not be unduly onerous in many cases.

The first question, ‘which plants are edible?’, can often be addressed through a literature survey. In the first two case studies below, lists of edible plants were taken from the literature: one from an academic journal and the other from a ‘Flora’. For the palaeodietary isotope scholar, the limitation of this approach is that one is reliant upon the quality of this previous research. Where such data are unavailable or clearly insufficient, the alternative approach is to undertake an ethnobotanical study personally, likely collaborating with colleagues in other disciplines (for example, botany and social anthropology). Given enough time and resources this is entirely feasible for the palaeodietary isotope scientist, as shown by our third case study below (Cadwallader *et al.* 2012), but requires an investment of time, money and training that is unlikely to be within the scope of most studies. Nevertheless, where a scholar’s research agenda is focused on a particular region, such a study will pay dividends throughout their research career, with all subsequent palaeodietary analyses, as well as their thinking about the past, informed by the plant survey. A final point is that both approaches suffer from the limitation that the plant species currently growing in a region will be an imperfect reflection of the past, and that lists of edible plants are in reality lists of ‘plants recognized as edible’, and may exclude plants that are not currently known to be edible to the local people and/or the researchers involved. Nevertheless, if the aim of the study is to provide an assessment of the general level of edible C₄ and CAM plants available for human and/or animal consumption, such limitations are acceptable, provided that the resulting lists are not biased towards or against one type of photosynthetic pathway.

The second question, ‘which plants use the C₄ photosynthetic pathway?’, may also be addressed with a desk-based literature review as the most convenient starting point. Lists of C₄ plants are available for some regions of the world, ranging from Europe (Collins & Jones 1985) to Aldabra Atoll (Hnatiuk 1980) and including desert regions in India and China (Sankhla *et al.* 1975; Su *et al.* 2011). In such instances, a comparison of a list of C₄ plants and a list of edible plants in a region is simple. Where lists of C₄ species are not available, but a list of edible plants has been acquired, determining which species are C₄ is also relatively straightforward. Firstly, only 17 families contain C₄ species (Acanthaceae, Aizoaceae, Amaranthaceae, Asteraceae, Boraginaceae, Cappariaceae, Caryophyllaceae, Cyperaceae, Euphorbiaceae, Hydrocharitaceae, Molluginaceae, Nyctaginaceae, Poaceae, Polygonaceae, Portulacaceae, Scrophulariaceae and Zygophyllaceae: Simpson 2010) and 35 families contain CAM species (Simpson 2010)—plants in other families can be excluded. Within these families more research must be undertaken. Again, much of this work has already been carried out by scholars in other disciplines and most authors assume that all species within a genus use the same photosynthetic pathway, unless there is evidence to the contrary (Osborne *et al.* 2014). Furthermore, for the Poaceae or grass family (which includes almost half of the world’s C₄ species: Sage *et al.* 1999) a searchable database is available which includes information on each taxon’s photosynthetic pathway (see Osborne *et al.* 2014 for details). For the remaining species, one must search for published papers which have determined the photosynthetic pathway of the species (or, if necessary, genus) under question. There are provisos with this: for example, it is important to ensure that the correct nomenclature is being used, as there are many more recorded scientific names than there are accepted species of grasses (Osborne *et al.* 2014). Nevertheless, if the aim is to attain a general level of understanding of the proportion of edible C₄ plant taxa in the environment, such errors are acceptable, provided that they are acknowledged and that there is no systematic bias.

Where edible plant lists contain many species for which no previous research into their photosynthetic pathway has been undertaken, it may be necessary to study plant samples directly from modern communities: either by analysing their $\delta^{13}\text{C}$ values, or by assessing their photosynthetic physiology. The methodology for the former is straightforward, requiring that the plant be dried (or freeze-dried), ground, weighed and then analysed in an isotope-ratio monitoring mass spectrometer. If field sampling is not feasible (for example, due to import/export constraints), it

may be possible to collaborate with institutions such as herbaria and botanic gardens in the researcher's country to obtain samples of edible plants for analysis.

These methods will now be demonstrated through a consideration of edible C₄ plant availability in three regions: Sicily, Italy; Haryana, India; and the south coast of Peru. These regions were chosen to reflect different environmental conditions and to illustrate different methodological approaches to the problem of identifying the diversity of edible C₄ and CAM taxa available.

Sicily, Italy

The first case study is from Sicily, a region where one would expect the proportion of C₄ plants in the environment to be very low. Indeed, research suggests that between 2 and 2.5 per cent of the plant species are C₄ (Collins & Jones 1985), although the proportion of edible C₄ and CAM plants may vary compared to this. A published list of European C₄ plants contains 116 species (Collins & Jones 1985).

Licata and colleagues (2016) conducted a series of interviews with elderly residents in four national parks in Sicily. In total 802 people were interviewed and asked about wild plant food consumption, cooking and cultivation. A total of 119 wild plant foods were identified as being or having been used by the residents. We then compared this list to the list of European C₄ plants in Collins and Jones (1985).

Of the 119 wild plant foods identified by Licata and colleagues (2016), only one (common purslane, *Portulaca oleracea*) appeared on the list of European C₄ species (note that spot checks using the references utilized for Haryana, below, corroborated this finding). In addition, one CAM plant (Indian fig opuntia, *Opuntia ficus-indica*) was identified using a literature search (Ting 1989). Licata and colleagues (2016) also report the Cultural Importance Index for each species (which is a quantitative way to estimate the extent to which each species is present in the local culture and in the memory of the inhabitants), with *Portulaca oleracea* having a value of 0.08 and *Opuntia ficus-indica* a value of 0.19 (for all the plant species, the range of Cultural Importance Index values was from 0.004 to 0.50, with an average value of 0.08).

The data from Sicily therefore show that the number of wild C₄ and CAM plants recognized as edible by Sicilians today is very low. While this list does not include plant species eaten by animals but not humans, it seems reasonable to conclude that any consumption of C₄ or CAM species by humans would be insignificant and likely impossible to identify by stable isotope analysis of either bone collagen or bioapatite (even in the absence of C₄ crops). This

is reassuring and corroborates assumptions made by isotope scientists working in Sicily and the Mediterranean (e.g. Tafuri *et al.* 2009).

Haryana, India

We turn next to Haryana in northwest India. Haryana has three broad topographic zones—a mountainous tract, alluvial plains and sand-dunes—and a large part of the state is arid or semi-arid. Archaeologically, Haryana is notable as having sites dating to the Indus period (e.g. Shinde *et al.* 2008; Singh *et al.* 2011; Wright 2010). To date, limited carbon-isotope analyses have been carried out on skeletal Indus period samples from northwest India; however, even within the limited literature available, the assumption that a C₄ signal represents millet consumption can be found (Chase *et al.* 2014, millet species not specified). This may be true, but is impossible to verify without an assessment of edible C₄ plants in each eco-zone within the Indus region. Here we focus on Haryana due to our on-going research in this region (e.g. Petrie *et al.* 2017).

The *Flora of Haryana* (Kumar 2001) contains a table listing 146 plant species as being edible or used for fodder.¹ However, the individual species information included comments on the consumption of other plants that were not included in the table. These plants were added to the edible plant list, bringing the total to 256 plant species that are eaten by humans or animals today.² From this list, 108 species belong to the families known to contain C₄ or CAM species (see Simpson 2010) and were selected for further study (Table 14.1). Thirty-four of these species were Poaceae and their photosynthetic pathway was determined by searching the Kew taxonomy and photosynthetic pathway database using *Taxonomie* (Kluyver & Osborne 2013; Osborne *et al.* 2014). A literature review was undertaken to determine the photosynthetic pathway of the remaining 74 plant species (references in Table 14.1).

Of the original list of 256 edible plant species, 33 were determined to use the C₄ photosynthetic pathway and 2 utilize the CAM pathway. The photosynthetic pathway could not be determined for 10 species. Thus 13 per cent of edible or fodder species are C₄ and 1 per cent CAM (see Table 14.1). While this proportion of C₄ and CAM plants is relatively small, it is large enough to require consideration in palaeodietary analyses, particularly where human or animal stable carbon-isotope values indicate that C₄ plants (or animals consuming C₄ plants) formed a small proportion of the diet. In such circumstances, it may not be possible to distinguish between the consumption of, in this case, millet species and the consumption of one or more other C₄ plants.

Table 14.1. List of edible plants found in Haryana (derived from Kumar 2001) and their photosynthetic pathways.

Species	Family	Pathway	Reference for photosynthesis
<i>Peristrophe bicalyculata</i>	Acanthaceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Amaranthus roxburghianus</i>	Amaranthaceae	C ₃	Liu & Wang 2006
<i>Deeringia amaranthoides</i>	Amaranthaceae	C ₃	Sage <i>et al.</i> 2007
<i>Digera muricata</i>	Amaranthaceae	C ₃	Sage <i>et al.</i> 2007; Sankhla <i>et al.</i> 1975
<i>Coriandrum sativum</i>	Apiaceae	C ₃	Wullschleger 1993
<i>Cuminum cyminum</i>	Apiaceae		
<i>Daucus carota</i>	Apiaceae		
<i>Foeniculum vulgare</i>	Apiaceae	C ₃	Marchese <i>et al.</i> 2006
<i>Pimpinella involucreta</i>	Apiaceae	C ₃	Poorter <i>et al.</i> 1990
<i>Carissa congesta</i>	Apocyanaceae		
<i>Carissa spinarum</i>	Apocyanaceae	C ₃	Zhang <i>et al.</i> 2007
<i>Vallisneria spiralis</i>	Apocyanaceae		
<i>Amorphophallus campanulatus</i>	Araceae	C ₃	Ravi <i>et al.</i> 2009
<i>Colocasia esculenta</i>	Araceae	C ₃	Wullschleger 1993
<i>Carthamus oxyacantha</i>	Asteraceae	C ₃	Khaki-Moghadam & Rokhzadi 2015
<i>Centipeda minima</i>	Asteraceae	C ₃	Liu & Wang 2006
<i>Cichorium intybus</i>	Asteraceae	C ₃	Saini <i>et al.</i> 2011
<i>Helianthus annuus</i>	Asteraceae	C ₃	Wullschleger 1993
<i>Lactuca sativa</i>	Asteraceae	C ₃	Brownwell & Crossland 1972
<i>Oligochaeta ramosa</i>	Asteraceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Sonchus asper</i>	Asteraceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Sonchus brachyotus</i>	Asteraceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Sonchus oleraceus</i>	Asteraceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Ehretia acuminata</i>	Boraginaceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Ehretia aspera</i>	Boraginaceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Trichodesma amplexicaule</i>	Boraginaceae	C ₃	Sankhla <i>et al.</i> 1975; Ziegler <i>et al.</i> 1981
<i>Opuntia dillenii</i>	Cactaceae	CAM	Ting 1989
<i>Opuntia elatior</i>	Cactaceae	CAM	Winter <i>et al.</i> 2011
<i>Capparis decidua</i>	Capparaceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Capparis zeylanica</i>	Capparaceae	C ₃	Hnatiuk 1980
<i>Sueda fruticosa</i>	Chenopodiaceae	C ₄	Malik <i>et al.</i> 1991
<i>Beta vulgaris</i>	Chenopodiaceae	C ₃	Wullschleger 1993
<i>Kochia indica</i>	Chenopodiaceae	C ₄	Malik <i>et al.</i> 1991
<i>Spinacea oleracea</i>	Chenopodiaceae	C ₃	Crawford <i>et al.</i> 1986
<i>Ipomoea eriocarpa</i>	Convolvulaceae	C ₃	Hnatiuk 1980
<i>Benincasa hispida</i>	Cucurbitaceae		
<i>Citrullus fistulosus</i>	Cucurbitaceae	C ₃	Sankhla <i>et al.</i> 1975
<i>Citrullus lanatus</i>	Cucurbitaceae	C ₃	Akashi <i>et al.</i> 2011
<i>Cucumis melo</i>	Cucurbitaceae	C ₃	Govindachary <i>et al.</i> 2007
<i>Cucumis melo var. momordica</i>	Cucurbitaceae	C ₃	Govindachary <i>et al.</i> 2007
<i>Cucumis melo var. utilissimus</i>	Cucurbitaceae	C ₃	Govindachary <i>et al.</i> 2007
<i>Cucurbita maxima</i>	Cucurbitaceae	C ₃	Llano 2008
<i>Cucurbita pepo</i>	Cucurbitaceae	C ₃	Rintamaki <i>et al.</i> 1988
<i>Lagenaria siceraria</i>	Cucurbitaceae	C ₃	Tankersley <i>et al.</i> 2016
<i>Luffa acutangula</i>	Cucurbitaceae	C ₃	Cadwallader <i>et al.</i> 2012

Table 14.1. (Continued.)

Species	Family	Pathway	Reference for photosynthesis
<i>Luffa aegyptiaca</i>	Cucurbitaceae	C ₃	Cadwallader <i>et al.</i> 2012
<i>Luffa cylindrica</i>	Cucurbitaceae	C ₃	Cadwallader <i>et al.</i> 2012
<i>Momordica charantia</i>	Cucurbitaceae	C ₃	Lin <i>et al.</i> 1986
<i>Momordica dioica</i>	Cucurbitaceae	C ₃	Cadwallader <i>et al.</i> 2012
<i>Trichosanthes anguina</i>	Cucurbitaceae		
<i>Trichosanthes dioica</i>	Cucurbitaceae		
<i>Carex fedia</i>	Cyperaceae	C ₄	Smith & Epstein 1971
<i>Diospyros exculpta</i>	Ebenaceae	C ₃	Lancelotti <i>et al.</i> 2013
<i>Phyllanthus emblica</i>	Euphorbiaceae	C ₃	Sankhla <i>et al.</i> 1975; Hnatiuk 1980
<i>Ricinus communis</i>	Euphorbiaceae	C ₃	Wullschlegel 1993; Ziegler <i>et al.</i> 1981
<i>Sapium maritimus</i>	Euphorbiaceae		
<i>Securinega leucopyrus</i>	Euphorbiaceae		
<i>Vallisneria spiralis</i>	Hydrocharitaceae	C ₃	Hough & Wetzel 1977
<i>Ocimum sanctum</i>	Lamiaceae	C ₃	Marchese <i>et al.</i> 2006
<i>Gisekia pharnaceoides</i>	Molluginaceae	C ₄	Seeni & Gnanam 1983
<i>Moringa oleifera</i>	Moringaceae	C ₃	Hnatiuk 1980
<i>Moringa pterigosperma (oleifera)</i>	Moringaceae	C ₃	Hnatiuk 1980
<i>Oxalis corniculata</i>	Oxalidaceae	C ₃	Liu & Wang 2006
<i>Arachne racemosa</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Aristida funiculata</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Avena fatua</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Avena sterilis</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cenchrus biflorus</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cenchrus prierurii</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cenchrus setigerus</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Chloris dolichostachya</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Chrysopogon fulvus</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cymbopogon jwarancusa</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cymbopogon schoenanthus</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Cynodon dactylon</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Dichanthium annulatum</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Echinochloa colona</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Echinochloa crusgalli</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Eleusine coracana</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Eleusine indica</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Eragrostis cilianensis</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Hordeum vulgare</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Lasiurus scindicus</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Oryza sativa</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Panicum antidotale</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Panicum astrosanguinem</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Panicum paludosum</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Panicum trypheron</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Pennisetum typhoides</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Phalaris minor</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)

Table 14.1. (Continued.)

Species	Family	Pathway	Reference for photosynthesis
<i>Saccharum officinarum</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Setaria glauca</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Setaria pumila</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Setaria verticellata</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Sorghum vulgare</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Triticum aestivum</i>	Poaceae	C ₃	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Zea mays</i>	Poaceae	C ₄	<i>Taxonome</i> (Kluyver & Osborne 2013; Osborne <i>et al.</i> 2014)
<i>Fagopyrum esculentum</i>	Polygonaceae	C ₃	Liu & Wang 2006
<i>Rumex vesicarius</i>	Polygonaceae	C ₃	Raghavendra & Das 1978
<i>Borreria articularis</i>	Rubiaceae	C ₃	Ziegler <i>et al.</i> 1981
<i>Mitragyna parvifolia</i>	Rubiaceae	C ₃	Bidalia <i>et al.</i> 2017
<i>Morinda tomentosa</i>	Rubiaceae		
<i>Euphoria longana</i>	Sapindaceae	C ₃	Weng & Lai 2003
<i>Litchi chinensis</i>	Sapindaceae	C ₃	Hieke <i>et al.</i> 2002
<i>Scoparia dulcis</i>	Scrophulariaceae	C ₃	Yoneyama <i>et al.</i> 2010
<i>Dodonaea viscosa</i>	Vitaceae	C ₃	Rao <i>et al.</i> 1979
<i>Vitis vinifera</i>	Vitaceae	C ₃	Wullschleger 1993
<i>Zygophyllum simplex</i>	Zygophyllaceae	C ₄	Ziegler <i>et al.</i> 1981

South coast of Peru

Our third case study (Cadwallader *et al.* 2012) uses ethnobotanical research combined with field collection and herbarium specimens to consider C₄ and CAM food sources on the south coast of Peru. This is a region where maize has played an important social role with ritual significance, as well as being the main staple crop by the Inca Late Horizon period (Godelier 1977; Goldstein 2003; Hastorf & Johannessen 1993; Isbell 1988; Valdez 2006). As such, maize consumption has been well studied isotopically (e.g. Burger & van der Merwe 1990; Kellner & Schoeninger 2008), but, until recently, relatively few of these works consider other C₄ plant sources in the human diet.

