

# **From intermediate economies to agriculture: trends in wild food use, domestication and cultivation among early villages in southwest Asia**

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## **Abstract**

This paper addresses the range of subsistence strategies in the protracted transition to agriculture in southwest Asia. Discussed and defined here are the intermediate economies that can be characterized by a mixed-subsistence economy of wild plant exploitation, fruit cultivation and crop agriculture. Archaeobotanical data from sites located across the Fertile Crescent and dated 12000 to 5000 cal BC are compared alongside a backdrop of data for domestication (i.e. non-shattering rachises and seed size increase) and crop diversity with regionally distinct profiles of crop agriculture and wild food exploitation. This research highlights sub-regional variations across southwest Asia in the timing of subsistence change in the transition from hunting and gathering to diversified agricultural systems.

## **Keywords**

Archaeobotany, Neolithic, Foraging, Near East, Domestication

## **Résumé**

Cet article aborde la diversité des stratégies de subsistance au cours du long processus de transition vers l'agriculture en Asie du Sud-Ouest. Il s'agira de discuter et de définir les économies intermédiaires qui peuvent être caractérisées par une économie de subsistance mixte associant l'exploitation de plantes sauvages, la culture d'espèces fruitières et l'agriculture. Les données archéobotaniques de sites localisés à travers dans le Croissant Fertile et datés entre 12000 et 5000 cal BC sont comparées parallèlement à avec des données relatives à la domestication (c'est-à-dire des rachis indéhiscents et l'augmentation de la taille des graines) et à la diversité des plantes cultivées, avec l'établissement de profils régionaux distincts en termes d'agriculture et d'exploitation de plantes alimentaires sauvages. Cette recherche met en lumière des variations subrégionales à travers l'Asie du Sud-Ouest dans la période du passage d'une économie de chasse et de cueillette à des systèmes agricoles diversifiés.

**Mots-clés :** Archéobotanique, Néolithique, Proche-Orient, Domestication

## **Introduction**

The impact of the “Neolithic Revolution” on humanity and human diet cannot be understated. In the last 12,000 years we have seen a profound reduction in the diversity of species, both plant and animal, from which we derive our food resources. For most of the world, we have slowly transitioned out of a diet with great range of wild plant resources to just a handful of domestic cereal and legume or “pulse” crops constituting the majority of caloric intake. Although the greatest reduction in this diversity has occurred over the last 100 years, the change has its roots at the onset of the transition to agriculture (see Harris 2012). As recent

research has demonstrated crop domestication was a protracted process, taking millennia as opposed to decades (e.g. Tanno and Willcox 2012; Fuller *et al.* 2012; 2014). As such, the importance of the recognition of a phase of pre-domestication cultivation (Harris 1989; Harris and Fuller 2014) is it explains the evolutionary processes that link cultural practices (cultivation) to genetic changes (domestication) that these cultural practices brought about. This recognition can lead to questions of how changing practices or the changing domestication status of a crop relate to wider cultural transitions or environmental changes. The tendency for the start of cultivation or the presence of any domesticated-type morphologies to be conflated with the origins of agriculture is best avoided (see, e.g., Smith 2015; Zeder 2015). Following these lines of thought we explore in this paper how we might recognize quantitatively increased agricultural dependence as opposed to just cultivation of semi-wild or domesticated plants. That agriculture is a matter of scale was explored at some length by Smith (2001) who defined “low-level food production” as any system involving cultivation that provided less than ~50% (30-50%) of edible calories consumed, although reconstructing past dietary composition is not at all straightforward (Miller 2011). Nevertheless, it is imperative to ask whether the advent of cultivation massively increased economic dependence on grain crops and changed the diet of early cultivators in general, or whether such changes only occurred at the end of the domestication process. Harris (2012), like Smith (2001), highlighted the need to recognize the existence of intermediate economies that fall between foraging focused subsistence and later agricultural reliance. Here we explore this grade of intermediate economies, utilizing archaeobotanical evidence around the Fertile Crescent, to both assess the potential regional variation in wild food use and the extent to which this varies with the uptake of cultivars and ultimate coalescence of a full range of domesticates into an agriculturally-focused subsistence in the Near East.

Large regional datasets have highlighted several aspects of the transition to agriculture that were protracted. Reviews of the presence and absence of crop species and their wild progenitors on a site by site basis have highlighted how Pre-Pottery Neolithic A [PPNA] (i.e. before 8500 cal BC) sites generally have fewer founder crop species per site than sites of the Middle and Later Pre-Pottery Neolithic B [PPNB] (Fuller *et al.* 2011). Taken together with the sporadic appearance of various cultigens across the early Fertile Crescent this argues for a mosaic of early cultivation systems based on differing but partly overlapping sets of crop species (Willcox 2005; Fuller *et al.* 2011; Asouti and Fuller 2013). In addition, alongside this early cropping mosaic, is evidence for substantial quantities of various potential wild foods, including small- and large-seeded grasses, Polygonaceae and Cyperaceae nutlets, small legume seeds, fruits, and nuts (Willcox *et al.* 2009; Asouti and Fuller 2012; 2013; Riehl *et al.* 2013; Arranz-Otaegui *et al.* 2016a; 2017). While there was an overall trend throughout the region for cereal remains to form a greater proportion of all charred plant finds, there are many sites for which cereals accounted for a small minority of the archaeobotanical evidence, implying the persistence of wild food utilization as an important part of subsistence strategies during the transition to full agriculture (Asouti and Fuller 2012; Maeda *et al.* 2016). This same era saw the gradual evolution of non-shattering ears in cereals and increasing size of cereal grains and pulse seeds (Fuller *et al.* 2012; 2014), and in the western Levantine regions a greater investment in the production of sickles, tools that presumably became entwined with the increasing cultural importance of cultivation practices.

