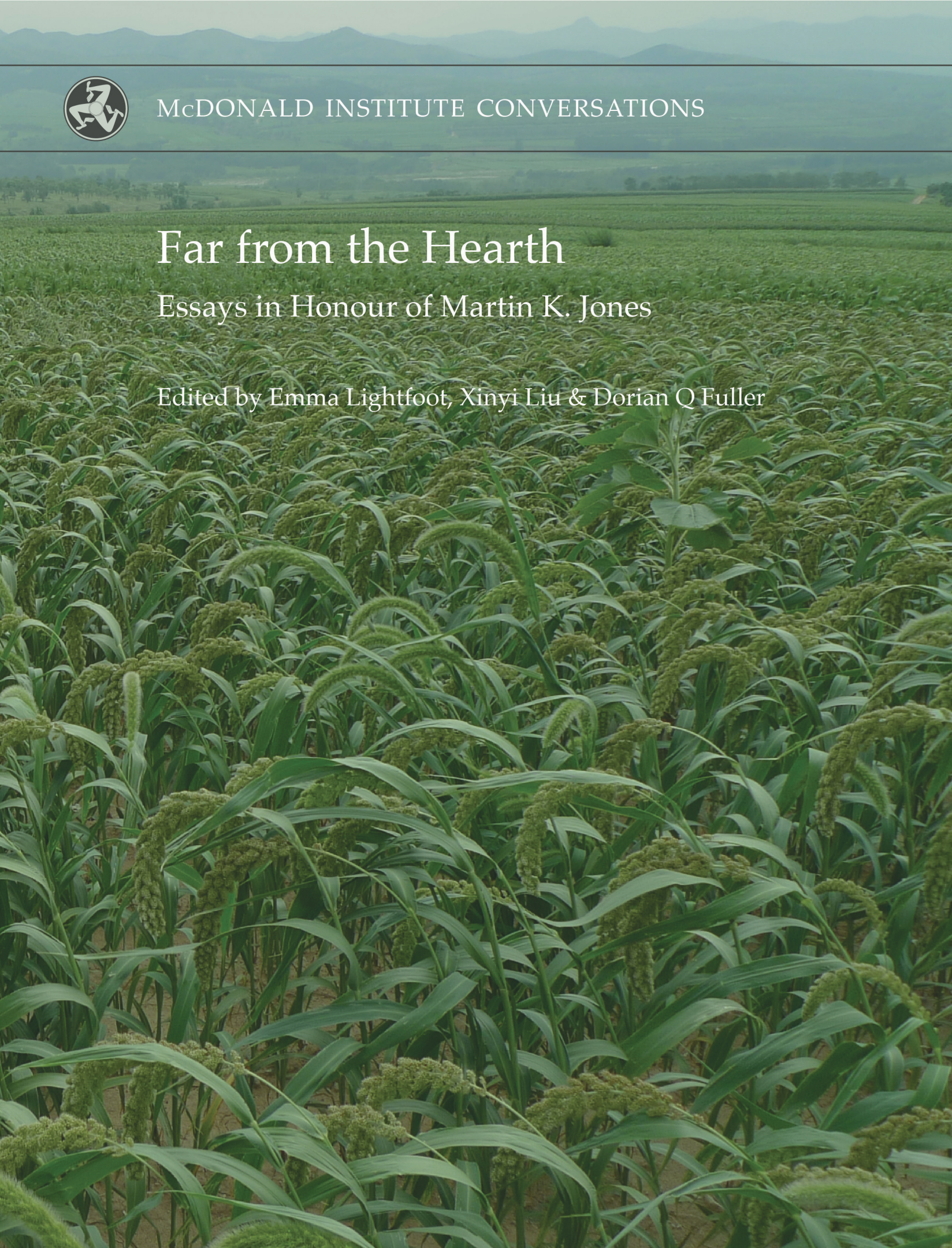

McDONALD INSTITUTE CONVERSATIONS

Far from the Hearth

Essays in Honour of Martin K. Jones

Edited by Emma Lightfoot, Xinyi Liu & Dorian Q Fuller

Far from the Hearth

(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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Figures