Cadwallader and colleagues (2012) conducted an ethnobotanical study to determine which plants were likely consumed by humans or animals; this included talking to local llama herders (Cadwallader pers. comm., 2017), as well as referring to published works. On this basis 89 species were selected for isotopic analysis. Samples of these species were then collected either from the field or from the Herbarium at the Royal Botanic Gardens Kew, UK. The samples were dried, ground, weighed and analysed in a mass spectrometer (refer to Cadwallader *et al.* 2012 for full details).

Of the 89 species analysed, 40 were found to use the C₃ photosynthetic pathway, 38 used the C₄ photosynthetic pathway and the remaining 2 used CAM photosynthesis. The authors combined these new

data with published studies from regions with similar ecologies, creating a synthesized dataset containing 144 different plant species (cf. DeNiro & Hastorf 1985; Tieszen & Chapman 1992). Of these, 96, 41 and 7 plant species use the C₃, C₄ and CAM photosynthetic pathways, respectively.

This study demonstrates that a third of the plants analysed from the south coast of Peru utilized the C₄ or CAM photosynthetic pathway. Clearly, this is hugely significant for the identification of maize consumption in the archaeological record and arguably undermines many of the previous palaeodietary studies in the region. Under such circumstances it is not advisable to equate a human or animal carbon-isotope value directly with a single crop, as there could well be a substantial contribution from other C₄ and CAM plant species. Many studies in the Andean region are now recognizing that maize may not be the only explanation for high human $\delta^{13}\text{C}$ values, and this has led to an improved and more nuanced understanding of the past (e.g. Marstella *et al.* 2016). Nevertheless, the idea that C₄ signals equal maize consumption persists in the literature.

Where does this leave us?

None of the above approaches allows a definitive determination of which edible C₄ and CAM plants were available in the past, particularly in the context of shifting distributions, nor do these approaches

comment upon whether plants that are recognized as edible today were actually consumed in the past. In particular, there is a risk of excluding plants that are no longer consumed by populations today, as exemplified by a number of indigenous American ‘lost crops’, once consumed regularly, but which have now largely or entirely fallen out of use (Mueller *et al.* 2017). Nevertheless, despite these limitations, the types of studies proposed here provide a relatively simple means for a more nuanced consideration of past diets. By conducting such studies, isotope scientists can better understand the extent to which C₄ and CAM plants other than the major crop species must be considered in their interpretations.

In situations such as Sicily, where only one edible C₄ and one edible CAM plant were found, it is reasonable to interpret any evidence for C₄ consumption in skeletal stable isotope values as the consumption of the appropriate C₄ crop. In prehistoric Europe this equates to one or more millet species, with maize another possible interpretation in more recent samples. Interpreting human and animal isotope data in contexts such as the southern coast of Peru is more challenging, given that approximately a third of the edible plants available use the C₄ or CAM photosynthetic pathways. In this area, a small enrichment in $\delta^{13}\text{C}$ values compared to that which would be expected for an entirely C₃-based diet may relate either to the consumption of maize or the consumption of other edible C₄ and CAM plants, or both. A careful consideration of the archaeobotanical data, and the use of multiple tissues from both human and animal remains, may shed more light on this problem (e.g. Cadwallader *et al.* 2012), but given the limitations of both archaeobotany and stable isotope analysis, it is likely to be impossible to exclude the consumption of C₄ and CAM plants other than maize in the past.

Compared to Sicily, where C₄ consumption is *unlikely* to include C₄ plants other than major crop species, or to the south coast of Peru, where C₄ consumption is *likely* to include C₄ plants other than major crop species, situations such as those in Haryana are perhaps more frustrating. Our study shows that edible C₄ and CAM species other than (various) millets are currently available; however, the proportion of these plants is intermediate between the negligible proportion available in Sicily and the notable proportion available in Peru. The interpretation of human and animal stable carbon isotope results is therefore problematic—while it is conceivable that many C₄ or CAM species were eaten by animals and/or humans, it is equally conceivable that only (various species of) millet were consumed in notable amounts. Without evidence from other sources (such as dung; Qiu *et al.*

2014), it may not be possible to distinguish between these two scenarios. While this does not preclude stable isotopic data from contributing to hypotheses and models of past human food systems, the degree of uncertainty that remains must be fully acknowledged.

Conclusion

Ultimately, stable carbon-isotope analysis of skeletal remains distinguishes between photosynthetic pathways (ignoring the potential confounding factor of aquatic resource consumption: see e.g. Bogaard & Outram 2013); it does not comment on the species of plant consumed. The interpretation of skeletal $\delta^{13}\text{C}$ values thus involves one or more assumptions based on varying amounts of supporting evidence. Any scientific interpretation is only as strong as the assumptions on which it is based, and testing those assumptions is an integral part of scientific endeavour. Here, we advocate for further consideration of one of these assumptions—that few edible C₄ (or CAM) plants exist in a region apart from the well-known major crop species. We show that addressing this issue need not be an onerous or expensive undertaking, but recognize that such a study is unlikely to be either completely comprehensive or entirely accurate. Nevertheless, on a general level, this approach serves to inform isotope scientists and other archaeologists of the potential for the consumption of C₄ and CAM plants other than the major crop species and thus helps to provide a more accurate, comprehensive and nuanced understanding of past diets and subsistence practices.

Notes

1. No plants were excluded from the analysis on the basis of their likely origin: e.g. maize is included on the list in Table 14.1.
2. Only plants explicitly noted as being eaten were included; medicinal plants, weeds and plants only described as cultivated were not included.

Appreciation and acknowledgements

All authors would like to thank past and present members of the Dorothy Garrod and George Pitt-Rivers laboratories for thought-provoking discussions over many years.

Martin Jones has played a pivotal role in the careers of all three authors, supervised all of our PhDs at one time or another and written us many, many references. It is fair to say that none of us would be where we are today without his help and guidance. Thank you, Martin.

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Chapter 15

The Geography of Crop Origins and Domestication: Changing Paradigms from Evolutionary Genetics

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Introduction

The question of single or multiple domestications is of enduring interest in the bioarchaeology of cultivated plants. It is considered by many as one of the key questions regarding domestication (e.g. Larson *et al.* 2014). The volume of attention devoted to this topic stems, in part, from its position at the interface of archaeology and evolutionary biology. It relates both to archaeological paradigms of socioeconomic revolution, technological innovation, contact and dispersal among human societies (Blumler 1992) and to the distinct evolutionary paradigms of adaptive novelty and speciation applicable to all biological taxa.

The biological question of the number of domestications (and implicitly, their locations in time and space) of crop plants is often a proxy for the archaeological question regarding the timing and location of the origins of agriculture. As such, as Harris (1990) and Langlie and colleagues (2014) have commented, researchers may find it hard to escape from the paradigm of ‘packages’ of crops that originated in distinct ‘centres of origin’ (Vavilov 1926; 1951), and often correlated with major ancient civilizations (cf. Langlie *et al.* 2014).

Vavilov both created the concept of centres of origin of crop plants and developed the first essentially genetic approach to inferring such centres. Since then, increasingly sophisticated genetic, genomic and statistical methods have driven successive paradigms for inferring the number and location of domestication ‘events’ (or ‘processes’, as discussed below). At the same time, the genomics revolution has opened up entire new areas for archaeogenetic research on domestication, such as the microevolutionary processes associated with domestication, the evolution of functional traits and epigenetics. Thus, the question of single *versus* multiple domestications, which dominated genetic research on domesticates in the

late 1990s–early 2000s (Bruford *et al.* 2003; Salamini *et al.* 2002), is now just one line of enquiry. Thus, while the origins of an increasingly diverse suite of crops and other ethnobotanically important plant species have been interrogated using genetic data, the extent of the analysis underpinning current interpretations is highly variable. For some species, especially those of greatest modern economic importance, successive research projects have revised and honed interpretations through cutting-edge data and analytical methods. Meanwhile, the conclusions for other species are still inferred from genetic markers and statistical analysis whose known limitations are often not properly discussed. Moreover, although ‘domestication’ is a notoriously thorny concept to define, many studies do not adequately engage with the term, or address whether the given data can discriminate between different ‘domestication’ scenarios as they use it.

In this chapter, we review the development of thought on the inference of domestication geographies from genetic data, exploring how paradigms have shifted from the centres of origin concept developed by Vavilov. We review the debate over single *versus* multiple domestications, and the implications of protracted domestication and on-going gene flow for inferring the geography of domestication. Rather than provide a state-of-the-art for any one crop, or a comprehensive survey of the many crops whose origins have now been interrogated using genetic data, we use diverse crops to illustrate how varying analytical approaches and paradigms of domestication have shaped the debate.

‘Origins’ *versus* ‘domestication’

The vast literature on crop evolution refers to both ‘origin[s]’ and ‘domestication’ of plant species (in both cases frequently preceded by the phrase ‘centres of’). These terms are sometimes used synonymously, but



Figure 15.1. Martin Jones with two of the co-authors visiting the N.I. Vavilov Research Institute for Plant Industry, St Petersburg, Russia, in November 2011. (Above) Touring the germplasm collections; (below) Vavilov's map of centres of crop origins, displayed above the main staircase in the Institute.

from a genetic point of view they represent different, but interrelated, evolutionary processes. 'Domestication' can be defined as a process of human-driven selection, resulting in the evolution of particular phenotypes adapted to cultivation and/or anthropogenic landscapes. These phenotypes include non-shattering seed-head habit, increased grain size, reduced branching, reduction of plant biochemical defences, loss of seed dormancy and more predictable germination (Harlan 1992). At the molecular level, this process entails the trajectory towards population fixation of domestic-type alleles, either from novel mutations or standing variation (Gepts 2014; Larson *et al.* 2014). In contrast, from a population genetics or phylogenetic perspective, 'origins' implies a process of reproductive isolation or phylogenetic bifurcation of the phenotypically wild from phenotypically domesticated taxon. These two processes may be linked by the

evolutionary trajectory of reproductive trait genes, but they have their own respective suites of associated processes and drivers. This distinction has implications for localizing 'origins' and/or 'domestication' in time and space.

Vavilov, centres and diversity

The origins of particular crops (an evolutionary process) may or may not correlate with 'agricultural origins' as a human cultural behaviour. The conceptual link between the two originates largely from Vavilov (1926); as commented by Harris (1990), 'Vavilov's concept of centres of origin of cultivated plants has had such a profound effect on students of the beginnings of agriculture that it remains very difficult for anyone who takes a world view of agricultural origins to escape the mental template of the Vavilovian pattern of centres'. The connection with human prehistory is made in the concluding section of Vavilov (1926): 'the elucidation of the centres of type-formation and the origin of cultivated plants allows us to approach objectively the establishment of basic foci of agricultural civilizations' (Fig. 15.1).

Harris notes that 'ever since Vavilov himself equated centres of crop diversity with the homelands of agriculture there has been conceptual confusion between the two phenomena' and that 'it is time that we conceptually decoupled the world pattern of crop-plant diversity that Vavilov so brilliantly demonstrated from our investigations of the origins and early development of agriculture'. In fact, Vavilov himself focuses strongly on crop 'origins' rather than 'domestication' or 'agriculture'; his writings are concerned principally with the evolution of 'types' [cultivated plant varieties], and the role of human agency, and integration with archaeological evidence, are mentioned only in passing. The question of single *versus* multiple origins of a given crop was not explicitly raised by Vavilov, who appears to have assumed that each crop could only be associated with one geographical centre. However, Vavilov's approach was an essential precursor to the debate of whether such origins were unique in geographical and phylogenetic space.

Vavilov's principal assumption was that the geographic origins of each crop taxon co-localized with its highest genetic [=phenotypic] diversity. The theoretical underpinning of this idea shares intellectual links with Willis' (1922) 'age and area' hypothesis on infrageneric diversity (see Hawkes 1983). Assuming a constant mutation rate and selection pressure, the evolution of diverse types or varieties would track the length of time a plant species had existed in a

given region. To a modern evolutionary geneticist, a number of questions immediately present themselves: Vavilov's theory explains the diversification of a crop species, but its origins from a wild ancestor remain nebulous. It is also unclear whether Vavilov imagined that diversity within a crop species arose by *de novo* mutation post-domestication, or was already present as standing variation in wild populations. This distinction is a key question in current research on adaptation genomics and domestication (Barrett & Schluter 2008; Ross-Ibarra *et al.* 2007). Vavilov's assumptions also appear to foreshadow the neutral theory of molecular evolution and the molecular clock hypothesis (Kimura 1983) in relating accumulation of diversity to age of a lineage. Given Vavilov's emphasis on phenotypic, adaptive traits, however, the downplaying of emphasis on the strength of diversifying selection, and its consequences for evolutionary rates, now appears problematic. The relative role of natural and anthropogenic diversifying selective forces is also little explored.

As studies of crop diversity moved into a molecular era unknown in Vavilov's time, an increasingly rigorous quantitative and statistical framework developed. This complexified the task of identifying centres of variation. Even simple descriptive population genetics has at its disposal several statistics for quantifying genetic diversity in a region, which may give conflicting answers regarding maximum diversity. Moreover, the designation of geographical regions for comparison is inherently subjective, one driving factor behind the development of modelling approaches in which samples are treated as individuals rather than being pre-assigned to subjectively defined populations (Pritchard *et al.* 2000).

Vavilov himself was well aware that an observed centre of crop diversity did not necessarily represent the crop's centre of origin, in particular considering hybridization with other wild species as a mechanism for generating secondary centres of diversity. He identified a number of other criteria by which centres of origin could be identified: the distribution of the wild ancestor; the presence of endemic forms; and high frequency of genetically dominant traits. Over his career, he revised the number of proposed centres from the initial five in 1926 to seven in his final synthesis published in 1940 (Vavilov 1940; Fig. 15.1). Subsequently, diverse authors from the Soviet Union, Britain, France and the USA proposed either additional centres, to as many as 16 (Darlington 1973), or as few as three (Harlan 1971, reviewed in Hawkes 1983 and Harris 1990). As noted by Hawkes, some of the disagreement comes down to the semantics of what constitutes a 'centre' and attempts to discriminate between 'megacentres'

and 'microcentres'. How large does a centre have to be, to be termed as such? Vavilov's centres were identified at the broad continental scale, but how precisely can and should we attempt to localize the origins of crops? This question is tied up with determining single *versus* multiple domestications.

Vavilov's concept continues to pervade thinking about agricultural origins and domestication, as explored by Harris (1990) and still true today. For example, Meyer and Purugganan (2013), in a statement that underplays the complexity of domestication, say 'crop species are domesticated in particular locales'. The linking of elevated genetic diversity with ancestral populations remains a minor strand of population genetic interpretation, especially for under-resourced crops and those where the direct wild ancestor is uncertain. For example, Hu and colleagues (2009) proposed China's Loess Plateau as the centre of origin of broomcorn millet (*Panicum miliaceum*) and Guo and colleagues (2014) inferred the classical Old World as the centre of origin of turnip rape (*Brassica rapa*), based on microsatellite diversity. However, while Vavilov's concepts persist in the broad intellectual landscape of understanding the origins of agriculture, the evolutionary emphasis for individual crops shifted to tracing ancestor-descendant relationships and unpacking the evolution of particular loci.

Phylogenetic methods to reconstruct crop domestication

From the late 1950s, phylogenetic methods gained ground as a new framework for identifying crop domestication 'events'. We put this term in quotation marks because it is frequently encountered in the early phylogenetic literature in particular, but (like 'centres') its usefulness is dependent on the temporal and spatial scale under consideration. As explained further below, both archaeobotanical and genetic evidence are now moving away from an 'event'-like concept of domestication.