In the paper we will explore the inter-relations between morphological domestication, the diversity within the crop package and the degree of reliance on wild foods versus crops. While some have argued that all the founder crops should be domesticated at more or less the same time, in the small region, and mark the advent of agriculture as opposed to wild food economies (e.g. Abbo *et al.* 2012), other have pointed to both more dispersed processes and slower processes (e.g. Fuller *et al.* 2012; Riehl *et al.* 2013; Maeda *et al.* 2016; Arranz-Otaegui *et*

al. 2016b; 2017). We summarize empirical evidence on particular sites and across a broader regions and we graph this evidence against time, including for changes in crop morphology, changes in crop diversity at particular sites, and changed in the range and importance of wild foods. We chart these data from the later Epipalaeolithic through to the Ceramic Neolithic. While there may be some precursor practices at the site of Ohalo II, ca. 23,000 BP, including cultivation, early domestication processes and wild food exploitation (Snir et al 2015) these are not connected yet by patterns of continuity with the later sites discussed in the present paper. Indeed, the evidence for fully wild cereals in assemblages at the end of the Pleistocene, implies that Ohalo II may have been local dead-end trajectory unconnected to Neolithic domesticates (Allaby et al. 2017).

## Materials and Methods

Our methods involve the compilation and exploration of a large body of published and unpublished (authors' data) archaeobotanical and radiocarbon data from two databases, OWCAD (Old World Crops Archaeobotanical Database, a work in progress on crop presence/absence across the entire Old World (for excerpts and discussion, see Stevens *et al.* 2016; Stevens and Fuller 2017) and a quantitative database expanded from that previously compiled by Lucas (2014, with references, and building of that of Colledge *et al.* 2004). This dataset is available freely online (Lucas and Fuller 2018). These data are explored for chronological trends by plotting plant data against time based on the median calibrated age for sites and phases. This research builds on earlier diachronic analyses (e.g. Fuller *et al.* 2012; 2014; Maeda *et al.* 2016; Allaby *et al.* 2017). The primary archaeobotanical data sources for most sites were reviewed in Asouti and Fuller (2013, supplement), with revised chronology and cereal frequencies in Maeda *et al.* (2016). Additional sites and data include Pınarbaşı (Fairbairn *et al.* 2014), Karain and Öküzini (Martinoli 2004), Dhra' (Colledge and Conolly 2018), Tell Qarassa North (Arranz-Otaegui *et al.* 2016b), Tepe Marani (authors' data; see Wengrow *et al.* 2016) and Jarmo (authors' data). From the primary data sources therein seed metrics and data on percentages of domesticated and wild rachises are compiled. Metrical data is from Fuller *et al.* (2014), while non-shattering (domesticated) rachis data are those published in Allaby *et al.* (2017). Median ages for sites and phases follow Maeda *et al.* (2016) based on extensive recalibration of summed radiometric data from 100s of sites and phases. In terms of considering crop presence or percentage we have considered all of the potential founder crop species regardless of whether or not the remains themselves might be, or were recorded by the archaeobotanists to be, morphologically wild, domesticated or of intermediate status. In terms of the crop percentages we have calculated the total number of whole specimens, seeds and chaff, of cereals (*Hordeum spontaneum*, *H. vulgare*, *Triticum*, and *Secale*; with the exclusion of indeterminate cereals), pulse taxa (*Pisum*, *Lens*, *Lathyrus*, *Cicer*, *Vicia ervilia* or *V. faba*) and flax (*Linum* spp. and *Linum usitatissimum*) combined. The potential wild foods are divided into two categories, nuts/fruits and nutlets. The nutlets comprise the total number of specimens identified to the following genera: *Polygonum*, *Rumex*, *Scirpus* and *Bolboschoenus*. The nuts and fruits comprise of specimens identified as nuts (i.e. *Amygdalus*, *Pinus*, *Pistacia*, and *Quercus*) and fruits (i.e. *Olea*, *Ficus*, *Prunus*, *Punica*, *Pyrus/Malus*, *Capparis*, *Ziziphus*, *Celtis*, and *Vitis*). Further details on classifications into these categories, as well as how the percentages were calculated, are given in open access dataset of Lucas and Fuller (2018).

Our approach uses the evidence for the domestication of crops, as recorded for morphological traits, to define a timeline against which to assess changes in reliance on cultivation versus wild foods. The data on non-shattering rachises, supported by those for seed size change, allow us to define three phases; *incipient pre-domestication cultivation* [IPDC] (less than ~20% non-shattering rachises), *entrenched pre-domestication cultivation* [EPDC] (20-80% non-shattering rachises, 10-30% increase in average seed size), and *domesticated*

*cultivation* [DC] (greater than 80% non-shattering rachises and >20% increase in average crop seed size). These phases are not expected to have clear chronologically demarcated boundaries, being rather gradually changing trends along a continuum of increasing percentages of non-shattering rachises and increasing seed size. Nevertheless, they do tend to correlate closely to major transitions in cultural chronology, namely the IPDC to EPDE correlates broadly to the transition from the Pre-Pottery Neolithic A (PPNA) to the Pre-Pottery Neolithic B (PPNB), and from Middle to Late PPNB to the EPDC to DC. We have then gradated pre-domestication economies in relation to their reliance on cultivated products, with 20-80% of crops in assemblages representing intermediate economies, as later assemblages with fully domesticated cereals appear to usually have at least 80% cereals in their assemblages, as was evident in the data of Maeda *et al.* (2016). Thus we define archaeobotanical assemblages with at least 80% crop remains as representing agricultural economies, whereas those with less than 20% crop remains can be regarded as foraging dominant economies. We recognize that these cut-offs are arbitrary, but they are exploratory and were chosen as they appear to correlate with established archaeological phasing, as indicated by the trends in morphological domestication traits.