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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 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 'oversimplistic 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 $\delta^{15}N$ 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 $\delta^{15}N$ 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*), mungbean (*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,

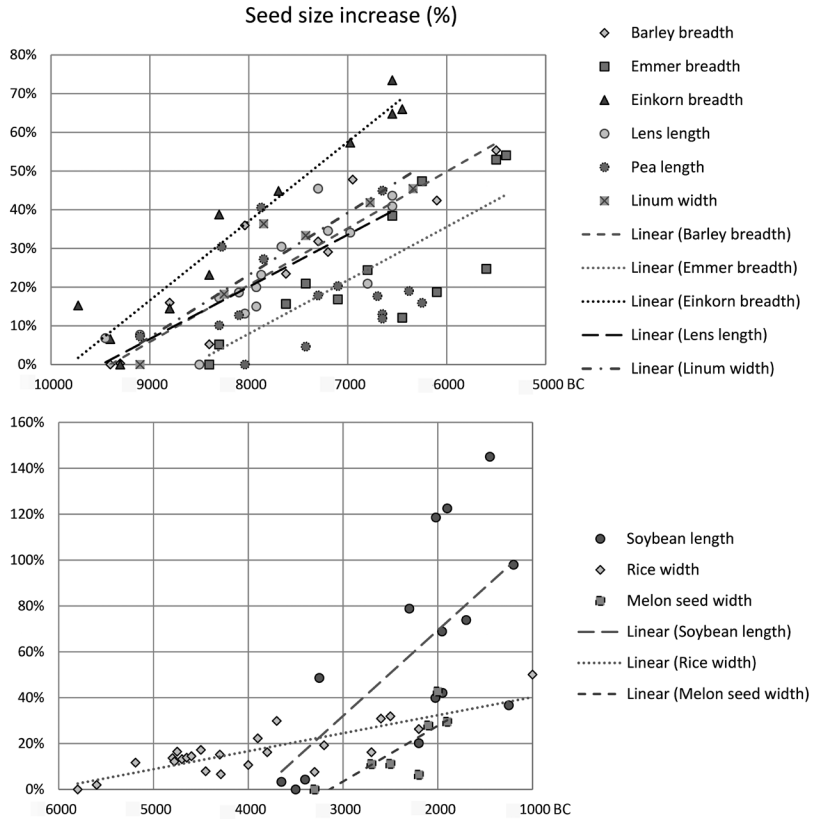

Figure 1.2. *Seed size increase over time standardized to percentage change, comparing Southwest Asia (10,000–5000 BC) and China (6000–1000 BC) for selected crops. Linear regressions indicated for some taxa to illustrate trends. (Raw data from Fuller* et al. *2014, except melon, from Fuller 2012.)*