The growth of phylogenetics was associated with the development of computers and the introduction of algorithms for phylogenetic reconstruction, as well as advances in understanding the molecular mechanism of evolution which led to the availability of 'direct' genetic data in the form of protein, and later DNA, sequences (Felsenstein 2004). A phylogeny constitutes an explicit hypothesis about ancestor-descendant relationships, speaking directly to one of the core paradigms of domesticates as discrete taxa descended from other, wild ancestral taxa. Phylogenies represent evolution as a branching genealogy, in which extant lineages result from a series of bifurcations from a

common ancestor; the monophyly of a domesticated taxon relative to its wild progenitor is therefore interpreted as a single domestication. The development of phylogeographic methods in the late 1990s drove efforts to localize ‘domestication events’ in space, by identifying where those wild varieties that shared the most recent common ancestor with the domesticated lineages were located.

For a review of phylogenetic methods, readers are referred to one of the numerous reviews and standard texts (e.g. Bleidorn 2017; Felsenstein 2004; Salemi *et al.* 2009; Uncu *et al.* 2015). The number and choice of genetic markers can affect the inferred phylogeny. Many studies on single genes have resolved a monophyletic origin of crops, along with strong selective pressures under domestication, while those based on genome-wide data show evidence of multiple domestications (Pankin & von Korff 2017). Additionally, different phylogenetic methods can suggest different domestication histories.

Work on phylogenetic inference of crop plant domestication began with wheat, using ‘anonymous’ genetic markers such as Amplified Fragment Length Polymorphisms (AFLPs). Heun and colleagues (1997) analysed AFLPs in domesticated einkorn (*T. monococcum* subsp. *monococcum*) and its wild progenitor (*T. monococcum* subsp. *aegilopoides*). All domesticated lines clustered together in a neighbour-joining tree, and their sister clade included wild accessions from only the Karaca Dağ Mountains in Turkey (fig. 2E in Heun *et al.* 1997). The authors concluded that einkorn was domesticated only once from wild einkorn in that region. The same approach applied to emmer wheat, based on AFLPs screened in domesticated lines (*T. turgidum* subsp. *dicoccum*) and wild emmers (*T. turgidum* subsp. *dicoccoides*), also found that the wild emmers closest phylogenetically to the cultivated clade were from the Karaca Dağ Mountains (fig. 1 in Özkan *et al.* 2002). This led many biologists and archaeologists to pinpoint southeast Turkey as the cradle of Near Eastern agriculture (Lev-Yadun *et al.* 2000).

Martin Jones and Terry Brown (M. Jones 2004; M. Jones & Brown 2000), synthesizing this first wave of phylogenetic crop domestication studies, noted the emerging consensus of single-origins conclusions for the major Old World crops inferred from monophyly of domesticated lineages. Maize followed the same pattern, in a major study based on microsatellites (Matsuoka *et al.* 2002). The phylogenies of all these crops were based on markers with no direct DNA sequence information. Patterns of similarity across many loci were compressed to pairwise genetic distance measures which are then used to construct phylogenetic trees using deterministic computer algo-

rithms. However, inferences from biallelic markers (including AFLPs) were called into question by Allaby and Brown (2003), who used computer-simulated AFLP data to show that domesticated crops could appear monophyletic even when the true history was a multiple-origin, polyphyletic scenario. An on-going debate ensued on the validity of different phylogenetic methods and on the effect of pollination type, pace of domestication, selection and population parameters on phylogenetic trees (Allaby *et al.* 2008; 2010; Heun *et al.* 2008; 2012; Honne & Heun 2009; Ross-Ibarra & Gaut 2008; Salamini *et al.* 2004). We return to these issues below.

Rice (*Oryza sativa*) has perhaps received more attention than any other crop with regard to debates on single *versus* multiple domestications. The extraordinary intensity of debate, including the volume of data and sophistication of models and computational methods, and frequent overturning of conclusions, can be attributed both to the parallel ferocity of archaeological debate on the trajectory(ies) to domesticated rice and the early sequencing of the rice genome (Goff *et al.* 2002; Yu *et al.* 2002). *Oryza rufipogon* is the wild ancestor of rice (*O. sativa*), but because this species is widespread throughout Asia it is unclear if the different rice varieties resulted from independent domestication events, or if rice was introduced from a single core area and gave rise to the different major varieties, *indica* and *japonica*, by local adaptation or by hybridization with native wild rice.

Phylogenetic analysis of DNA and protein sequences of rice domestication loci, controlling traits such as shattering (*qSH1*, *sh4*), erect growth (*PROG1*) or unpigmented seeds (*Rc*), all suggested a single origin for all cultivated rice (Konishi *et al.* 2006; Lin *et al.* 2007; Sweeney *et al.* 2007; Tan *et al.* 2008; Zhang *et al.* 2009). This conclusion was also supported by multi-locus phylogenies based on diverse markers, including nuclear gene sequences (Molina *et al.* 2011), RFLPs (Restriction Fragment Length Polymorphisms: Lu *et al.* 2002), microsatellites (Gao & Innan 2008) and whole-genome sequencing of 1083 *indica* and *japonica* cultivated rice varieties and 446 *O. rufipogon* accessions from all over Asia (Huang *et al.* 2012). In contrast, other phylogenetic studies concluded that *indica* and *japonica* (as well as other varieties) were independently domesticated in different regions, including China, India or Thailand. These comprise analyses on nuclear RFLPs (Wang *et al.* 1992), four nuclear genes (Zhu & Ge 2005), a haplotype network of both nuclear and chloroplast sequences (Londo *et al.* 2006), DNA sequences from 22 nuclear loci (Rakshit *et al.* 2007), whole nuclear genomes (Yang *et al.* 2011) or whole-chloroplast sequences (Civáň & Brown 2016).

Even the whole genome dataset published by Huang *et al.* (2012) has been re-analysed in a way that shows three independent domestications of rice (Choi *et al.* 2017; Civián *et al.* 2015; but see also Huang & Han 2015).

The contrasting results in rice arise from the combined choices of phylogenetic methods, markers and sampled accessions, rather than any one of these factors in isolation. Efforts have been made to reconcile both claims considering *de novo* domestications that replaced independently domesticated local varieties (Sang & Ge 2007), extensive introgression and selection (He *et al.* 2011), the roles of past demographic processes in both rice and wild rice populations (Choi *et al.* 2017), the influence of population structure in phylogenetic inference (Kim *et al.* 2016) and the confusing effect of feral and weedy varieties mimicking wild plants (Qiu *et al.* 2017; Wang *et al.* 2017). We return to this question below.

Archaeobotanical data and their interrelation with phylogenetic inference: fast *versus* protracted domestication scenarios

The speed of domestication (that is, the rate of fixation of phenotypic traits) has emerged as a major theme from the controversies and complex answers associated with questions of single *versus* multiple domestications. This in turn has led to debate over which traits were selected in the primary domestication episode and which represent crop improvement post-domestication, for example selection for waxy maize starch (Fan *et al.* 2009) or loss of photoperiod sensitivity (H. Jones *et al.* 2008). The former traits show a clear phenotypic dimorphism between the wild progenitor and the domesticate (Abbo *et al.* 2014). They result from mutations in a few loci, with major effects, whose resulting phenotypes would have been visible in populations, positively selected by early farmers, and hence fixed in ancient crop populations (Lin *et al.* 2012). The latter have accumulated over millennia of crop evolution, and often show a phenotypic continuum. These include alterations in flowering-time pathways, increased seed size, pest and disease resistance, grain quality and the loss of appendages that aid seed dispersal, such as awns. A key issue here is how many genes and mutations were required for a critical domestication transition of wild to domesticated (Sang 2009). Spike brittleness is the trait most strongly associated with domestication for the annual cereal crops, and sometimes considered to be the only trait that reliably distinguishes between wild and cultivated forms, for example in barley (*Hordeum vulgare* subsp. *spontaneum* and *H. vulgare* subsp. *vulgare*, respectively; Pankin & von Korff 2017). The

evolution of other traits, specifically the naked caryopsis and six-rowed spike characters in barley, are also major domestication traits, but appeared over a millennium later than the tough rachis and the global domesticated barley genepool remains polymorphic for these two traits today (Sang 2009).

Early theoretical and field work suggested that domestication trait alleles, such as those controlling rachis fragility, can become fixed in wild plant populations in a few generations given intense human selection for desired traits (Hillman & Davies 1992). Yet for these to be fixed in a population, reproductive isolation from plants carrying the wild alleles was necessary, and this process would have taken a long time (protracted model). Martin Jones and Terry Brown (2007) argued that reproductive isolation was at least as important, or more important than, strong selection in driving the transition to ‘full domestication’, in the sense of populations showing a high frequency of the human-selected phenotype.

Protracted domestication scenarios may explain why phylogenetic interpretations are not always corroborated by archaeological data. Martin Jones and colleagues questioned the interpretation of Heun and colleague’s (1997) genetic analysis of einkorn, which localized its domestication in the Karaca Dağ mountains. The oldest archaeobotanical remains with signs of domestication (plumper kernels and rough rachis-breakage scars) do not come from sites in this region, but from the southern Levant (Brown *et al.* 2009; Fuller *et al.* 2011; M. Jones *et al.* 1998). In the case of emmer wheat, the earliest archaeobotanical remains with a rough breakage scar (indicative of a tough rachis, considered by some authors the only definitive domestication trait), come from northern sites of Cayönü and Cafer Höyük (8250–7550 cal BC), not far from where genetic data indicated its single origin (Zohary *et al.* 2012). Some archaeobotanists, however, consider that the observed increase in size and changing shape of grains is also diagnostic of domestication (Brown *et al.* 2009). This would imply that a mixture of domesticated and wild emmer was cultivated together for millennia during the Pre-Pottery Neolithic B (PPNB) in southern Levant sites such as Tell Aswad and Jericho (Feldman & Kislev 2007). According to this school of thought, the fixation of the tough rachis trait took place later and does not in itself define domestication. Other authors consider that increased grain size may represent pre-domestication cultivation; this may largely reflect differing definitions of domestication.

The archaeobotanical record of wheat and barley in the Near East, and rice in China, shows wild and domesticated forms, defined by rachis scars or grain size, occurring in variable proportions for

almost 4000 years until domesticated forms become exclusive (Fuller *et al.* 2014). Likewise, the presence of arable weeds associated with wild plant remains in the archaeological record suggests that intensive cultivation of wild species preceded full domestication in both the Near East and China (Arranz-Otaegui *et al.* 2016; Weiss *et al.* 2006; Willcox & Stordeur 2012). Similar patterns have been proposed for some non-cereal species, for example lentil (*Lens culinaris* ssp. *culinaris*: Abbo *et al.* 2009; Sonnante *et al.* 2009).

The body of emerging evidence for a protracted transition to morphologically domesticated forms highlights that the paradigm of discrete ‘domestication events’ found in some of the phylogenetic literature is, at best, an oversimplification and, in some cases, seriously misleading. While the fixation of a domestication trait allele may take millennia and occur over a wide geographical area, the initial mutation that gives rise to that allele has a defined point in space and time, and can be characterized at the DNA sequence level.

Inferences from domestication ‘switch’ genes

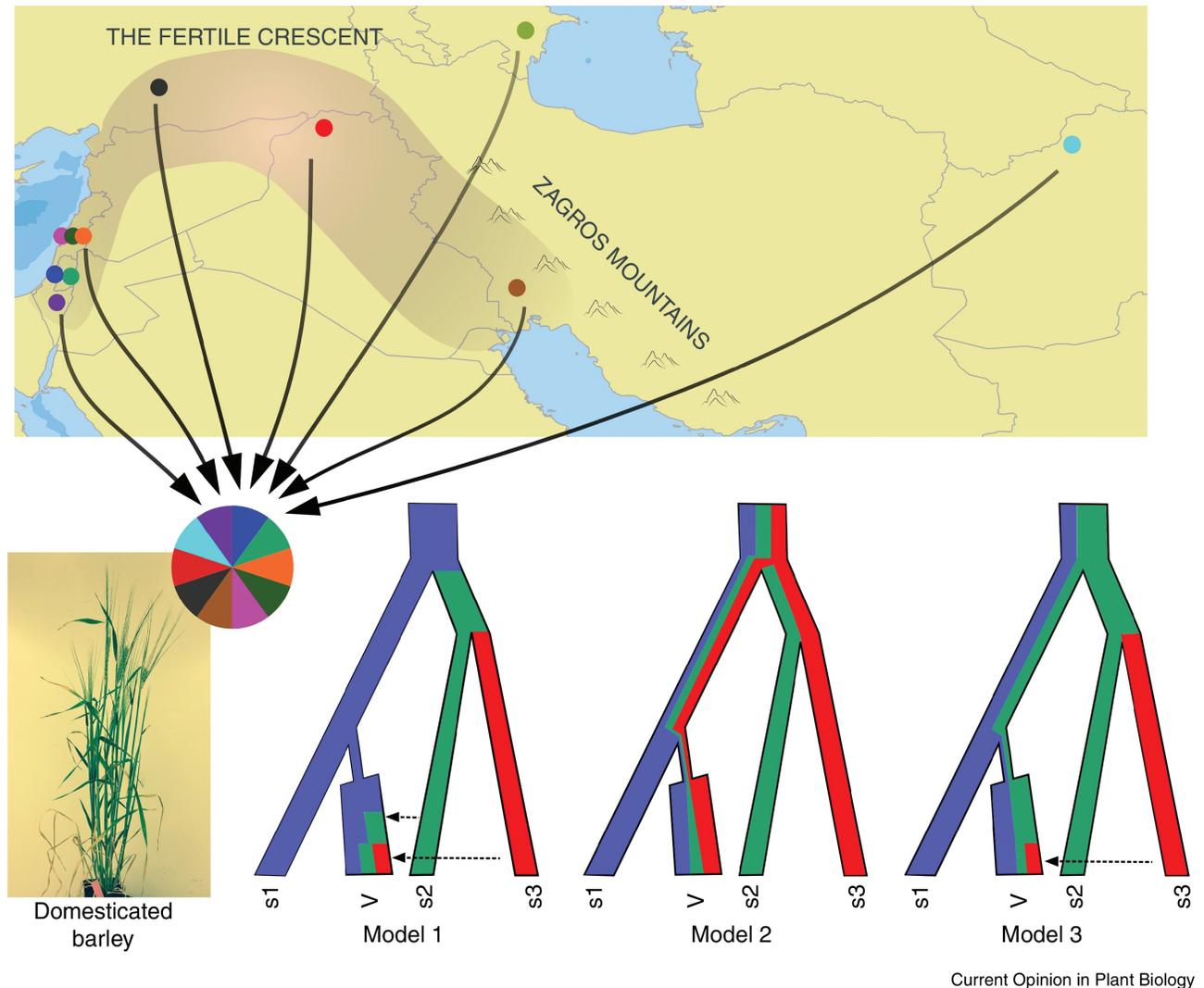
The growth of functional genomics approaches from the mid 2000s facilitated the discovery of genes underlying these key crop domestication traits (Olsen & Wendel 2013; Ross-Ibarra *et al.* 2007). This has enabled direct analysis of the number of evolutionary switches leading to the domesticated phenotype. Work has focused mostly on the rachis phenotype of cereals, which is typically under the control of one or a few loci with major effects. In einkorn wheat, a single mutation is responsible for the non-brittle rachis, leading to the inference of a single domestication event that equates to the fixation of this allele in the cultivated population (Zohary 1999). By contrast, in barley there are three independent mutations, each of which confers the tough rachis phenotype, two in the brittle rachis *Btr1* gene and one in *Btr2* (Azhaguvel & Komatsuda 2007; Civián & Brown 2017; Pourkheirandish *et al.* 2015). The two mutations described by Azhaguvel and Komatsuda (2007) have differential distributions in the east and west Fertile Crescent. These are associated with distinct domesticated lineages, leading to the long-established separation of ‘occidental’ and ‘oriental’ types of barley (Takahashi 1955), which is backed up by other genetic studies (Morrell & Clegg 2007; Morrell *et al.* 2013; Saisho & Purugganan 2007). In sorghum, there are three non-shattering haplotypes at the *Shattering1* (*Sh1*) locus; from the distributions of these non-shattering haplotypes among sorghum landraces, it is suggested that three geographically separated human populations independently selected for

the non-shattering phenotype (Lin *et al.* 2012). These studies provide appealingly clear answers, but the challenge is to relate the evolutionary trajectory of loci with a major effect on domestication traits, particularly grain shattering, to those of loci controlling grain size and shape, where multiple loci and the environment each contribute modestly to the phenotype.