## Results

Data is available from a large part of the Fertile Crescent and adjacent areas, from which a number of sub-regions have been defined (fig. 1). While it is now clear that the evolution of morphological domestication traits was protracted and taking place between ca. 9500 BC and 6000 BC (fig. 2), there is general congruence across regions for these trends. The defining trait of domesticated cereals is the non-shattering rachis (see Zohary *et al.* 2012; Abbo *et al.* 2012). The percentage of non-shattering to shattering rachises in charred assemblages goes from predominantly near ~0% prior to 9000 BC to between 20% and 80% non-shattering for assemblages dated between 9000 and 7000 BC. The assemblages of >80% and up to ~100% non-shattering occur only after 7500 BC for barley and 7000 BC for wheat (fig. 2C). There are some outliers, likely due to imprecision in the data, e.g. Tell Qaramel has higher than expected percentages of non-shattering rachises given the site's date, but broad time ranges in radiocarbon calibrations (see Asouti and Fuller 2013: fig. 7). Other outliers are probably due to local variance in practices, such as a continued focus on gathering from wild stands, especially of barley in the southeastern Levant, which appears to have continued until the 7<sup>th</sup> millennium BC (Colledge 2001; Fuller 2007). Nevertheless, the overall trend is clear. Further, it would be incorrect to regard this as a single trend, i.e. change at a uniform rate, as might be inferred by a straight line regression or logistic curve, since to do so would imply that selection pressures were uniform over a period of millennia (Fuller *et al.* 2010; Allaby *et al.* 2017) despite changes in cultural practices, cultivation technologies, and regional environment. Instead it would appear that selection pressures driving the evolution of non-shattering ears were variable, and increased markedly later in the process between 8000 and 7500 BC in barley and einkorn wheat, and between 7500 and 6500 BC for emmer wheat, at the end of which this domestication trait was essentially fixed (Allaby *et al.* 2017). Grain size increases consistently over the same period, not just for cereals but also pulses, although this generally appears to have been more protracted than seen for non-shattering (Fuller *et al.* 2012; 2014; 2017), starting already before ca. 9000 BC and finishing around 6000 BC (fig. 2B)

These morphological data, i.e. non-shattering rachis and grain-size increase, provide a baseline against which to consider changes in the subsistence system. In relation to this we can see that earlier sites, either in the Foraging Stage or IPDC tend to have only a few of the founder crops of the Near East, whereas the larger package of founder crops came together during the EPDC (fig. 2A). In other words, there was a coalescence of crops across the region resulting in increased crop diversity on a site by site basis towards the end of the domestication process. It

is worth noting that the increase in crop diversity is most marked in the Northern Fertile Crescent region, but is still evident in the Southern and Northern Levant. Once domestication cultivation [DC] was established in the Late PPNB, there was a tendency for crop diversity when viewed on an individual site basis to reduce somewhat. This suggests that the transition to agriculture involved a certain amount of constriction in crop plant diversity in comparison to the more exploratory cultivation systems during the domestication process.

When we consider these same site assemblages in terms of the reliance on the founder crops, we also find that there was quite a range of reliance on crops during the exploratory phases of pre-domestication cultivation (fig. 3). Intermediate economies in which crops account for between 20% and 80% of archaeobotanical assemblages are frequent during EPDC and describe around half the sites during IPDC. Crop dominated assemblages, those which we might consider truly agricultural (>80% crop remains), are completely absent before 8500 BC in the IPDC and are scarce during EPDC, becoming frequent only after 7000 BC, around the end of pre-domestication cultivation. Even after 7000 BC intermediate economies were common. Further, at an assemblage level the transition to an agricultural economy, one that is predominantly focused on the production of crops, was very gradual, even more gradual than the morphological domestication process. Thus, neither the presence of domesticated morphotypes nor their dominance necessarily equates with an agricultural economy. Instead we would suggest that agricultural economies became established in the Late Pre-Pottery Neolithic and the Pottery Neolithic, especially in the Levant and Northern Fertile Crescent. At the same time intermediate economies, with significant wild food components persisted throughout the Pre-Pottery Neolithic and only really started to become rare in Late Pre-Pottery Neolithic and Pottery Neolithic.

In order to further explore the nature of these intermediate economies and the role and range of wild foods within them, we classified sites by region, period and economic grade (table 1). From those classed as forager or intermediate economies in each period, we have then considered which non-crop taxa might have played key roles as wild foods in each of these sites (fig. 4). Those taxa that recur and which have dry, starchy seeds that are readily storable include several nuts (*Pistacia*, *Amygdalus*, *Quercus*) and small nutlets (Cyperaceae, Polygonaceae), as well as various wild grasses. Counted with nuts in the present analyses are a number of tree fruits, such as, *Prunus* spp. (*sensu stricto*) and *Ficus*. These could also have been dried and stored and would have typically had a similar seasonality of availability as the nuts in summer to early autumn.