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 Hurerya, 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/ch)**	**Asikli Höyük**	**Halula**	**Abu Hureyra 2**	**Cafer Huyok IV-I**	**Ras Shamra (Vc)**	**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
Adonis	O		X	X		X		X	X	X		X	X		X		X		X	X
Bellevalia	O	X		X	X	X	X	X	X		X	X			X			X	X	X
Bupleurum	O			X																
Centaurea	O		X		X	X	X	X	X			X	X			X			X	X
Fumaria	O		X		X	X		X	X	X		X	X							
Galium	O	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Glaucium	O	X		X				X	X			X	X						X	X
Heliotropium	O	X	X	X	X	X	X	X	X		X	X	X	X		X		X	X	X
Lolium temulentum	O														X					
Ornithogalum	O	X		X				X	X				X		X					
Papaver	O			X				X				X	X				X	X		
Phalaris	O			X				X		X		X			X				X	X
Silene/Gysposila	O/F	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
Teucrium	O					X			X		X	X	X						X	
Vaccaria	O					X			X	X		X							X	
Valerianella	O								X		X	X			X				X	X
Aegilops	F			X				X	X					X	X	X		X		X
Avena	F	X										X			X					
Coronilla	F			X				X	X			X								
Crucianella	F		X	X				X			X	X			X			X	X	
Erodium	F	X	X					X					X						X	X
Lolium cf. *remotum*	F																			
Lolium sp./*perenne/ rigidum*	F	X		X				X	X	X		X		X	X	X	X	X		X
Onobrychis	F	X	X					X	X			X	X	X				X		
Thymelaea	F					X	X	X	X	X	X				X	X			X	
Trifolieae	F	X		X	X	X	X	X	X	X	X	X	X			X	X		X	X
Trigonella astroites	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**	**Gesher**	**Gilgal**	**Iraq ed-Dubb**	**Netiv Hagdud**	**Zahrat Adh-Dhra 2**	**el-Hemmeh**	**Aswad**	**Tell Qarassa**	**Beidha**	**Wadi Jilat 7**	**Aswad-2**	**Nahal Hemar**	**Ghoraifé**	**Basta**	**Ramad**	**Aitlit 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
Adonis	O				X			X	X		X	X		X		X	X
Bellevalia	O				X			X				X	X	X		X	
Bupleurum	O					X										X	X
Centaurea	O	X			X		X		X		X	X	X			X	X
Fumaria	O	X	X		X		X		X		X	X				X	X
Galium	O	X		X	X		X	X	X		X	X		X	X	X	
Glaucium	O			X												X	
Heliotropium	O				X	X			X							X	X
Lolium temulentum	O																X
Ornithogalum	O							X	X			X		X		X	
Papaver	O																
Phalaris	O	X			X		X		X				X	X		X	X
Silene/Gysposila	O/F			X	X		X	X	X			X		X	X	X	
Teucrium	O															X	
Vaccaria	O							X	X			X		X		X	
Valerianella	O								X								
Aegilops	F	X	X	X	X	X	X			X		X				X	
Avena	F		X		X	X		X	X		X	X	X	X	X	X	X
Coronilla	F															X	
Crucianella	F											X				X	
Erodium	F	X	X		X		X										
Lolium cf. *remotum*	F															X	
Lolium sp./*perenne*/ *rigidum*	F							X	X	X		X		X		X	X
Onobrychis	F				X	X		X	X				X			X	
Thymelaea	F					X		X	X			X		X			X
Trifolieae	F	X					X	X	X		X	X	X	X	X	X	
Trigonella astroites	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

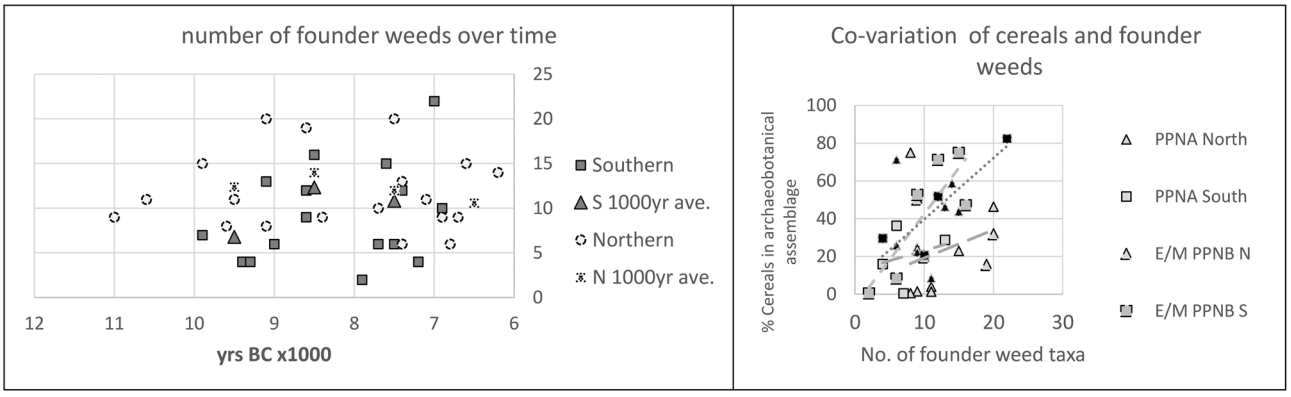

Figure 1.3. *(Left) Chart showing the number of founder weed taxa over time (from the select list in Table 1.1), plotted by site against median age; averages for northern and southern regions calculated for each millennium; (right) Chart showing correlation between number of founder weed taxa and total 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-domesticate *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 rogueing 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.

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