Towards an accommodation of on-going wild-domestic gene flow

The paradigm of protracted domestication allows for continued gene flow between individuals with domesticated alleles and their wild counterparts. On-going introgression is likely where a domesticated plant population is in sympatry with the wild population; a large proportion of plant crop species maintain gene flow at least in some part of their range (Ellstrand *et al.* 1999; Jarvis & Hodgkin 1999). The consequence of on-going gene flow is that phylogenetic methods appropriate for reconstructing macroevolutionary lineages of species across different genera, families or phyla evolving through vast spans of time may not always be suitable for analysing closely related taxa that are in the process of diverging or have done so only in the past few millennia, as is the case with crops and their wild progenitors. Results are thus confounded by the biological realities of hybridization, fertility, selection, recombination and the mode of reproduction. To detect these processes, both statistical refinements of phylogenetic methods which explicitly model gene flow and alternative clustering methods, which make different assumptions about the evolutionary process, are employed. Canonical clustering methods (e.g. Principal Components Analysis, PCA) represent genetic similarity and differentiation in a way that makes few assumptions about the evolutionary process. Bayesian- and likelihood-framework clustering methods, as implemented in the widely used software STRUCTURE (Pritchard *et al.* 2000), ADMIXTURE (Alexander *et al.* 2009) and others, enable probabilistic inference of distinct populations, assigning individuals to populations, analysing hybrid zones, identifying admixture and migrants and estimating population allele frequencies. The domestication history of a crop is recorded in patterns of genetic diversity within and between individuals and populations and in its relationship to wild progenitors (Fig. 15.2).

Since the early 2000s, such methods have been a standard part of the toolkit for inference of domesticated origins, enabling comparative evaluation of distinct geographical hypotheses. Occasionally, such methods have resolved apparently straightforward scenarios. Identification of genetic clusters in wild and



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Figure 15.2. Barley exemplifies the complexity of inheritance of different segments of a domesticated crop's genome from wild ancestral populations. This scenario is probably typical for many crops. The map shows the approximate locations of Near Eastern wild barley (*H. vulgare* ssp. *spontaneum*) populations that have contributed to the cultivated barley genome (*H. vulgare* ssp. *vulgare*; Poets et al. 2015). The pie chart represents the mosaic ancestry of the modern cultivated barley genome, comprising genomic contributions from *spontaneum* from the Fertile Crescent and east of the Zagros Mountains (Poets et al. 2015). Three candidate models of barley domestication are illustrated, all of which assume that a single lineage gave rise to the *vulgare* genome (V). The mosaic ancestry of the *vulgare* genome could have originated from: repeated introgressions of genetic material from *spontaneum* populations (s2 and s3) into the proto-*vulgare* lineage (Model 1); the ancestral population structure of the wild founder lineage (s1; Model 2); or a combination of the two (Model 3). Genome resequencing is enabling statistical testing comparing these models; the most plausible scenario is not yet clear. (Reproduced from Pankin & von Korff 2017 under a Creative Commons license (CC BY-NC-ND-4.0), with minor changes to only the above caption.)

domesticated populations of sunflower (*Helianthus annuus*) supported a single origin of domesticated sunflower in eastern North America (ENA; Blackman et al. 2011). Wild *H. annuus* from Mexico and ENA divided into two genetic groups based on geography, while domesticated varieties from both regions showed a very high proportional allocation to the ENA gene pool,

with very low levels of genetic input from the wild Mexican cluster.

In contrast, in the case of another major New World domesticate, maize (*Zea mays*), the phylogenetic inference of a single origin from the lowland Mexican ancestor Balsas teosinte (*Zea mays* subsp. *parviglumis*; Matsuoka et al. 2002) was substantially refined by the

use of non-phylogenetic approaches. The most ancestral domesticated lineages were found in highland Mexico, which was puzzling, given the lowland distribution of Balsas teosinte. This ‘ecological paradox’ was resolved by analysis of a SNP dataset using PCA and Bayesian clustering approaches. Results demonstrated that a different teosinte (*Zea mays* subsp. *mexicana*) had been hybridizing with highland domesticated maize, rendering this maize population genetically similar to *Z. mays* subsp. *parviglumis*. Subsequent analyses inferred the location of domestication in the Mesoamerican lowlands, congruent with archaeological, ecological and biogeographical evidence (van Heerwaarden *et al.* 2011).

Prior to the next-generation sequencing revolution, the optimal domesticate-wild relative system for studying introgression was one where gene flow occurred at moderate levels (Jarvis & Hodgkin 1999). With the advance in high-throughput methods, introgression in both frequently hybridizing, out-crossing crop species like maize and inbreeding species that hybridize with low frequency can be achieved in high resolution. The trajectory of research on barley illustrates how advances in genomics technologies have altered both the nature of the questions asked and the way we address them, in little more than a decade. A Bayesian clustering study based on DNA markers sparsely distributed through the genome found two genetic clusters in both wild and domesticated barley, leading to the inference of two geographically separated domestications (Morrell & Clegg 2007). Recent genome-wide analyses using dense coverage across all chromosomes have revealed complex patterns of genetic ancestry. Poets and colleagues (2015) showed that cultivated barley has a mosaic ancestry with wild populations across its range contributing differentially to the genome of domesticated barley in the Near East. While a tough rachis mutant must come from a specific locality, the geographic origin of the overall genomes in a domesticated population should not be attributed to the same location. Introgression events may date back to the early history of widespread barley cultivation, as linkage blocks were not shared between cultivated and wild populations (Fig. 15.2). These patterns may well hold true for other crops, such as emmer and einkorn (Allaby 2015).

Phylogenetic methods whose assumptions are particularly suited to closely related samples, including phylogenetic networks, and statistics applied to phylogenetic trees, have been developed to allow and test explicitly for gene flow between wild and domesticated plants (Mardulyn 2012). Phylogenetic networks applied to DNA sequences from 18 loci supported the hypothesis of a single domestication

of einkorn in Turkey (Kilian *et al.* 2007). For emmer, however, these methods revealed contributions from different wild populations to domesticated ones, supporting multiple domestications (Civáň *et al.* 2013). Some authors have proposed models that account for the inconsistencies in the emmer wheat results, such as a pre-domestication stage of cultivation and movement of wild wheat (Fuller & Colledge 2008), or the dispersed-specific model (Kilian *et al.* 2010). Another possibility is that some accessions classified as wild are in fact feral varieties descending from domesticated individuals which escaped cultivation and, either by selective pressures or by hybridization with wild plants, have acquired a wild phenotype (Oliveira *et al.* unpublished data).

As illustrated in the case of maize discussed above, on-going introgression into a domesticated crop may involve more than one related wild species or subspecies, rather than just one wild ancestral taxon. Phylogenomic methods can be harnessed to trace the history of emergence of a domesticated lineage, and subsequently allele frequency statistics can be applied to that phylogenetic framework to test for past introgression. The recently developed *D* statistic, commonly applied as the ABBA-BABA test (Green *et al.* 2010), detects asymmetry in three-population gene trees. The premise is that gene flow between closely related populations causes this asymmetry. A strength of this method is that it can detect archaic admixture even in the absence of archaic samples. In analysis of common bean (*Phaseolus vulgaris*; Rendón-Anaya *et al.* 2017), alleles underlying domestication traits characteristic of common bean originated from several local wild populations, revealing signatures of adaptive introgression from local populations of diverse wild species. These analyses depend upon meaningful delimitation and identification of sampled taxa and populations, which is not always straightforward in practice.

A modified version of the ABBA-BABA test, the D_{FOIL} test (Pease & Hahn 2015), can handle phylogenies with more taxa and reliably detects introgression and its direction, even if present at low levels. This method, combined with coalescence-based modelling, has recently been applied to rice (Choi *et al.* 2017). Results validate the ‘multiple origin, single domestication hypothesis’. This proposes that *Oryza sativa* ssp. *indica* and ssp. *japonica* had phylogenetically distinct origins, but the origin of domestication traits was unique to ssp. *japonica*. These traits were subsequently ‘captured’ by introgression into ssp. *indica* and ssp. *aus*. The model suggests a resolution of the heated debate about the number of rice domestications, highlighting the distinct processes of crop phylogenetic origins and

domestication trait acquisition. Choi and colleagues comment ‘in the end, our analysis calls into question how we conceptualize our definition of domestication’, supporting our dissection of ‘origins *versus* domestication’ above.

Conclusion

Evolutionary transitions from wild to domesticated crop forms, driven by the selective pressures imposed by human manipulation of plant life cycles, are beguiling as plausibly discrete events that took place in narrowly circumscribed tempo-spatial locations. This notion is reinforced by the legacy of Vavilov’s ‘centres of origin’ concept, even though Vavilov’s centres were geographically broad and many aspects of the evolutionary process were beyond the scientific currency of his time. A framework of domestication ‘events’ maps neatly onto the apparently unambiguous topology of phylogenetic trees, which have dominated much research on crop origins. The ‘single or multiple domestications’ question relates naturally to this macroevolutionary model. In the last decade, however, complementary insights from archaeobotanical and genomic data show that the picture is rarely that black-and-white, and that the microevolutionary processes of population genetics give rise to a geographically far more complex interrelation between forms designated ‘wild’ and ‘domesticated’. Nevertheless, the quest for geographic patterns in the evolution of crop genomes remains intensely worthwhile. The challenge in the interdisciplinary dialogue between archaeologists, archaeobotanists and plant and evolutionary biologists, with their different emphases on the human, plant morphological and genomic shifts, is to re-explore the meaning of ‘domestication’ in a common language, retaining this umbrella term where it is useful, but also advancing explicit mutual understanding of the underlying processes.

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Chapter 16

The Adoption of Wheat and Barley as Major Staples in Northwest China During the Early Bronze Age

Haiming Li & Guanghui Dong

Introduction

The history and impact of food globalization in prehistory has been increasingly contested and discussed in recent years (Dong *et al.* 2017b; Jones *et al.* 2011; 2016; Liu & Jones 2014). It is an important process that can be described as bringing the Fertile Crescent ‘Neolithic founder crops’ to the East and Chinese domesticates such as millets to the West (Diamond & Bellwood 2003; Dong *et al.* 2017a; Hunt *et al.* 2008; Jones & Liu 2009; Liu *et al.* 2016; Spengler *et al.* 2014; Stevens *et al.* 2016). With the application of plant flotation technology and ancient crop direct dating in the last 10 years, the chronology and pathways of these prehistoric agricultural expansions have become increasingly clear (e.g. Jones *et al.* 2011). For example, previous research shows that broomcorn millet (*Panicum miliaceum*) spread to the western side of Eurasia possibly during the sixth and fifth millennia BC (Hunt *et al.* 2008), while updated research based on single grain radiocarbon analyses indicated that both Chinese and southwest Asian crops were present in the late third millennium BC (directly dated 2461–2154 cal. BC) in Begash in east Kazakhstan (Liu *et al.* 2016; Motuzaite-Matuzeviciute *et al.* 2013; 2015; Spengler 2015). In addition, a recent archaeobotanical study suggests that the eastward spread of free-threshing wheat (*Triticum cf. aestivum*) and naked barley (*Hordeum vulgare*) were through different routes, wheat following a northern route (via the Inner Asian mountain corridor) and barley passing through more a southerly route (south of the Tibetan Plateau) into China from southwest Asia during the late third and early second millennia BC (Frachetti 2012; Frachetti *et al.* 2010; Liu *et al.* 2016; 2017). These studies provide valuable clues for reconstructing the timelines and routes of agricultural interactions across Eurasia in prehistoric times. However, the specific timing in which these foreign crops replaced local staple foods, and the driving forces of these transformations, remains unclear.

Although the timelines and routes of the eastward movement of wheat and barley into China are controversial, it is almost certain that wheat was introduced into Shangdong between 2500 and 2000 BC (Jin *et al.* 2011), and wheat and barley dispersed into northwest China around 2000 BC (Dong *et al.* 2017a; Liu *et al.* 2016). However, the time taken for these exotic crops to become the primary staples in China varies from region to region. For example, stable isotopic and radiocarbon data show that wheat became a staple food in the Central Plains by 500 BC (Atahan *et al.* 2014), while wheat and barley became important staples in northwest China during the Early Bronze Age (Atahan *et al.* 2011; Ma *et al.* 2016; Zhang 2006). The archaeobotanical and stable isotope evidence indicates that wheat was introduced into the Hexi Corridor around 2000 BC (Dong *et al.* 2017a; Liu *et al.* 2014; Zhao 2009; Zhou *et al.* 2016), and rapidly replaced millet to become a staple crop after 1700 BC (Zhou *et al.* 2016). Stable carbon and nitrogen isotopic data also suggest that human diets shifted from C₄ (presumably foxtail millet and broomcorn millet) to mixed C₄ and C₃ (probably through the inclusion of wheat and barley into the diet) in the northeastern Tibetan Plateau (NETP) after 1600 BC (Ma *et al.* 2016), but a detailed history of the adoption of these exotic crops as major staples in the area remains unclear, due to the absence of systematic archaeobotanical study from excavation of Early Bronze Age sites.

In this chapter, we present the results of archaeobotanical analysis and direct radiocarbon dates of charred crop seeds unearthed from the excavation of Lijiping site in the Hehuang basin of NETP, and compare the results with previous archaeobotanical analyses and published radiocarbon dates in the NETP and the adjacent Hexi Corridor, to explore when and where wheat and barley were accepted as staple crops in northwest China, as well as the influencing factors behind the process.

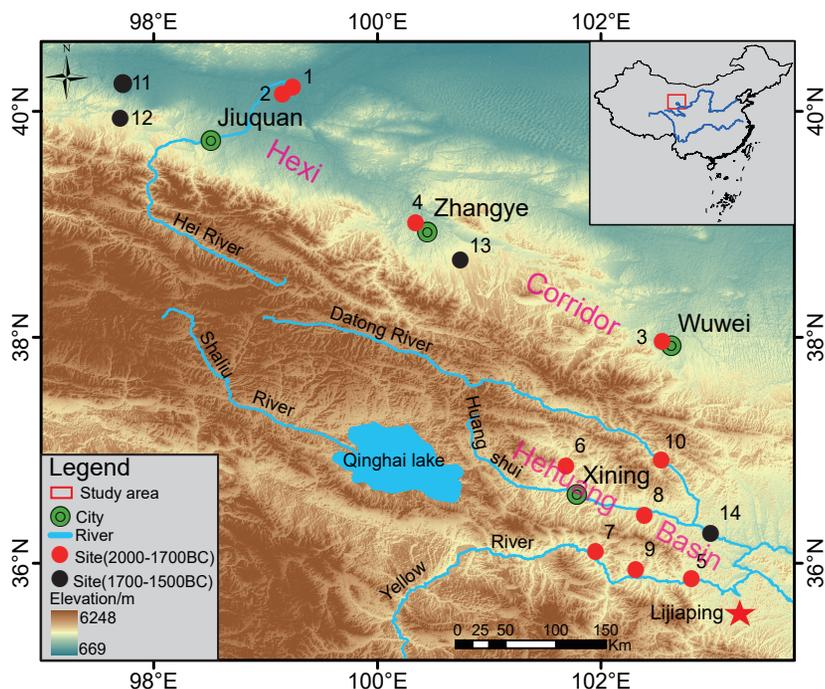


Figure 16.1. Distribution of prehistoric sites with archaeobotanical analysis and AMS dates in the NETP and Hexi Corridor.

(1) Huoshiliang; (2) Ganggangwa; (3) Huangniangniangtai; (4) Xichengyi; (5) Lajia; (6) Ajiacun; (7) Zhaongtan; (8) Zhaojiashuang; (9) Gongshijia; (10) Jinchankou; (11) Shaoguoliang; (12) Huoshaogou; (13) Donghuishan; (14) Wayaotai.

Study area

The Hehuang basin (Fig. 16.1) is located on the NETP and connects the Tibetan Plateau, Hexi Corridor and the Loess Plateau. This area covers the upper reaches of the Yellow River and the Huangshui and its tributaries. The climate of this region is characterized as semi-humid and semi-arid. The average annual precipitation in the Hehuang basin is 240–600 mm and decreases from southeast to northwest. The mean annual temperature varies between 2.2°C and 10.6°C with an average annual temperature of 5.8°C. Major crops in this region today include wheat, barley, maize, potato and broad bean.

The Lijiaping site (35°33'55.6"N, 103°13'5.4"E) is located in southeast Linxia county with an altitude of 2508 m a.s.l (Fig. 16.1). It is an important cultural relic protection unit of Gansu Province in China. Linxia county experiences a continental monsoon climate today, with a mean annual temperature of 5.9°C, mean annual precipitation of 631 mm and an annual frost-free period of about 150 days. A total of 54 Neolithic and Bronze Age sites were found in Linxia county, 43 of which are Qijia sites (Bureau of National Cultural Relics 2011). The Lijiaping site was excavated in 2011 by Gansu Province Institute of Cultural Relics and Archaeology and the Museum of Linxia County. The site covers an area of 210 sq. m, including four trial pits of 5×5 sq m (T1, T2, T3, T6), two trial pits of 5×10 sq. m (T4, T5) and a trial trench of 2×5 sq. m (G1). Plenty of pots and pottery sherds that display typical Qijia

characteristics (such as double-ear jars), stone artefacts and bones were excavated. Many ash pits and trenches were found during the excavation of the site.