The use of nuts by hunter-gatherers and early cultivators is well-known, and the utility of these taxa has been discussed often in the past (e.g. Hole *et al.* 1969; van Zeist and Bakker-Heeres 1985; Hillman *et al.* 1989; Fairbairn *et al.* 2014; Willcox *et al.* 2009; Arranz-Otaegui *et al.* 2016a; 2017). *Pistacia* spp. are the most numerous finds in this category at many sites, and as noted by Willcox *et al.* (2009) their availability would have been quite resilient in the face of climate change as established trees can readily survive with as little of 200mm of rainfall per annum. *Pistacia* nuts are high in energy in the form of lipids (ca. 40-60% by weight), and they can be stored after roasting, with minimal processing requirements (Martinoli 2004). Almonds (*Amygdalus* spp.), at least in their shrubbier forms, can also persist on very low rainfall, and together with *Pistacia* characterize a dry open steppe with scattered trees around the drier parts of the Fertile Crescent (Moore *et al.* 2000: 60). Although wild almonds normally require processing to detoxify them, they are easy to dry for storage and provide substantial levels of lipids (~48%) and proteins (~20%) (Martinoli 2004). Acorns (*Quercus* spp.) and hackberries (*Celtis* sp.), as with most of the encountered fruits, require generally wetter forest or parkland habitats. While hackberry stones may be processed for their oily seeds these, along with most fruits, would have provided calories from sugars as well as vitamins. Acorns, by contrast, are consumed for their high starchy carbohydrate content (~80%). Acorns are

potentially under represented due to the combined factors of thin shells that are poorly preserved in recognizable form in charred assemblages, and that they are often processed in bulk near the tree stands, without transporting the shells back to habitation sites (Hillman 2000: 366-368). Hillman (2000) also suggested that the absence of *Amygdalus* endocarp remains at Abu Hureyra could have been due to the same strategy of reducing transport costs by deshelling away from sites. Nevertheless, the presence of these taxa on some sites in the Levant testifies to their use. These nuts would have become available for collection in late summer and autumn (Hillman *et al.* 1989; Martinoli 2004). Epipalaeolithic cave sites in Mediterranean Turkey, including Öküzini and Karain, testify to a largely fruit and nut plant-based subsistence in the terminal post-Glacial Pleistocene, which is also evident at Pınarbaşı (Fairbairn *et al.* 2014), equivalent in chronology if not culture to the PPNA. At PPNA sites with inferred IPDC in the southern Levant, heavy use of *Ficus* and *Pistacia* with some almond is attested (e.g. Iraq ed-Dubb, Dhra', el-Hemmeh). In the northern Levant and the north, figs were less common and almonds were more prominent (e.g. Dederiyeh, Jerf el Ahmar, Tell Qaramel, Hassankeyf Höyük, Göbekli Tepe, Çayönü). Some variants include the *Celtis*- and *Pistacia*-dominated Ain-el Kherkh in the northern Levant, and the fruit-rich but nut-poor assemblage at Sha'ar Hagolan.

The knotweed family (Polygonaceae) includes taxa that produce abundant seeds annually, and many taxa favour damp or alluvial habitats, such as the Euphrates knotgrass (*Polygonum corrigioloides*) found in quantity at Abu Hureyra (Hillman 2000) and Tell Mureybet (van Zeist and Bakker-Heeres 1984; Miller 2011). The domesticated buckwheats (*Fagopyrum* spp.) (Weisskopf and Fuller 2014; Hunt *et al.* 2017) and the ancient crop of North America, *Polygonum erectum* (e.g. Asch and Asch 1985; Mueller 2017a; 2017b), testify to the potential utility of starchy pseudo-cereals from this family. Polygonaceae nutlets have previously been suggested to have been important wild food resources in the Northern Levant by Hillman (2000: 356-358; Hillman *et al.* 1989; 2001) and Willcox *et al.* (2009), and in the northern Fertile Crescent at sites such as Demirköy and Hallan Çemi (Savard *et al.* 2006). These would have been readily gathered in quantity from the floodplains, from summer through autumn (Hillman *et al.* 1989), and thus, we would expect these in quantity at sites situated near floodplains, as was apparently the case at several early Euphrates sites from the largely wild plant economies of Mureybet and Abu Hureyra (Hillman 2000) to the Late Neolithic intermediate economy of Sabi Abyad (van Zeist and de Roller 2000).

Sedge nutlets (Cyperaceae) often are dominated by *Scirpus* sp. (*sensu lato*), but probably most often *Bolboschoenus glaucus* (Wollstonecroft *et al.* 2011). Phytolith evidence from some Epipalaeolithic sites, in the Southern Levant for example, indicates significant exploitation of coarse wetland environments, especially sedges, by some communities, such as those represented by Kharaneh IV and the earlier Ohalo II (Ramsey and Rosen 2016). While sedges may have been exploited as raw material for building or basketry, for example, the diagnostic cone phytolith is a product of the nutlets, and it seems likely that they were an established food resource for many groups. These have starchy kernals that could be gathered in the summer and autumn and readily processed by grinding (Hillman 2000: 354-356; Hillman *et al.* 1989), as well as the starchy rhizome tubers that could be gathered in the autumn or spring (Hillman *et al.* 1989; 2001; Atalay and Hastorf 2006; Wollstonecroft *et al.* 2008; Wollstonecroft 2009). Recently it has been established that pulverized *Bolboschoenus* tubers were sometimes mixed with cereal flowers in early breads in the Neolithic (Gonzalez Carretero *et al.* 2017) and Epipalaeolithic (Arranz-Otaegui *et al.* 2018). Tubers and nutlets would have provided carbohydrate sources in different seasons.

The presence of these sedge nutlets (*Scirpus/Bolboschoenus*) in quantity on sites has sometimes been attributed to the cultivation of cereals in wetland areas (e.g. Hole *et al.* 1969; cf. Charles 2011), but available arable weed flora as we currently understand it (e.g. Willcox 2012; Hartmann *et al.* 2015; Fuller and Stevens 2017) argues against that. Instead the

substantial quantities of these nutlets on early sites, with wild dominated, or intermediate economies, suggests deliberate gathering. At some later, more agricultural sites, such as Çatalhöyük, the high ubiquity of these nutlets is attributed to their consumption by livestock and subsequent use of dung fuel (Filipovic 2012; Bogaard *et al.* 2013), but this seems less likely to have been the case prior to livestock domestication (Fuller *et al.* 2014; but see Miller 2011). Thus we suggest that nutlets were human food for some communities, such as Ganj Dareh (van Zeist *et al.* 1984) and Chogha Golan (Riehl *et al.* 2015) with wild-dominated economies, and in the foraging economies in central Anatolia at Pınarbaşı (Fairbairn *et al.* 2014), in the northern Fertile Crescent at Körtik Tepe (Riehl *et al.* 2012), Demirköy and Hallan Çemi (Savard *et al.* 2006). From Late Pre-Pottery Neolithic times it was more often a naturally occurring fodder, e.g. at Çatalhöyük, and perhaps too in the crop-dominated economy of Tell Bouqras. In other words sedge nutlets shifted from being collected as human food to being consumed by grazing animals. It is worth noting that in later periods, such as Bronze Age sites on the Upper Euphrates, these nutlets are extremely scarce (e.g. van Zeist and Bakker-Heeres 1985) suggesting that their place as food or fodder resources was largely restricted to the Neolithic, with more use as human food in the earlier, pre-agricultural foraging and intermediate economies. Ramsey and Rosen (2016) argue that the degree of use was partly a product of the nature of wetlands near a site with more level and extensive marshes being more productive for resources such as this, which was likely also true of Polygonaceae nutlets.

When looking across the wild plants that occur on intermediate sites (fig. 4B), some regional and sub-regional variations can be suggested. In the northern Levant, parts of the northern and eastern Fertile Crescent where sites were located near alluvial wetland, the reliability of starchy nutlets, of Cyperaceae and/or Polygonaceae can be inferred. In contrast small-seeded grasses, appear to have been more important in many areas of the Southern Levant, where in many cases small legumes were also gathered (see Asouti and Fuller 2012; 2013). Similarly small-grained grasses and small legumes appear to have been important in some parts of the Northern and Eastern Fertile Crescent as recognized in the work of Savard *et al.* (2006) and Riehl *et al.* (2015), but some sites, as noted above, went heavily for almonds, *Pistacia* and some fruits. Figs are a more prominent part of the wild food record in the Southern Levant, alongside more *Pistacia* than almonds. What is striking is that sites in close proximity to each other are more likely to have stayed true to the same range of wild foods overtime (see fig 4). Thus, nutlet gatherers in the Upper Euphrates (Abu Hureyra, Mureybet, Sabi Abyad) generally had fewer fruits or nuts, whereas sites rich in fruits and nuts tended towards fewer small nutlets. This may indicate that local micro-environments provided more open or wooded resource zones, but equally local cultural traditions of plant use patterns may play a role and local environments were probably significant in determining patterns of plant use, perhaps more than broader arbitrary geographical zones.

## **Discussion and conclusion**

The growing database of archaeobotanical evidence from across the greater Fertile Crescent highlights that the origins of agriculture was not a singular event but rather a mosaic of protracted processes, including several slow evolutionary transformations of crops and many long-lasting traditions of mixed-subsistence or intermediate economies where various wild foods, but often fruits and nuts, or nutlets, or small-grained grasses, played as great or greater a role in subsistence than cereals. This leads to two general conclusions, as to why cereal cultivation began in the first place and as to how and why an agricultural economy emerged. First, it indicates that the early cultivation of cereals was unlikely to be driven primarily by a quest for calories, i.e. as a solution for needing more food, the hypothesis that is built into many explanations for agricultural origins, such as those that highlight climatic change (e.g. Moore and Hillman 1992; Hillman *et al.* 2001; Bar-Yosef 2011; cf Miller 2011). Recent