Methods

In total, 13 samples were collected from ash pits that were found in the excavation of the Lijiaping site, which were then floated by washover flotation in a bucket. Carbonized remains were collected by a sieve with #80 mesh (aperture size of 0.2 mm), then dried in the shade and sorted. Charred plant seeds were identified in the Paleoethnobotany Laboratory, Institute of Archaeology, Chinese Academy of Social Sciences.

Two charred seed samples were dated via accelerator mass spectrometry (AMS) at Peking University in Beijing, China, and another charred seed sample was dated via the AMS method by Beta Analytic, Miami, USA. Results were calibrated using Calib (v. 7.0.2; Stuiver & Reimer 1993) and the IntCal13 calibration curve (Reimer *et al.* 2013). All ages are reported as 'cal. BC'.

Results

Chronology

All of the radiocarbon dates from Lijiaping are listed in Table 16.1, including previously published dates. The three calibrated ¹⁴C ages from remains of barley and wheat at the Lijiaping site reveal that the age of the site is mainly distributed between *c.* 1700 cal. BC

Table 16.1. Calibrated radiocarbon data in the Hehuang Basin and Hexi Corridor.

Site	Lab. no.	Dating material	Radiocarbon age (br)	Calibrated age (cal bc; Reimer <i>et al.</i> 2013)		Location	Reference
				1 sigma	2 sigma		
Lijiaping	BA120213	Barley seed	3370±35	1729–1623	1748–1536	Hehuang Basin	This study
	BA120214	Barley seed	3380±35	1733–1630	1759–1561	Hehuang Basin	This study
	Beta-324458	Wheat seed	3240±30	1598–1453	1610–1440	Hehuang Basin	This study
Ajiacun	Beta-314717	Foxtail millet seed	3640±30	2106–1950	2132–1920	Hehuang Basin	Chen <i>et al.</i> 2015
Zhongtan	Beta-303694	Foxtail millet seed	3640±30	2106–1950	2132–1920	Hehuang Basin	Chen <i>et al.</i> 2015
Gongshijia	Beta-303689	Barley seed	3620±30	2023–1945	2117–1894	Hehuang Basin	Chen <i>et al.</i> 2015
Zhaojiazhuang	BA110904	Foxtail millet seed	3595±25	2010–1913	2022–1891	Hehuang Basin	Chen <i>et al.</i> 2015
Wayaotai	BA120199	Broomcorn millet seed	3410±30	1745–1665	1864–1627	Hehuang Basin	Chen <i>et al.</i> 2015
Jinchankou	BA110913	Barley seed	3595±20	2008–1917	2020–1892	Hehuang Basin	Chen <i>et al.</i> 2015
Huangniangniangtai	OZK418	Wheat seed	3570±60	2021–1781	2126–1746	Hexi Corridor	Zhou <i>et al.</i> 2012
Huoshiliang	OZK603	Wheat seed	3635±45	2118–2097	2135–1894	Hexi Corridor	Dodson <i>et al.</i> 2013
Ganggangwa	OZK658	Wheat seed	3560±50	2008–1780	2029–1754	Hexi Corridor	Dodson <i>et al.</i> 2013
Xichengyi	QAS1311	Wheat seed	3430±25	1754–1690	1873–1660	Hexi Corridor	Zhang <i>et al.</i> 2015
	QAS1312	Wheat seed	3460±25	1872–1699	1879–1693	Hexi Corridor	Zhang <i>et al.</i> 2015
	QAS1314	Wheat seed	3390±30	1736–1643	1750–1620	Hexi Corridor	Zhang <i>et al.</i> 2015
	QAS1315	Wheat seed	3355±30	1685–1619	1739–1535	Hexi Corridor	Zhang <i>et al.</i> 2015
	QAS1316	Wheat seed	3385±25	1732–1642	1743–1624	Hexi Corridor	Zhang <i>et al.</i> 2015
	QAS1317	Wheat seed	3400±25	1740–1663	1749–1631	Hexi Corridor	Zhang <i>et al.</i> 2015
Shaguoliang	OZK668	Wheat seed	3450±60	1877–1689	1915–1623	Hexi Corridor	Dodson <i>et al.</i> 2013
	OZK669	Wheat seed	3390±50	1744–1626	1875–1533	Hexi Corridor	Dodson <i>et al.</i> 2013
Huoshagou	OZK672	Wheat seed	3430±50	1870–1663	1881–1628	Hexi Corridor	Dodson <i>et al.</i> 2013
Donghuishan	OZK653	Wheat seed	3260±45	1611–1498	1629–1436	Hexi Corridor	Zhou <i>et al.</i> 2012
	OZK654	Wheat seed	3405±50	1754–1630	1879–1565	Hexi Corridor	Zhou <i>et al.</i> 2012
	OZK655	Wheat seed	3425±40	1859–1664	1877–1629	Hexi Corridor	Zhou <i>et al.</i> 2012
	OZK656	Wheat seed	3410±50	1764–1635	1881–1611	Hexi Corridor	Zhou <i>et al.</i> 2012

and 1500 cal. bc (1 sigma). According to the results of the radiocarbon dates, the age of these sites in the NETP and Hexi Corridor can be divided into two periods (Figs 16.2 & 16.3; Table 16.1): the first period (2000–1700 bc) including the sites Huoshiliang, Ganggangwa, Huangniangniangtai, Xichengyi, Lajia, Ajiacun, Zhongtan, Zhaojiazhuang, Gongshijia and Jinchankou, and the second period (1700–1500 bc) including the sites Shaguoliang, Huoshagou, Donghuishan, Xichengyi, Wayaotai and Lijiaping (Chen *et al.* 2015; Dodson *et al.* 2013; Zhang *et al.* 2015; Zhou *et al.* 2012).

Carbonized plant remains from Lijiaping site

We identified 3402 charred grains in 13 samples taken during the excavation of the Lijiaping site in 2011 (Fig.

16.4; Table 16.2). Remains of four crops were identified, including 1989 foxtail millet (*Setaria italica*), 561 broomcorn millet (*Panicum miliaceum*), 286 barley (*Hordeum vulgare*) and 8 wheat (*Triticum aestivum*) grains, accounting for 58.4, 16.5, 8.4 and 0.2 per cent of the total identified charred plant seeds, respectively. The ubiquities of charred foxtail millet, broomcorn millet, barley and wheat in the 13 floated samples are 100, 92.31, 84.62 and 23.08 per cent, respectively. Seventeen other grass seed types were also present in those samples; 388 bristlegrass (*Setaria sp.*) seeds and 79 grains belonging to the pea family (Leguminosae) were also identified in seven and nine samples, respectively, which account for 11.41 and 2.32 per cent of total identified charred grains, respectively. In addition, 91 charred grains were identified as a

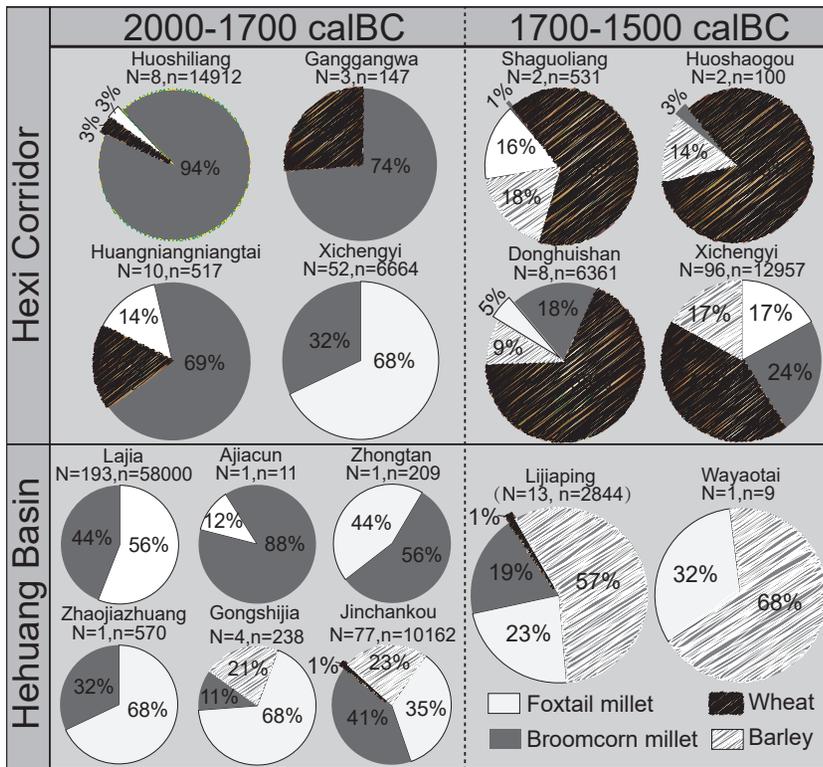


Figure 16.2. The actual yield percentage of the sites in the NETP and Hexi Corridor.

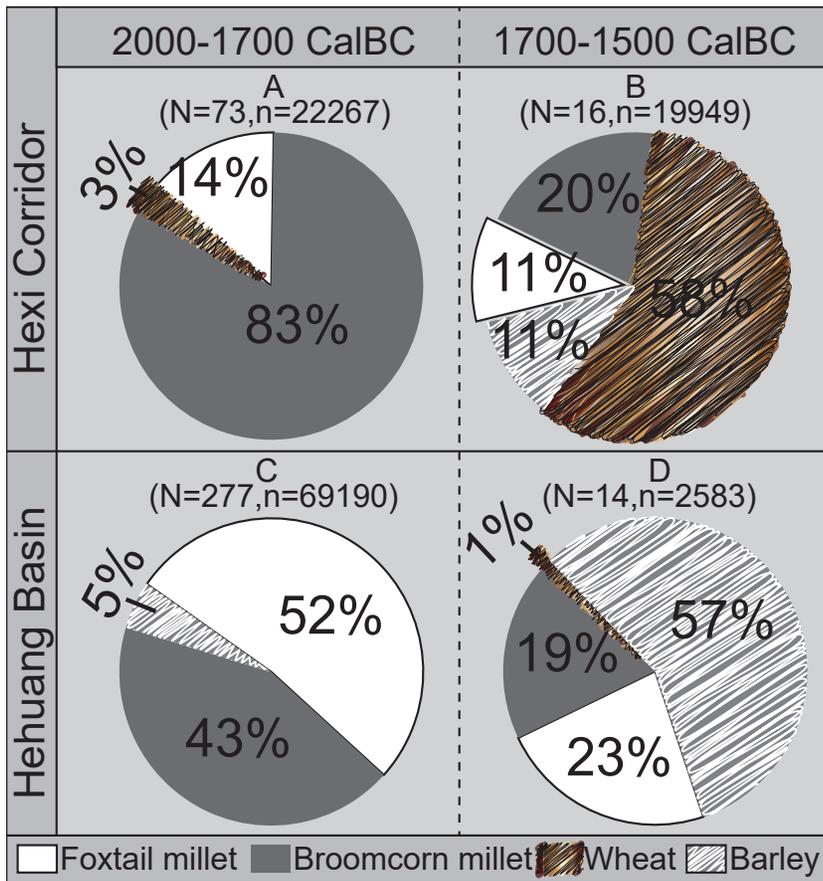


Figure 16.3. Sum of the actual yield percentage of the sites in the NETP and Hexi Corridor. (A) Sum actual production of Huoshiliang, Ganggangwa, Huangniangniangtai and Xichengyi; (B) Sum actual production of Shaguoliang, Huochaogou, Donghuishan and Xichengyi; (C) Sum actual production of Lajia, Ajiacun, Zhongtai, Zhaojiazhuang, Gongshijia and Jinchankou; (D) Sum actual production of Lijiaping and Wayatai.

Table 16.2. Charred seeds from the Lijiaping site, Linxia county, Gansu Province, China.

Sample no.	LM LT2 H1	LM LT3 H2	LM LT6 H1①	LM LT6 H1②	LM LT6 H1③	LM LT6 H1④	LM LT6 H1⑤	LM LT6 H2	LM LT6 H3	LM LT6 H4	LM LT4 G1a	LM LT4 G1b	LM LT5 G1	Total	Unearthed probability
Flotation quantity (L)	9	9	11	15	10	9	10	10	9	12	8	7	8	127	
<i>Setaria italica</i>	29	1	378	191	241	497	43	96	15	399	54	8	37	1989	100%
<i>Panicum miliaceum</i>	3		48	82	104	215	25	23	2	28	7	3	21	561	92%
<i>Hordeum vulgare</i>		1	60	22	27	19	25	40		65	1	1	25	286	85%
<i>Triticum aestivum</i>							2		1	5				8	24%
<i>Avena fatua</i> L.				3		12								15	15%
<i>Setaria</i> sp.	1		11		10	25	337			1	3			388	54%
Gramineae			2	2										4	15%
<i>Herba Agastaches</i>				1		2		1						4	24%
Leguminosae	2		8	6	19	27	5	1		10			1	79	69%
Hippophae						1								1	8%
<i>Peganum harmala</i> L.					1									1	8%
Violaceae			2			3								5	15%
Malvaceae			1			1		1						3	23%
Compositae			1											1	8%
Polygonaceae				1		1								2	15%
Chenopodiaceae				2	1									3	15%
<i>Chenopodium</i> L.			1	4	2	24								31	31%
<i>Salsola</i> L.			5	3										8	15%
Rosaceae			2	1		4								7	24%
<i>Rubus</i>							1							1	1
Cruciferae						5								5	5
Unknown			4	18		4		3						29	29
Total	35	2	523	336	405	840	438	165	18	508	65	12	84	3431	

variety of taxa. Some of those grains can be assigned to the genus/species level, such as *Avena* sp., *Herba Agastaches*, *Peganum harmala* (esfand), *Chenopodium* sp., *Salsola* sp. and *Rubus* sp., and the others can be only assigned to the family, such as Gramineae, Violaceae, Polygonaceae and Cruciferae. Results of the archaeobotanical identification are listed in Table 16.2, with images presented in Figure 16.4.

Lijiaping and contemporary sites

Between 2000 and 1000 BC, there was a global climatic transition from the Middle Holocene Megathermal to the relatively cold Late Holocene (Wanner *et al.* 2008). The monsoon system in Asia weakened, which led to many local agricultural systems becoming unstable and eventually changing in different parts of the Old World. The Hehuang basin of NETP and Hexi Corridor are located on the margin of the Asian monsoon region and are highly sensitive to climate change (Chen *et al.* 2010; Wu 1980). Over the last few decades, systemic chronological and archaeobotanical studies

have been carried out at Lijiaping and contemporary sites from the NETP and Hexi Corridor dating to 2000–1000 BC (Chen *et al.* 2015; Yang *et al.* 2016; Zhang *et al.* 2013; Zhou *et al.* 2016), which can give us a clear understanding of the transformation time of agricultural structures in these two regions. According to the results of radiocarbon dating of these sites in the NETP and Hexi Corridor, combined with the actual yield percentage calculated by Zhou *et al.* (2016), in the study area, the different patterns of agricultural transformation in the Hehuang basin of NETP and Hexi Corridor can be observed (Figs 16.2 & 16.3). Between c. 2000 and 1700 BC, in both the Hexi Corridor and in the NETP, the actual yield percentages of broomcorn millet and foxtail millet are over 70 per cent in all sites, which indicates that millets were the dominant crop; while from 1700 to 1500 BC, wheat began to appear as an important crop in Hexi Corridor and barley was the dominant crop in the NETP. In the Hexi Corridor, wheat makes up the largest percentage of the production ratio, up to 58 per cent. However, the largest

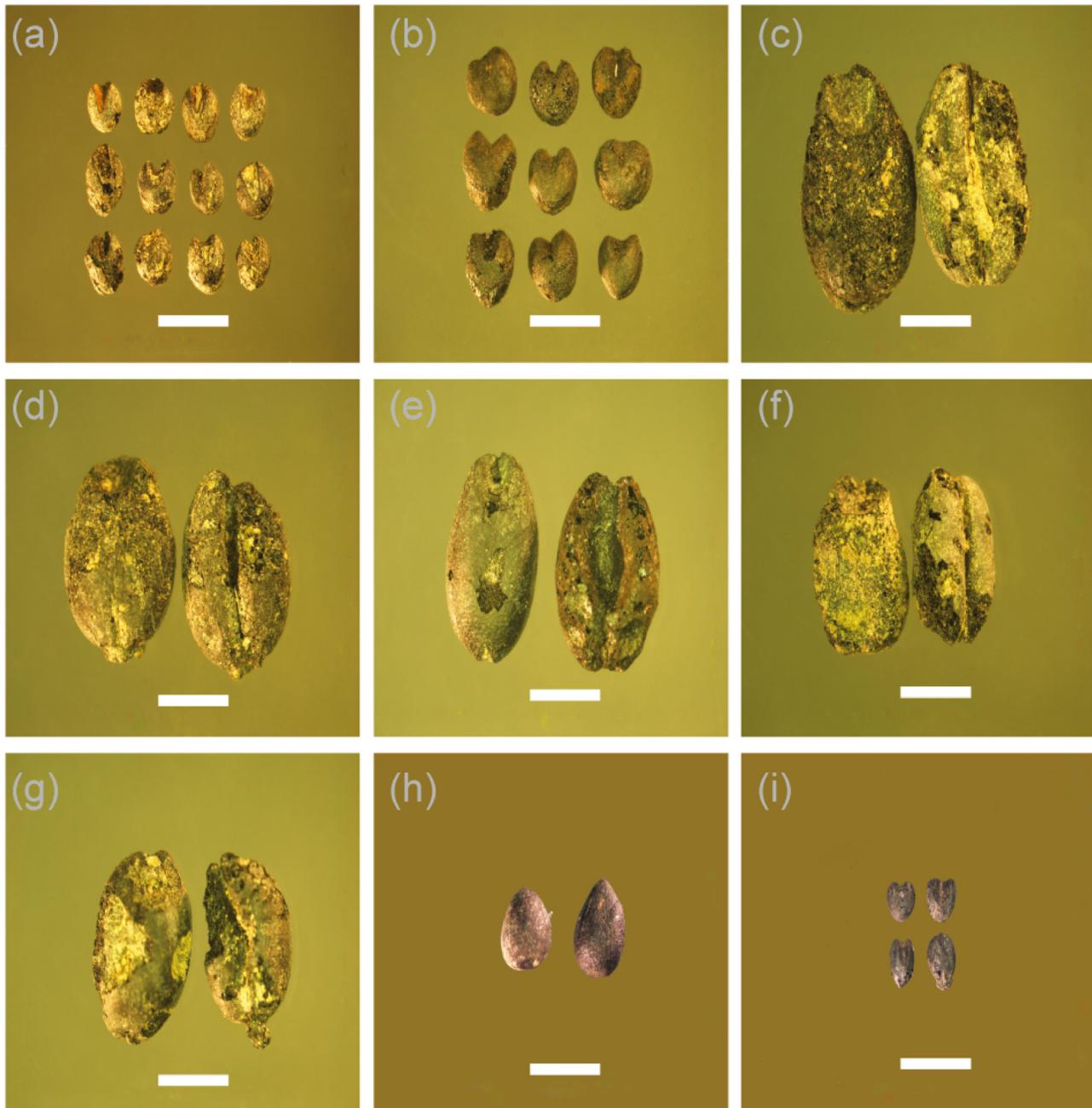


Figure 16.4. Carbonized plant seeds collected from Lijiaping Site. (a) Foxtail millet (*Setaria italica*); (b) Broomcorn millet (*Panicum miliaceum*); (c, d, e) Barley (*Hordeum vulgare*); (f, g) Wheat (*Triticum aestivum*); (h) Mallow family (*Malvaceae*); (i) Bristlegrass (*Setaria sp.*).

percentage of the production ratio in the NETP was barley, up to 57 per cent (Fig. 16.3).

Discussion

The stability of agricultural systems in various ecological environments is critical for understanding ancient cultural development in the context of a changing

climate (Riehl 2009). Studies of the structural changes in agricultural systems, combined with accurate radiocarbon dating, may help us better understand the adaptation strategies of ancient human societies worldwide. Based on the archaeobotanical and radiocarbon dating results from Lijiaping, barley was the most important cultivated crop at the site between c. 1700 and 1500 cal. BC. Other utilized crops include

foxtail millet, broomcorn millet and wheat. As shown in Figure 16.2, barley comprised the largest proportion of the production ratio in the Lijiaping site, up to 57 per cent, whereas the actual yield percentage of millets and wheat only comprise 43 per cent in total. Another macrofossil analysis also indicated that barley was the primary cultivated crop in the NETP from 1700 BC to 1500 BC (Chen *et al.* 2015). Additionally, stable isotopic evidence also suggested that more C_3 foods (probably wheat, barley and animals fed with C_3 foods) were added to human diets after 1600 BC in Gansu and Qinghai provinces (Ma *et al.* 2016). In contrast, millets were the main crops in most of the sites in the eastern Gansu province during the whole Qijia cultural period (2300–1500 BC: Jia *et al.* 2012; Wang 2012; Yang 2014; Zhou *et al.* 2011).

Compared with the Hehuang basin in the NETP, wheat-based agriculture was the primary subsistence strategy in the Hexi Corridor between 1700 and 1500 BC (Fig. 16.2; Fan 2016; Flad *et al.* 2010; Zhou *et al.* 2016). For example, the actual yield percentages of wheat in Shahuoliang, Huoshaogou, Donghuishan and Xichengyi are 65, 83, 68 and 42 per cent, respectively (Fig. 16.2; Zhou *et al.* 2016). However, whether in the NETP or in the Hexi Corridor, millets dominate the charred plant assemblages between 2000 and 1700 BC (Fig. 16.2). For instance, millets comprise 97, 74, 83 and 100 per cent of the production ratio at Huoshiliang, Ganggangwa, Huangniangniangtai and Xichengyi in the Hexi Corridor, respectively (Fig. 16.2). Foxtail and broomcorn millet also remained the main crops at all six sites in the NETP (Fig. 16.2).

To describe the crop assemblage in these two regions more clearly, we summarized the crops of all sites in the same area in one pie chart (Fig. 16.3). It can be seen very clearly that barley and wheat make up the largest percentage of the production ratio in the NETP and Hexi Corridor between 1700 and 1500 BC, up to 57 and 58 per cent, respectively (Fig. 16.3), whereas between 2000 and 1700 BC, the actual yield percentage of millets is 97 per cent in the Hexi Corridor, accounting for 95 per cent in the NETP. Stable carbon isotope research from these two areas also shows that C_4 -type millets were the dominant food from 2000 to 1700 BC (Atahan *et al.* 2011; Ma *et al.* 2016). Therefore, we can conclude that humans had adopted barley and wheat as the primary staples in the NETP and Hexi Corridor, respectively, between 1700 and 1500 BC. But prehistoric people in these two regions mainly engaged in the cultivation of millet crops from 2000 BC to 1700 BC. In brief, the agriculture structure changed significantly in the NETP and Hexi Corridor around 1700 BC. The impetus for this change is likely a response to changes in the climate, as millet

production is vulnerable to temperature drops (Brink 2006; Cappers *et al.* 2010; Kamkar *et al.* 2006), which occurred during this period (e.g. An *et al.* 2005). Barley and wheat are more resistant to lower temperatures than millets (Klepper *et al.* 1998; Saseendran *et al.* 2009; Stoskopf 1985) and were likely quickly accepted by the local people as staple cereal grains.

Why did wheat become a staple crop after 1700 BC and rapidly replace millet after 200 to 300 years in the Hexi Corridor, while barley was the dominant crop in the NETP between 1700 and 1500 BC? This spatial difference might be caused by temperature decline and different hydrothermal condition in these two areas. As we all know, millets are frost-sensitive crops which need to grow in a warmer and wetter environment (Chai 1999; Guedes & Butler 2014; Wang 1994). The NETP is an extremely harsh environment with high altitude, low temperature and low oxygen level, which creates difficult conditions for plants and human to survive. More importantly, multiple climate records have demonstrated that the climate was wetter and warmer during the middle Holocene, and became cooler and drier after 2000 BC in Gansu and Qinghai provinces (An *et al.* 2004; 2005; Chen *et al.* 2015; Marcott *et al.* 2013; Wang *et al.* 2005; Zhao & Yu 2012). Therefore, millet production might have decreased, since it can hardly survive in such cooler and drier climate conditions after 2000 BC. However, barley has a longer growing season and is more frost-hardy than millets (Páldi *et al.* 2001). The climate model of Guedes (2015) also shows that growing degree days of millets has higher temperature requirements than wheat and barley (Guedes 2015). Thus, the low-temperature tolerance of barley enables it to be cultivated in higher-altitude regions such as the NETP. Finally, barley replaced millet as a staple crop between 1700 and 1500 BC in the NETP. Recent archaeobotanical studies also found that barley-based agriculture facilitated permanent prehistoric human settlements in the areas above 2500 masl after 1600 BC in the NETP, where temperatures are lower (Chen *et al.* 2015; Dong *et al.* 2016). The plant macrofossil analysis results also suggest that humans were heavily reliant on barley-based agriculture in northeast Qinghai province during the Kayue culture period (1600–500 BC; Wang 2012; Zhang & Dong 2017; Zhao 2010). Besides, the optimal (wetter and warmer) climate during the middle Holocene might have led the population to grow rapidly in the western Loess Plateau (Bureau of National Cultural Relics 1996; 2011; Ma *et al.* 2016; Zhou *et al.* 2016). The large population might have migrated from the western Loess Plateau to the NETP when the climate became cooler and drier after 2000

bc (Chen *et al.* 2015). However, the yields of wheat and naked barley are higher than millets (Dong & Zheng 2006), and barley is a crop that is more suitable for growth in lower temperatures than wheat (Klepper *et al.* 1998; Saseendran *et al.* 2009; Stoskopf 1985). As a result, the low yield of millets may have been inadequate to feed large populations, and led to barley becoming a staple crop in the NETP.

In the Hexi Corridor, recent research has found that its climate and landscape environment were similar to the Near East (Zhou *et al.* 2016). As mentioned above, compared to rain-fed millet cultivation, the yields of wheat and naked barley are higher (Dong & Zheng 2006). Meanwhile, wheat is a C₃-type plant, and water supply is the most important factor for maintaining its high yield (Klepper *et al.* 1998; Saseendran *et al.* 2009). In contrast to the valley and hilly regions in most parts of NETP, the oasis regions of the Hexi Corridor have a lot of flat areas (Zhou *et al.* 2016). Water supply is dependent upon irrigation by rivers, and farmlands can be easily irrigated via access to shallow underground water supplies in the oasis (Zhou 2002). Therefore, these flat lands in the Hexi corridor are better suited for the cultivation of wheat than barley. Moreover, bronze mining and smelting were introduced to the Hexi Corridor during the Bronze Age and developed significantly (Dodson *et al.* 2009; 2013; Yang *et al.* 2016; Zhang *et al.* 2017). The development of mining and smelting requires an external labour force and a food supply. In addition, based on the results of the Second National Archaeological Survey, the number of sites in the Hexi Corridor is large, which shows the high intensity of human settlement during the Early Bronze Age (Bureau of National Cultural Relics 2011). These high-intensity human settlements require more food supplies in this area. Hence, high-yield wheat might have been chosen to meet the labour force needed in the bronze mining and smelting industry, and consequently replaced traditional lower-yield millet agriculture in the Hexi Corridor after 1700 bc.

In summary, cooler and drier climate conditions after 2000 bc, as well as the characteristics of barley's low-temperature tolerance, promoted the cultivation of barley in the NETP between 1700 and 1500 bc. The easily irrigated oasis flat land in the Hexi Corridor and development of a bronze mining and smelting industry enabled people to choose high-yield wheat agriculture from 1700 bc to 1500 bc. The decrease in temperature after 2000 bc and the different hydrothermal conditions in different regions may be the two key factors contributing to the various agricultural structures in the NETP and Hexi Corridor.

Conclusion

Archaeobotanical analysis and radiocarbon dating from the excavation of the Lijiaping site suggest that humans mainly cultivated barley, and supplemented this with millet and wheat during the period c. 1700–1500 bc. Combined with previous archaeobotanical studies in the NETP and Hexi Corridor, we argue that humans adopted barley and wheat, respectively, in these two areas approximately 300 years later than the introduction of these two exotic crops to northwest China around 2000 bc. The evident cooling trend in the Early Bronze Age may have led to unstable production of millets, which are sensitive to lower temperatures. The rapid transition from rain-fed agriculture to farming mainly based on the cultivation of cold-tolerant crops, and the spatial variation in adoption of barley and wheat, are likely a result of different hydrothermal conditions in the Hexi Corridor and the NETP.

Acknowledgements

This research was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences, Pan-Third Pole Environment Study for a Green Silk Road (Pan-TPE), the National Key R&D Program of China (2018YFA0606402), the National Natural Science Foundation of China (Grant Nos. 41620104007)

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Chapter 17

When and How Did Wheat Come Into China?

Zhijun Zhao

Introduction

Wheat has its origin in the Fertile Crescent in West Asia. Remains of the earliest wheat have been excavated from the archaeological sites of the EPPNB period (Early Pre-Pottery Neolithic B), which is dated to 10,500–9500 BP (Weiss & Zohary 2011). *Triticum monococcum* (einkorn wheat) and *T. turgidum* (emmer wheat) are two varieties of the earliest domesticated wheat. About 8000 years ago, *T. turgidum* was introduced into the river valley between the northern Iranian plateau and southeastern Caspian Sea, and hybridized with local *Aegilops tauschii* (Tausch's goat-grass), which gave birth to a new cultivated variety that is widely planted and used today—*T. aestivum*, which is also called common wheat or bread wheat (Zohary & Hopf 2000).

Wheat gradually spread to become the main crop in the regions of the major ancient civilizations, including the Mesopotamian civilization in the Euphrates and Tigris valleys, the ancient Egyptian civilization in the Nile Valley, the ancient Indian civilization in the Indus Valley and the ancient Greek and Roman civilizations, which were all established on the basis of agricultural production with wheat as the main crop.

In Central Asia, the eastward spread of wheat was very slow. According to archaeological findings, wheat had already spread into the southwestern areas of Central Asia, such as the northern slopes of Kopet-Dagh in Turkmenistan, as early as 7000 years ago (Harris 2010), but only moved eastward to East Asia thousands of years later. There were many reasons for this hindrance of the eastward spread of wheat, among which the different climates of western and eastern Asia should be the main factor. The birthplace of wheat, West Asia, enjoys a Mediterranean climate with hot, dry summers, and cold, damp winters, with frequent rainfall in winter and spring. However, East Asia, including China, the Korean Peninsula and the Japanese archipelago, enjoys an East Asian monsoon climate with hot, wet summers, cold, dry winters, and

frequent rainfall in summer. The difference in rainy seasons had a great impact on the growth of wheat. As a winter crop, wheat is sown in autumn and harvested in summer. Water is needed in spring, the growing season for wheat, but rain is scarce in East Asia at this time. For example, in the vast areas of northern China, it is said that rain in spring is as precious as oil. The lack of water is not conducive to the jointing and filling of wheat in the growing season, while the frequent rain in summer also affects its maturation and harvest. Under these conditions, East Asia is actually not suitable for growing wheat unless irrigation is used. Therefore, climatic differences in western and eastern Asia are the main reason for the very gradual eastward spread of wheat.

According to historical documents, however, wheat continued to spread eastward, reaching the middle and lower reaches of the Yellow River, which was the core area of ancient Chinese civilization. Gradually replacing such local crops as foxtail millet (*Setaria italica*) and broomcorn millet (*Panicum miliaceum*), wheat became the major crop of dry-land farming in northern China, leading to China's current agricultural production pattern of rice in the south and wheat in the north. Thus, it follows that in spite of the fact that wheat did not originate in China, the time when it was introduced into China, the route it took to enter China, the method of its spread in China and its impact on ancient Chinese civilization are all important issues deserving serious attention.

In this chapter, archaeological remains of wheat are studied using the methods of archaeobotany so as to explore the time and routes of the introduction of wheat into China. Specifically, the credibility and reliability of the dates of unearthed remains of early wheat are assessed, thereby determining the time of its introduction into China. This will involve integrating archaeological materials concerning wheat found in different regions and synthesizing the environmental characteristics and cultural traditions in ancient China. The means and routes of wheat's transmission into China will be explored, especially to the core region

of Chinese civilization, namely, the middle and lower reaches of the Yellow River.

Archaeological data collected in the last century

For the time when wheat spread into China, some clues can be found in historical documents. For example, an ancient historical text, in the chapter ‘Duke Cheng of Lu (590–573 BC)’ in *Zuo Zhuan* 左传 (Zuo Qiuming’s commentary on *Spring and Autumn Annals*), compiled in the early fourth century BC, records that ‘周子有兄而无慧, 不能辨菽麦, 故不可立’ [the brother of Zhou Zi is not qualified to be a king, because he is not intelligent enough to distinguish soybean and wheat]. It is clear from this document that wheat was widely grown in northern China during the Eastern Zhou period (770–256 BC). In addition, Chinese characters relating to wheat have been identified in China’s earliest written artefacts, the so-called oracle bone inscriptions (inscriptions on bones or tortoise shells) dating from the period of the late Shang Dynasty, roughly 1200–1050 BC. For example, though the two characters *lai* 来 and *mai* 麦 have been explained as Triticeae crops, the former is regarded as denoting wheat and the latter barley (Song 2002). The character referred to wheat originally, but later was used as a word meaning ‘come’. Some scholars thus believe that this indicated that wheat came (来) from regions outside China (Ho 1985), though other scholars hold different views (Luo 1990). At all events, the Chinese character in the oracle bone inscriptions clearly confirms that wheat had already entered China no later than the Shang period (before 3000 years ago).