syntheses of paleoenvironmental change and demography have failed to find a strong correlation between climatic events and cultural change or rapid population growth and the onset of the PPNA (Roberts *et al.* 2018; Shennan 2018). Actually the pollen and wood charcoal evidence both point to an expansion of woodlands that included *Pistacia*, oaks, and other fruits and nuts towards the end of the Pleistocene and in the Early Holocene (Roberts *et al.* 2018), and thus the potential gathering of these resources would have been improved in much of the Fertile Crescent in the lead up to IPDC. Instead, the slow rise of cultivation and the persistence of foraging gives additional weight to the idea that cereals and other crops were desirable because of what they allowed people to do in terms of cooking and consumption, i.e. that crop production allowed for controlled production of favored or chosen resources that could have facilitated social networking and trade (e.g. Sherratt 2007; Asouti and Fuller 2013). These trends suggest a role for inherent internal drivers, as might be predicted from entanglement theory (e.g. Hodder 2012; 2016; Fuller *et al.* 2016), versus external stimuli such as climate shifts. It may be that controlled availability of stored cereal and pulses, and special foods made from these was a pull factor that encouraged their cultivation. This is akin to the hypothesis of “scheduled availability” as driver for cultivation (Marshall and Hildebrand 2002). One of the reasons these foods may have been required could have been to supply feasts, and feasting for funerals and for commensal politics that likely played a part of the social world (Hayden 2014a; 2014b). Nevertheless there is no apparent correlation between sites with more agricultural and crop-focused assemblages and those with more elaborate structures, including large scale storage, that might relate to shared religious events, feasts, or otherwise aggrandizing behaviours. A key aspect of feasting not represented in the archaeobotanical evidence, of course, was animal meat (Twiss 2008; Meier *et al.* 2017). Understanding how particular plant use economies fit together with meat procurement and consumption clearly needs further research.

In the specific context of the Near East one of the desirable characteristics of crops, apart from them being controlled through production and storage, was the utility of the Near Eastern cereals for making bread. It has been noted before that the gluten content in wheat and barley is unique when compared to grasses chosen for domestication in other world regions and this would have allowed their flour to make foods not readily made from other wild staples (Lyons and D’Andrea 2003; Fuller and Rowlands 2011). In other words, a growing cultural interest in bread may have been a driving factor in domestication and in the particular choice of wheat and barley among early cultivars (Fuller and Rowlands 2011; Maeda *et al.* 2016; Arranz-Otaegui *et al.* 2018). It is now clear that well-established bread making practices dominated cereal consumption by the earliest phases at Çatalhöyük, ca. 7000 BC (Gonzalez Carretero *et al.* 2017). The beginnings of bread-making can now be traced to before domestication, based on charred bread remains at the Epipalaeolithic site of Shubayya 1, Jordan, ca. 12600-9600 BC (Arranz-Otaegui *et al.* 2018). Bread would have been more labour intensive to make than simple gruels, but the prominence of querns and the early development of ovens, in advance of cooking pots, highlights the cultural investment in this food stuff alongside the domestication process, if not before (Fuller and Rowlands 2011; Fuller and Gonzalez Carretero *in press*). The investment in ovens, like the use of heavy grinding stones even earlier, is part of a web of entanglements between cereals, cultivation and sedentism (Hodder 2012: 199). From this point of view the pull towards cereal cultivation was not so much a solution to getting more calories but a new economic activity that required calories, the investment of labour in fields, stores, processing, and ovens.

The second general conclusion is that the transition to an agricultural economy dominated by the crops was protracted (>3000 years), and that intermediate systems that combined extensive foraging and cultivation persisted for a long time. While it is the case that morphologically domesticated cereals evolved before crop-focused economies became



widespread, it is not the case that domesticated crops—the end of the morphological evolution trajectory—correlate with the advent of agricultural economies. For many sites intermediate economies continued through the Late PPNB and into the Ceramic Neolithic (see Table 1). One of the reasons for this may be that given the demographic parameters of the Neolithic Fertile Crescent there simply was not significant population pressure, indeed population growth appears to be such that there was no serious competition between wild lands and cultivated lands (Shennan 2018). In addition the seasonality of cereals (sown in the autumn and harvested in late spring/early summer) did not compete for labour with seasonality of most of the wild gathered resources, which as we have seen were available in the summer through autumn after cereal harvests. This presents a potential contrast with the transition in other parts of the world, such as the Yangtze basin in China, where wild nuts—including acorns and starchy aquatic seeds (*Euryale*, *Trapa*) — were widely used during the era of rice domestication (Fuller and Qin 2010), but where the seasonality of rice seed set and the availability of these nuts overlapped in time, at the end of summer. What is more the aquatic nuts and rice had more potential to compete for space as well. Current data suggest that transition to agricultural economies was extremely rapid (<500 years) once rice was domesticated (Fuller and Qin 2010; Stevens and Fuller 2017), an apparent contrast to the Near East. Thus, the seasonal competition, for labour and attention, between different resources needs to be seen as a key component in how human societies became entangled and entrapped in certain forms of economic practice (Fuller *et al.* 2016). Increasing investment in cultivation, and connected technologies such as sickles (see Maeda *et al.* 2016) or ovens (see Fuller and Gonzalez Carretero *in press*), or storage (Bogaard *et al.* 2009), created increasing entanglements between the stuff of agriculture and society, while the domestication processes themselves made harvest yields higher but also more dependent on continued labour investment.

The protracted nature of the transition to agriculture is now clear from empirical evidence. There was no single “Neolithic Revolution” and archaeobotanical analysis is needed to unravel the polythetic features of economic change in the Neolithic. The coalescence of the elements for true agricultural economies took place in the Middle PPNB as morphological domestication neared fixation and crop packages became more diverse and presumably increasingly integrated with livestock (Miller 2011). Most sites in the Late PPNB can be classed as truly agricultural and it is during this period that potential staples among wild foods markedly decline in the archaeobotanical record at most, but not all, sites. The later Neolithic sees a tendency to slip towards more reduced crop packages alongside an overall less diverse diet as wild foods became scarce.