These are the earliest historical records about wheat. To trace any further into the past requires archaeological findings that precede these historical documents, that is, archaeological materials dated to earlier than 3000 years ago. This is the chronological demarcation line for the discussion of the present study.

The most direct archaeological evidence for when the introduction of wheat occurred should come from the remains of ancient wheat found during archaeological research. The fact is, though, that only in rare cases is wheat preserved in cultural deposits, because the plant as an organic material tends to rot away. Unlike other archaeological remnants, wheat grains are too small to be observed by the naked eye, with the result that it is very difficult to find any wheat remains by means of the usual methods employed in archaeological excavation. Despite this, there were still some reports of wheat remains in archaeological excavations in the previous century. Archaeological sites where remains of early wheat from 3000 years

ago were discovered include the Donghuishan site in Minle County, Gansu Province (Gansu Provincial Institute of Cultural Relics and Archaeology and Northern Archaeology Laboratory of Jilin University 1998), the Zhaojialai site in Wugong County, Shaanxi Province (Institute of Archaeology, Chinese Academy of Social Sciences 1988), the Diaoyutai site in Bo County, Anhui Province (Anhui Museum 1957), the Haimenkou site in Jianchuan County, Yunnan Province (Preparatory Office of Yunnan Museum 1958), the Changguogou site in Shannan in Tibet (Fu 2001), the Gumugou site in Lop Nor (Wang 1983), the Lanzhouwanzi site in Balikun County (Wang *et al.* 1985) and the Wubao Tomb in Hami in Xinjiang Uygur Autonomous Region (Xinjiang Institute of Cultural Relics and Archaeology 1992) (Table 17.1).

It should be noted that most of these wheat remains were discovered by chance, and there is a fair margin of doubt about the period and species that they belong to, provoking some debate. For example, the ceramic pot in which the wheat remains were found unearthed at the Diaoyutai site was initially considered to date to the Late Neolithic, about 4000 years ago, but was subsequently identified as a relic of the Western Zhou period (1046–771 BC: Yang 1963). Another example is that, although there is agreement on the age of the wheat remains found at the Zhaojialai site (Longshan period, c. 4300–3800 BP), the determination of their species requires further research. It was reported that the wheat remains from this site were actually found in the traces of some plant stems present in the mud used to daub a wall (Huang 1991). However, it is difficult enough to identify the species of fresh stems of most crops based on appearance, let alone the impressions of stems left in such material.

The most influential and controversial of such wheat remnants discovered in the twentieth century are those unearthed at the Donghuishan site located in the Hexi Corridor 河西走廊, Gansu Province. Li Fan was the first to research those wheat remains. Based on the wheat grains he collected at the site in 1985 and 1986, he identified them as *Triticum aestivum* and *T. compactum* and determined that the wheat grains dated to 5000±159 cal. BP, based on radiocarbon dating analysis of bulk samples (black carbon soil) collected from the site (Li *et al.* 1989). Since Li Fan is a well-known agronomist rather than archaeologist, his identification of the wheat species is credible, but the methods he used to collect the samples of plant remains and to assess their date require further confirmation by professional archaeologists.

In 1987, a combined archaeological team from the Gansu Institute of Archaeology and the Archaeology Department of Jilin University officially began excava-

Table 17.1. *Early wheat remains in last-century archaeological discoveries.*

Site	Location	Findings	Relative date	Absolute age BP	Dating material/method	References
Donghuishan	Minle County, Gansu Province	charred wheat grains	Siba	5000±159	soil/conventional	Li <i>et al.</i> 1989
Donghuishan	Minle County, Gansu Province	charred wheat grains	Siba	3770±145	charcoal/conventional	Gansu Provincial Institute of Cultural Relics and Archaeology and Northern Archaeology Laboratory of Jilin University 1998
Donghuishan	Minle County, Gansu Province	charred wheat grains	Siba	4230±250	wheat grain/conventional	
Zhaojialai	Wugong County, Shaanxi Province	wheat straw impression	Longshan	c. 4300–3800	–	Huang 1991
Zaojiaoshu	Luoyang City, Henan Province	wheat grains	Erlitou	3660±150	charcoal/conventional	Cultural Relics Team of Luoyang 2002
Haimenkou	Jianchuan County, Yunnan Province	ears of wheat	late Neolithic	c. 3500	–	Preparatory Office of Yunnan Museum 1958
Changguogou	Shannan County, Xizang (Tibet) Autonomous Region	wheat grains	Neolithic	3370	charcoal/conventional	Fu 2001
Gumugou	Lop Nor, Xinjiang Uyghur Autonomous Region	wheat grains	–	3765–3925	coffin, sheepskin and blanket/conventional	Wang 1983
Lanzhouwanzi	Balikun County, Xinjiang Uyghur Autonomous Region	charred wheat grains	–	3285	wood and fur/conventional	Wang <i>et al.</i> 1985
Wupu Tombs	Hami City, Xinjiang Uyghur Autonomous Region	wheat grains	–	3260–2960	charcoal/conventional	Wang 1983

tion of the Donghuishan site. The results obtained by the team show that the site belongs to the Siba culture (Gansu Provincial Institute of Cultural Relics and Archaeology and Northern Archaeology Laboratory of Jilin University 1998, 131–2), an Early Bronze Age culture in the Hexi Corridor dated from 3900 to 3400 years ago. Therefore, the date of the Donghuishan site determined by archaeologists based on excavation was over 1000 years later than that of the wheat remains at the site identified by Li Fan. Even more complicated are the two radiocarbon dating results published in the appendix of the official archaeological report (Gansu Provincial Institute of Cultural Relics and Archaeology and Northern Archaeology Laboratory of Jilin University 1998, 190). The calibrated result of the radiocarbon age of charcoal samples with clear acquisition layer was 3770±145 cal. BP, which was precisely in the period of the Siba culture. However, the conventional radiocarbon age of charred wheat collected from the Siba cultural layer was 4230±250 BP, which seemed to be closer to Li Fan's assessment. These contradictory radiocarbon dating results added to the confusion over the age of the wheat remains

found at the Donghuishan site, leading to further academic debate (Li & Mo 2004).

In 2005, a joint team consisting of Chinese and American archaeologists made a special trip to the Donghuishan site. Using the flotation technique, more remains of wheat and barley were discovered. Based on over 10 series of charred wheat samples selected through flotation, the age of this newly unearthed wheat was directly dated using the AMS (accelerator mass spectrometry) dating technique by the Radiocarbon Laboratory of Peking University. The calibrated results indicated that most wheat samples were dated from 3600 to 3400 BP (Flad *et al.* 2010). In recent years, new sampling and dating by Chinese and Australian scholars have determined that the calibrated results of radiocarbon dating age were in a range from 3800 to 3500 BP (Dodson *et al.* 2013). These new data irrefutably prove that the cultural deposits and remains of wheat from the Donghuishan site are from the period of the Siba culture, and their absolute age was around 3600 BP. As a result, this archaeological problem, which had been confusing academic circles for years, was finally solved.

Table 17.2. *Early wheat remains with only relative ages.*

Sites	Location	Acquisition methods of wheat remains	Relative age	Presumed absolute age BP	Basis for the presumed age	References
Liangchengzheng	Rizhao City, Shandong Province	archaeological excavation	Longshan	c. 4300–3800	feature of the cultural remains in the site	Crawford <i>et al.</i> 2004
Jiaochangpu	Liaocheng City, Shandong Province	archaeological excavation	Longshan	c. 4300–3800	feature of the cultural remains in the site	Zhao 2004
Zhaogezhuang	Yantai City, Shandong Province	archaeological excavation	Yueshi	c. 3839–3627	radiocarbon dating results of other materials	Jin <i>et al.</i> 2010
Maan	Zhangqiu City, Shandong Province	archaeological excavation	Yueshi	c. 3800–3600	feature of the cultural remains in the site	Chen & Guo 2009
Daxinzhuang	Jinan City, Shandong Province	archaeological excavation	Shang	c. 3600–3000	feature of the cultural remains in the site	Chen & Fang 2008
Yuhuicun	Bengbu City, Anhui Province	archaeological excavation	Longshan	c. 4300–4140	radiocarbon dating results of other materials	Yin 2013
Xijincheng	Bo'ai County, Henan Province	archaeological excavation	Longshan	c. 4300–3800	feature of the cultural remains in the site	Chen <i>et al.</i> 2010
Wangchenggang	Dengfeng County, Henan Province	archaeological excavation	Late Erlitou	c. 3640–3520	radiocarbon dating results of other materials	Zhao & Fang 2007
Wadian	Yuzhou City, Henan Province	archaeological excavation	Longshan	c. 4260–4150	radiocarbon dating results of other materials	Liu & Fang 2010
Baligang	Dengzhou City, Henan Province	archaeological excavation	Late Longshan	c. 4300–3800	feature of the cultural remains in the site	Deng & Gao 2012
Xinzhai	Xinmi City, Henan Province	archaeological excavation	Xinzhai Phase	c. 3910–3830	radiocarbon dating results of other materials	Zhao 2011
Erlitou	Yanshi City, Henan Province	archaeological excavation	Phase IV of Erlitou	c. 3510–3480	radiocarbon dating results of other materials	Zhao 2015
Zhouyuan	Fufeng City, Shaanxi Province	archaeological excavation	Pre-Zhou	c. 3080–2870	radiocarbon dating results of other materials	Zhao & Xu 2004
Xishanping	Tianshui City, Gansu Province	Profile sampling in environmental survey	–	c. 4650	presumption of deposition rate of sediments of profile	Li <i>et al.</i> 2007
Fengtai	Huzhu County, Qinghai Province	archaeological excavation	Kayue	c. 3200–2800	feature of the cultural remains in the site and radiocarbon dating results of other materials	Zhao 2004

New archaeobotanical data

Flotation is currently the most effective way to obtain ancient plant remains from archaeological excavations. Since the beginning of this century, flotation

has been vigorously promoted and popularized in Chinese archaeology, making it much easier to find ancient plant remains in the process of excavation. It has now been used at hundreds of archaeological sites, resulting in the discovery of a large number of charred

Table 17.3. Directly dated early wheat remains.

Site	Location	Acquisition methods of wheat remains	Calibrated results of ¹⁴ C dates (cal. BP)	Dating materials	Laboratory/method	References
Zhaojiazhuang	Jiaozhou County, Shandong Province	archaeological excavation	4411–4158	wheat grains	Peking University/AMS	Jin <i>et al.</i> 2008
Dinggong	Zouping County, Shandong Province	archaeological excavation	4150–3929	wheat grains	Poznan University/AMS	Long <i>et al.</i> 2018
Dinggong	Zouping County, Shandong Province	archaeological excavation	4143–3903	wheat grains	Poznan University/AMS	Long <i>et al.</i> 2018
Huoshiliang	Jinta County, Gansu Province	profile sampling on cultural layer	4085–3845	wheat grains	Oxford/AMS	Dodson <i>et al.</i> 2013
Ganggangwa	Jinta County, Gansu Province	profile sampling on cultural layer	3976–3709	wheat grains	Oxford/AMS	Dong <i>et al.</i> 2014
Donghuishan	Minle County, Gansu Province	profile sampling on cultural layer	3829–3488	wheat grains	Oxford/AMS	Dodson <i>et al.</i> 2013
Donghuishan	Minle County, Gansu Province	profile sampling on cultural layer	3573–3402	wheat grains	Peking University/AMS	Flad <i>et al.</i> 2010
Jinchankou	Datong County, Qinghai Province	archaeological excavation	3980–3720	wheat grains	Beta/加速器	Dong <i>et al.</i> 2014
Aiqingya	Gangcha County, Qinghai Province	profile sampling on cultural layer	3406±49	wheat grains	Beta/加速器	Chen <i>et al.</i> 2015
Xiariyamakebu	Dulan County, Qinghai Province	profile sampling on cultural layer	3316±69	wheat grains	Peking University/AMS	Chen <i>et al.</i> 2015
Shuangerdongping	Ledu County, Qinghai Province	profile sampling on cultural layer	3251±88	wheat grains	Peking University/AMS	Chen <i>et al.</i> 2015
Xiaohu Tombs	Lop Nor, Xinjiang Uyghur Autonomous Region	archaeological excavation	3640–3370	wheat grains, millet grains and tips of animals' ears	Peking University/AMS	Xinjiang Institute of Cultural Relics & Archaeology 2007
Xintala	Heshuo County, Xinjiang Uyghur Autonomous Region	profile sampling in environmental survey	3677–3830	wheat grains	Oxford/AMS	Zhao <i>et al.</i> 2012

plant remains of great value to Chinese archaeological research (Zhao 2014). These plant remains also include ancient wheat, providing new evidence with which the introduction of wheat into China can be explored (Zhao 2009).

According to incomplete statistics, there have been dozens of cases of discoveries of early wheat remains reported or formally published in this century. In contrast to the findings from the previous century, the remains of wheat discovered in this century have three distinctive characteristics. First, instead of being found by chance, they have been mostly acquired deliberately through flotation or sieving during archaeological excavations or field investigations. Second, some geologists and biologists have participated in this process and in research on these early wheat

remains. Finally, with increasingly advanced radiocarbon dating technology, especially improvements in the AMS dating technique, a single grain of wheat now qualifies as a dating sample (see Liu *et al.* 2016, for a review of direct wheat dates). In addition, thanks to China's growing economy, adequate research funds have meant that such samples can be tested by radiocarbon laboratories at home and abroad, resulting in a stream of relatively accurate dating data.

These early wheat remains have been acquired in two different ways. Some have been discovered in deposits at archaeological sites through standard excavation. These remains usually corresponded to specific cultural layers, though highly specific dating of them is absent in most cases. The relative age of the wheat is basically calculated based on the cultural features

of the site or on the dating of other samples excavated from the same layers, such as charcoal, animal bones, fur and even bulk samples. On the other hand, some have been acquired from profile sediments or cultural deposits through environmental observation or archaeological investigation. Although these remains may not be clearly located in archaeologically attested cultural contexts, they mostly have reliable dating data gained from direct AMS dating.

According to the statistics in Table 17.2, with the exception of those found at Xishanping in Gansu Province, early wheat remains with only relative dating were all obtained through standard archaeological excavation. Based on their relative age determined by cultural periodization, the earliest date from the Longshan period, from 4300 to 3800 years ago, while some belong to the Erlitou culture, from 3800 to 3500 years ago. According to the statistics in Table 17.3, those early wheat remains with direct dating data were obtained through both archaeological excavation and profile sampling during investigation (Chen *et al.* 2015). With the exception of those from Zhaojiazhuang site and Dinggong site in Shandong Province, the samples tested by AMS dating all come from no earlier than 4000 years ago. Among these two sets of statistics, Xishanping, Zhaojiazhuang and Dinggong are special cases and deserve further analysis.

Although the wheat remains from Xishanping in Gansu Province were gained from sediment profiles through environmental observation, the age of the wheat was based on speculation due to the lack of direct AMS dating of the grains unearthed. According to the original report:

Twenty samples with the thickness of 10–15 cm and weighing approximately 80 kg were acquired from a 650-cm-thick sedimentary section. Various archaeological remains were then extracted through sieving and flotation. Wheat was detected in the top profile of the eight samples, with an earliest date of 4650 cal. BP. (Li *et al.* 2007)

After being published, the report immediately attracted wide attention due to the relatively early dating, and has been cited as data relating to the earliest wheat in China in many relevant papers.

However, the question remains concerning how the date 4650 cal. BP was obtained, and how accurate and reliable it is. Tables in the original report offered eight radiocarbon dating results in which the date of 4650 cal. BP was not included. The eight dated samples mainly consisted of charcoal (six samples), a rice grain and a millet grain (*Setaria italica*), but these samples contained no wheat grains. Clearly, no AMS

dating was carried out on any unearthed wheat in this research, and thus the date of the wheat found at Xishanping must have been calculated based on the relative age of the layer from which it was discovered. In which layer, then, was the wheat actually found? What was the basis of the determination of the layer's age? The eight sets of age data in the report all corresponded to the layer depth of the sedimentary sections, yet, other than recording that wheat was discovered in the top eight samples, the report does not refer to the layer depth in which it was found, making it impossible to identify the age.

The only information of reference value in the report is the relative dates in the pollen spectrum, which was calculated based on deposition rate of sediments. The period between the two relative dates of 4600 and 4500 corresponded to the layer depth of 200 cm, which was roughly the position where the 'top eight samples' with wheat were unearthed. Thus, the date of the wheat remains unearthed at Xishanping was calculated based on the depth of the sedimentary section, the dates of which were determined by the deposition rate of the corresponding section. Clearly, due to this lack of credibility, the relative dating obtained through this method could only serve as a reference, rather than as firm data for the earliest wheat in China.

In contrast, the wheat remains unearthed at Zhaojiazhuang and Dinggong in Shandong Province were acquired from archaeological excavation, and have provided data based on direct age dating. According to the original report (Jin *et al.* 2008; Long *et al.* 2018), both Zhaojiazhuang and Dinggong included cultural deposits from the Dawenkou and Longshan periods. By means of the application of flotation during the archaeological excavations, rich charred plant remains were obtained that include wheat grains from both sites. After analysis using the AMS dating method, the conventional radiocarbon age of the wheat grains from the Zhaojiazhuang site was determined to be 3905±50 BP (Jin *et al.* 2008), and the calibrated result was 4411–4158 cal. BP. There are two radiocarbon dates of wheat grains from the Dinggong sites (Long *et al.* 2018). One is 3705±35 BP (4150–3929 cal. BP); the other is 3680±35 BP (4143–3903 cal. BP). Therefore, combining both the clear archaeological cultural background and accurate dating data, the wheat remains from Zhaojiazhuang and Dinggong are highly credible and of great research value.

In summary, based on analysis of the ages of early wheat remains unearthed from over 30 archaeological sites listed in Tables 17.1 to 17.3, wheat had already been introduced into China by 4000 years ago, and was widely planted in northern China. According to the dates of the wheat remains from Zhaojiazhuang

MAP OF THE PEOPLE'S REPUBLIC OF CHINA

Edition of Administrative Region



GS (2008) 1413 号

Jun. 2008

Produced by State Bureau of Surveying and Mapping

Figure 17.1. The potential routes for the spread of wheat into China: (1) Northern Cultural Zone; (2) The western part of the Loess Plateau. The dashed line indicates the Steppe Route and the dotted line indicates the Oasis Route.

and Dinggong sites in Shandong Province, it is likely that wheat entered China as early as a time period between 4500 and 4000 BP.

Multiple routes for the introduction of wheat

As stated above, there are more than 30 archaeological sites in China that contain wheat remains of an early period, that is, over 3000 years ago. These sites are mainly distributed along a belt of terrain stretching for several thousand kilometres from the Tianshan Mountains in the west to the Shandong Peninsula in the east. This belt is located at approximately 34–46°N latitude (Figure 17.1). According to the features of its ecological environment and the archaeological division of cultural regions, it included three regions: from east to west, the Haidai Region, Central China Region and Northwest Region.

The Haidai Region refers to the areas where the Dawenkou culture (c. 6000–4300 BP) and Haidai-Long-

shan cultures (c. 4300–3800 BP) of the Neolithic period and the Yueshi culture (c. 3800–3600 BP) of the Bronze Age flourished. It basically embraces today's Shandong Province and northern parts of Anhui Province and Jiangsu Province (Luan 1997). Archaeological sites within the Haidai Region include: Zhaojiazhuang in Jiaozhou (Jin *et al.* 2008); Dinggong in Zouping (Long *et al.* 2018); Liangchengzhen in Rizhao (Crawford 2004); Jiaochangpu in Liaocheng (Zhao 2004); Zhaogezhuang in Yantai (Jin *et al.* 2010); Ma'an in Zhangqiu (Chen & Guo 2009); and Daxinzhuang in Jinan (Chen & Fang 2008), all located in Shandong Province, and Yuhuicun in Bengbu (Yin 2013), located in Anhui Province. The importance of the wheat remains found at Zhaojiazhuang and Dinggong has already been stated. The findings from Liangchengzhen, Jiaochangpu and Yuhuicun also deserve proper attention, because charred wheat grains have been found at all three sites belonging to the Longshan culture (c. 4300–3800 BP), although no direct dating data has been published.

The Central China Region refers to the Zhongyuan-Longshan culture of the Neolithic period and the Erlitou culture of the Bronze Age in the middle Yellow River area, which is the core area for the formation of Chinese civilization. This region generally covers today's Henan Province and the southern parts of Shanxi Province and Hebei Province. Archaeological sites in the region where early wheat remains have been unearthed using flotation in recent years include: Wangchenggang in Dengfeng (Zhao & Fang 2007); Xijincheng in Bo'ai County (Chen *et al.* 2010); Wadian in Yuzhou (Liu & Fang 2010); Baligang in Dengzhou (Deng & Gao 2012); Xinzhai in Xinmi (Zhao 2011); and Erlitou in Yanshi (Zhao 2015), all located in Henan Province. The most noteworthy of these sites are Xijincheng, Wadian and Baligang, because charred wheat grains belonging to the Longshan culture (c. 4300–3800 BP) have been excavated at these three sites. The wheat remains found at the Wadian site were delivered to a radiocarbon dating laboratory for dating, as yet without satisfactory results. The tests indicated that the date of the wheat was evidently later than the Longshan period, and further analysis and verification are required.

The Northwest Region covers a vast territory of complex geographical units, involving the upper Yellow River area, the Hexi Corridor and most parts of Xinjiang region. Wheat remains from an early period found in the Northwest Region have been obtained mainly through environmental and archaeological investigation, and most of them have direct dating data. The sites in which these wheat remains have been unearthed are mainly distributed across three areas, that is, the eastern part of Qinghai Province, the Hexi Corridor in Gansu Province and the eastern part of Xinjiang region; their chronology falls between 4000 to 3500 years ago. Important sites here include Jinchankou in Datong County of Qinghai Province (Dong *et al.* 2014), Huoshiliang and Ganggangwa in Jinta County of Gansu Province (Dodson *et al.* 2013). The direct dating data for the charred wheat grains found at these three sites reaches or approaches 4000 BP, the earliest absolute chronological data obtained so far, besides Zhaojiazhuang and Dinggong in Shandong Province.

Wheat was introduced to China from West Asia through Central Asia. Therefore, the Northwest Region seems to be most closely related to the route along which wheat came to China. Correspondingly, in historical times, especially since West Han Dynasty (202 BC–AD 8), the major channel of cultural exchange between East and West was the so-called Silk Road, and the Hexi Corridor was a key section of this route. In addition, the Northwest Region is where early

wheat remains have been most commonly found, which easily leads to the conclusion that wheat was brought to China by that route. Therefore, it seems that wheat spread from Central Asia, crossed the Oasis Route along the northern and southern sides of Tarim Basin in southern Xinjiang region, passed down the Hexi Corridor and the Wei River valley to the Central China Region, and finally arrived in the Haidai Region.

However, the distribution of archaeological sites in which early wheat remains around 4000 years old have been unearthed does not show a west-to-east spreading pattern, since they have been found in all three regions: the Northwest Region in the west, Central China Region in the middle and the Haidai Region in the east. Moreover, the earliest wheat remains of highest reliability found so far were unearthed at the Zhaojiazhuang and Dinggong sites, which are located in the Shandong Peninsula, right at the eastern end of this belt of terrain. Therefore, whether wheat simply followed the route of the Silk Road to China from the west requires rethinking.

In fact, the Silk Road was not the only channel for exchange between the cultures of the East and West in ancient times. There were other routes at different times, such as the Maritime Silk Road, the Southern Silk Road and the Eurasian Steppe Route. The latter is an ancient route that stretches along the Eurasian Steppe, linking East and West. The channel extends from the Greater Khingan Mountains in Northeast Asia to the Carpathian Mountains in Central Europe, passing through the Mongolian Plateau, south Siberia, Central Asia and the northern part of Western Asia to Central Europe. This Eurasian Steppe Route, the main part of which is vast, flat prairie presenting no difficulties in overcoming natural barriers, serves as a natural corridor linking the cultures of East and West.

As mentioned earlier, wheat reached Central Asia about 7000 years ago and continued spreading eastwards to East Asia, including China. Therefore, the starting point for this propagation of wheat should be Central Asia. The region that connects to Central Asia is the eastern part of the Eurasian Steppe, including south Siberia, the Sayan-Altai-Tianshan Region and the Mongolian Plateau. Archaeological discoveries have verified that by 5600 to 3400 years ago, several early cultures of the Bronze Age were widely distributed across the eastern part of Eurasian Steppe, such as the Afanasevo, Okunyevo, Chemurchek, Seima-Turbino and Andronovo cultures (Lin 2014; Table 17.4). These Bronze Age cultures scattered over the vast steppes may not have been successive, yet they share common cultural features, such as bronze accessories with animal designs and bronze daggers, and a mixed type of economic production and lifestyle combining

Table 17.4. List of archaeological cultures in the Central Asian Steppe.

South Siberia	Sayan-Altai	Altai-Tianshan
Afanasevo Culture, c. 3600–2500 BC	Afanasevo Culture, c. 3600–2500 BC	Afanasevo Culture, c. 3600–2500 BC
Okunyevo Culture, c. 2100–1800 BC	Chemurchek Culture, c. 2500–2100 BC	Chemurchek Culture, c. 2500–2100 BC
	Seima-Turbino Culture, c. 2200–1700 BC	Okunyevo Culture, c. 2100–1800 BC
Seima-Turbino Culture, c. 1800–1700 BC		Seima-Turbino Culture, c. 1800–1700 BC
Andronovo Culture, c. 1600–1400 BC	Andronovo Culture, c. 1600–1400 BC	Andronovo Culture, c. 1600–1400 BC

animal husbandry and farming. This shows that these early bronze cultures interacted closely, making possible cultural exchanges on the Eurasian Steppe and ensuring smooth communication between cultures of East and West.

During about the same period, namely 5000 to 3000 years ago, archaeology has revealed a special complex of cultures in northern China (Su & Yin 1981) known as the Northern Cultural Zone (Yang 2004) or Northern Zone (Watson 1971). The scope of this zone varies at different times, but basically it is a strip from northeast to southwest around the line where the Great Wall now runs, including the south and north of the Yanshan Mountains, the north of Shanxi Province, the southern part of Inner Mongolia, the north of Shaanxi Province and the Hetao area. What is noteworthy is that the Northern Cultural Zone falls exactly at the ecologically sensitive zone, called ecotone, of the transition from the semi-arid zone to arid zone in northern China. This zone is suitable for both agriculture and animal husbandry. In other words, the Northern Cultural Zone in archaeology coincides with the ecotone between agriculture and animal husbandry.

The Northern Cultural Zone is sandwiched in between the Bronze Age cultures on the steppes and the agricultural cultures around the middle and lower reaches of the Yellow River. Thus the zone, apart from the cultural features peculiar to it, such as large earthen pots with snake design (west) and pottery with decorative patterns of the Chinese character 'zhi' (之) (east), also possessed characteristics of Early Bronze Age cultures on the steppes, such as bronze daggers, bronze accessories with animal designs and horn-shaped eared cups, as well as features of ancient cultures around the middle and lower reaches of the Yellow River, such as painted and corded pottery.

Lin Yun notes that many typical bronze wares of the Early Bronze Age cultures on the Eurasian Steppe first arrived in the Northern Cultural Zone in China, and then spread to the middle and lower Yellow River areas. For example, bronze daggers, tube-holed axes and bow-shaped tools, artefacts typical of the Northern Cultural Zone, unearthed from Shang Dynasty sites, can be traced back to the Bronze Age

cultures on the Eurasian Steppe (Lin 1987). Hence, it can be seen that the Northern Cultural Zone played an important role as a medium for cultural communications between the Early Bronze Age cultures on the Eurasian Steppe and ancient cultures in the region of the middle and lower reaches of the Yellow River.

In summary, the most likely way that wheat spread to China is the Eurasian Steppe Route; about 7000 years ago, wheat was brought to Central Asia from West Asia and spread gradually eastwards, becoming the staple crop of early agricultural production in river valleys in Central Asia. Around 5000 years ago, wheat cultivation was adopted by the Early Bronze Age cultures in the eastern part of the Eurasian Steppe, which were characterized by a mixed production pattern of animal husbandry and farming, with wheat as one of the crop varieties. Due to frequent contact between these Early Bronze Age cultures on the steppe, wheat quickly spread eastwards, through the Sayan-Altai-Tianshan Region to the Mongolian Plateau, where it was adopted by the Northern Cultural Zone in the south of the plateau. Since the connection between the Northern Cultural Zone and ancient cultures around the middle and lower reaches of the Yellow River is longitudinal, the direction of the spread of wheat took a turn south, and reached the middle and lower Yellow River areas along multiple river valleys, such as those of the Luan River, Sanggan River/Yongding River and Yellow River on both sides of the Hetao area. It is significant to note that this route is driven by cultural factors rather than population migration.

Early cultures of the East and West communicated in a variety of ways, and the routes along which wheat travelled to China were not limited to the Eurasian Steppe Route. As mentioned early, wheat remains around 4000 years old were found at several sites near the Hexi Corridor in Gansu Province, such as the Huoshiliang site and Ganggangwa site in Jinta County, which means early wheat appeared in the Northwest Region through the Oasis Route at the same time as it did in the Northern Cultural Zone through the Steppe Route. This means that it left Central Asia, crossed Pamir to the Tarim Basin, followed the Oasis Route on the northern and southern

extremes of the Taklimakan Desert, and passed down the Hexi Corridor to the Loess Plateau. This Oasis Route is basically the same as the famous Silk Road of later history.

However, recent archaeological findings reveal that the Loess Plateau might be the destination of the eastward spread of wheat through the Oasis Route, that is, wheat entering China through the Oasis Route was likely to stop in the western part of the Loess Plateau after passing down the Hexi Corridor. For example, no evidence of early wheat dated to before 3000 years ago has been found in the Guanzhong Plain of Shaanxi Province, which is located between the Northwest Region and the middle and lower reaches of the Yellow River, although archaeological work is well developed in this area. Moreover, the early wheat remains found through archaeological excavations in Northwest Region are often accompanied by barley remains, and in some cases the barley remains are even more abundant than wheat remains in the assemblages of plant remains recovered. However, no barley remains dated before 3000 years ago have been found in the middle and lower Yellow River area. It has been proposed that the introductions of wheat and barley into central China might be distinct in both time and space (Liu *et al.* 2017). This evidence might suggest that wheat introduced into China through the Oasis Route reached only the western part of the Loess Plateau, and did not continue to spread eastward to the middle and lower Yellow River area, the core area of ancient Chinese civilization.

Conclusion

I met Martin Jones for the first time in 2004 in Beijing. That was about the time when application of the flotation technique in China had just taken off. During the last 15 years or so, flotation programmes have fundamentally transformed our understanding of early agricultures of this country, with a growing mass of archaeobotanical data, including substantial number of wheat remains recovered. According to statistics, there are over 30 archaeological sites where early wheat remains have been discovered. The application of AMS dating on such unearthed wheat grains has provided reliable data to explore the time when wheat entered into China. Following comprehensive analysis of excavated early wheat remains, the conclusion is that wheat had already been introduced into China no later than 4000 years ago.

Wheat entered China by more than one route. Analysis of the distribution of archaeological sites where early wheat remains have been found indicates that early wheat in the middle and lower reaches of the

Yellow River and in Northwest Region may have been introduced by two different routes: the Steppe Route and the Oasis Route. As for the former, from Central Asia, wheat entered the eastern Eurasia Steppe. With the close connection among Bronze Age cultures on the grassland, early wheat moved eastward and was adopted in the Northern Cultural Zone in China after being introduced into the Mongolian Plateau. Finally, wheat was spread into the middle and lower reaches of the Yellow River along river valleys. As for the Oasis Route, from Central Asia, wheat crossed the Pamir Mountains and entered the Tarim Basin. From there it passed along the oases on the northern and southern extremes of the Taklimakan Desert, finally reaching the Loess Plateau through the Hexi Corridor. Note that the Oasis Route for the spread of wheat ended in the western part of the Loess Plateau.

These spreading routes and means are only hypothetical, as archaeological materials are still insufficient to be absolutely conclusive. Early wheat remains have not yet been discovered in the Northern Cultural Zone in China or the eastern foot of the Pamir Mountains, something that requires further great efforts in archaeology, especially in archaeobotany. In the past decade, Martin Jones has played an important role in contextualizing the archaeobotanical data from East Asia in a global framework, often in an inquisitive manner of building hypotheses and asking new questions. For these years, he has been working closely with Chinese archaeobotanists and contributing significantly to the recent flourishing.

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