A less understood component of the cultural inheritance, was continuance of traditions of gathering and wild food storage. Variability across sites, regions and periods in how economies changed undermines any expectation of a single cause, such as a climate change event, that can be regarded as pushing people into cultivation, domestication or agriculture. Instead the processes by which people constructed new ecological niches of cultivation and sedentary settlements set in train evolution of new species and ecologies, domesticated species, weeds, commensal animals (Smith 2015; Fuller and Stevens 2017). This brought with it new chains of technological developments—technologies and techniques for agriculture—and while the constructed arable niche became ecological inheritance, the chains of entanglements (*sensu* Hodder 2012) were part of cultural inheritance. Archaeobotany has a key role to play in unravelling both the ecological and cultural inheritances of early cultivation.

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### References cited

ABBO S., LEV-YADUN S. and GOPHER A.

2012 Plant domestication and crop evolution in the Near East: on events and processes. *Critical Reviews in Plant Sciences* 31,3: 241-257.

ALLABY R.G., STEVENS C., LUCAS L., MAEDA O. and FULLER D.Q.

2017 Geographic mosaics and changing rates of cereal domestication. *Phil. Trans. R. Soc. B* 372, 1735: 20160429.

ARRANZ-OTAEGUI A., COLLEDGE S. IBÁÑEZ J.J. and ZAPATA L.

2016a Crop husbandry activities and wild plant gathering, use and consumption at the EPPNB Tell Qarassa North (south Syria). *Vegetation history and archaeobotany* 25,6: 629-645.

ARRANZ-OTAEGUI A., COLLEDGE, S., ZAPATA, L., TEIRA-MAYOLINI, L.C. and IBÁÑEZ, J.J.

2016b Regional diversity on the timing for the initial appearance of cereal cultivation and domestication in southwest Asia. *Proceedings of the National Academy of Sciences*, 113, 49: 14001-14006.

ARRANZ-OTAEGUI, A., LÓPEZ-SÁEZ, J.A., ARAUS, J.L., PORTILLO, M., BALBO, A., IRIARTE, E., GOURICHON, L., BRAEMER, F., ZAPATA, L. and IBÁÑEZ, J.J.

2017 Landscape transformations at the dawn of agriculture in southern Syria (10.7–9.9 ka cal. BP): Plant-specific responses to the impact of human activities and climate change. *Quaternary Science Reviews* 15: 145-163.

ARRANZ-OTAEGUI A., GONZALEZ CARRETERO, L., RAMSEY, M., FULLER, D. Q. and RICHTER, T.

2018 Archaeobotanical evidence reveals the origins of bread 14,400 years ago in northeastern Jordan. *Proceedings of the National Academy of Sciences*  
doi:10.1073/pnas.1801071115

ASCH, D.L. and ASCH, N.B.

1985 Prehistoric Plant Cultivation in West-Central Illinois in Prehistoric Food Production in North America. *Anthropological Papers* 75: 149-203.

ASOUTI, E. and FULLER, D.Q.

2012 From foraging to farming in the southern Levant: The development of Epipalaeolithic and Pre-Pottery Neolithic plant management strategies. *Vegetation history and archaeobotany* 21,2: 149-162.

ASOUTI, E. and FULLER, D.Q.

2013 A contextual approach to the emergence of agriculture in Southwest Asia: reconstructing Early Neolithic plant-food production. *Current Anthropology* 54,3: 299-345.

- ATALAY, S. and HASTORF, C.A.  
2006 Food, meals, and daily activities: food habitus at Neolithic Çatalhöyük. *American Antiquity* 71,2: 283-319.
- BAR-YOSEF, O.  
2011 Climatic fluctuations and early farming in West and East Asia. *Current Anthropology* 52,S4: S175-S193.
- BOGAARD, A., CHARLES, M., TWISS, K.C., FAIRBAIRN, A., YALMAN, N., FILIPOVIĆ, D., DEMIRERGI, G.A., ERTUĞ, F., RUSSELL, N. and HENECKE, J.  
2009 Private pantries and celebrated surplus: storing and sharing food at Neolithic Çatalhöyük, Central Anatolia. *Antiquity* 83,321: 649-668
- BOGAARD, A., CHARLES, M., LIVARDA, A., ERGUN, M., FILIPOVIC, D. and JONES, G.  
2013 Archaeobotany of the Mid-later occupation levels at Neolithic Çatalhöyük. In: HODDER, I. (ed.), *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 seasons*: 93-129. Los Angeles: *Monographs of the Cotsen Institute of Archaeology*.
- CHARLES, M.  
2011 Interpretation of *Scirpus* from early farming sites in western Asia and Europe: a cutting sedge of archaeobotanical research? In: HADJIKOUMIS, A., ROBINSON, E. and VINER-DANIELS, S. (eds.) *Dynamics of Neolithisation in Europe: Studies in honour of Andrew Sherratt*: 113-130. Oxford: Oxbow Books
- COLLEDGE, S.  
2001 *Plant exploitation on Epipalaeolithic and early Neolithic sites in the Levant*. Oxford: J. and E. Hedges (BAR international series 986).
- COLLEDGE, S. and CONOLLY, J.  
2018 Plant domestication, production intensification and food storage at Pre-Pottery Neolithic A Dhra. *Levant*: 1-17. DOI: 10.1080/00758914.2018.1424746
- COLLEDGE, S., CONOLLY, J. and SHENNAN, S  
2004 Archaeobotanical evidence for the spread of farming in the Eastern Mediterranean. *Current anthropology* 45,S4: S35-S58.
- FAIRBAIRN, A.S., JENKINS, E., BAIRD, D. and JACOBSEN, G.  
2014 9th millennium plant subsistence in the central Anatolian highlands: new evidence from Pınarbaşı, Karaman Province, central Anatolia. *Journal of Archaeological Science* 41: 801-812.
- FILIPOVIC, D.  
2012 *An archaeobotanical investigation of plant use, crop husbandry and animal diet at early-mid Neolithic Çatalhöyük, Central Anatolia*. PhD, University of Oxford.
- FULLER, D.Q.  
2007 Contrasting patterns in crop domestication and domestication rates: recent archaeobotanical insights from the Old World. *Annals of Botany* 100,5: 903-924.

- FULLER, D.Q. and GONZALEZ CARRETERO, L.  
In press. The early oven cultures: a particular Neolithic in the macro-archaeology of food. *Journal of World Prehistory*
- FULLER, D.Q. and QIN, L.  
2010 Declining oaks, increasing artistry, and cultivating rice: The environmental and social context of the emergence of farming in the Lower Yangtze Region. *Environmental Archaeology* 15,2: 139-159.
- FULLER, D.Q. and ROWLANDS, M.  
2011 Ingestion and Food Technologies: Maintaining differences over the long-term in West, South and East Asia. In: BENNET, J., SHERRATT, S., WILKINSON, T. C. (Eds.). *Interweaving Worlds - systematic interactions in Eurasia, 7th to 1st millennia BC. Essays from a conference in memory of Professor Andrew Sherratt*: 37-60. Oxford: Oxbow Books
- FULLER, D.Q. and STEVENS, C. J.  
2017 Open for competition: domesticates, parasitic domesticoids and the agricultural niche. *Archaeology International* 20: 110-121
- FULLER, D.Q., ALLABY, R.G. and STEVENS, C.  
2010 Domestication as innovation: the entanglement of techniques, technology and chance in the domestication of cereal crops. *World archaeology* 42,1: 13-28.
- FULLER, D.Q., WILLCOX, G., ALLABY, R. G.  
2011 Cultivation and domestication had multiple origins: arguments against the core area hypothesis for the origins of agriculture in the Near East. *World Archaeology* 43,4: 628-652.
- FULLER, D.Q., ASOUTI, E. and PURUGGANAN, M.D.  
2012 Cultivation as slow evolutionary entanglement: comparative data on rate and sequence of domestication. *Vegetation History and Archaeobotany* 21,2: 131-145.
- FULLER, D.Q., DENHAM, T., ARROYO-KALIN, M., LUCAS, L., STEVENS, C.J., QIN, L., ALLABY, R.G. and PURUGGANAN, M.D.  
2014 Convergent evolution and parallelism in plant domestication revealed by an expanding archaeological record. *Proceedings of the National Academy of Sciences* 111,17: 6147-6152.
- FULLER, D.Q., STEVENS, C., LUCAS, L., MURPHY, C. and QIN, L.  
2016 Entanglements and entrapments on the pathway toward domestication. In: DER, L. and FERNANDINI, F. (ed.) *The archaeology of entanglement*: 151-72. Walnut Creek (CA): Left Coast Press.
- FULLER, DQ., COLLEDGE, S., MURPHY, C., STEVENS, C.  
2017 Sizing up cereal variation: patterns in grain evolution revealed in chronological and geographical comparisons. In *Miscelánea en homenaje a Lydia Zapata Peña (1965-2015)*. (pp. 131-149). Bilbao, Spain: Universidad Del País Vasco
- GONZALEZ CARRETERO, L., WOLLSTONECROFT, M. and FULLER, D.Q.  
2017 A methodological approach to the study of archaeological cereal meals: a case study at Çatalhöyük East (Turkey). *Vegetation History and Archaeobotany* 26,4: 415-432.

HARRIS, D.R.

1989 An evolutionary continuum of people-plant interaction. *In: HARRIS, D.R. and HILLMAN, G. (eds.) Foraging and farming: the evolution of plant exploitation: 11-26* London: Unwin Hyman.

HARRIS, D.R.

2012 Evolution of agroecosystems: biodiversity, origins, and differential development. *In: GEPTS, P., FAMULA, T. R., BETTINGER, R. L., BRUSH, S. B., DAMANIA, A. B., MCGUIRE, P. E. and QUALSET, C. O. (eds.) Biodiversity in agriculture. Domestication, evolution, and sustainability: 21-56.* Cambridge: Cambridge University Press

HARRIS, D.R. and FULLER, D.Q.

2014 Agriculture: definition and overview. *In: SMITH, C. (ed.) Encyclopedia of global archaeology: 104-113.* New York: Springer.

HARTMANN-SHENKMAN, A., KISLEV, M.E., GALILI, E., MELAMED, Y. and WEISS, E.

2015 Invading a new niche: obligatory weeds at Neolithic Atlit-Yam, Israel. *Vegetation History and Archaeobotany* 24,1: 9-18.

HAYDEN, B.

2014a Competitive feasting before cultivation? A comment on Asouti and Fuller. *Current Anthropology* 55,2: 230-231

HAYDEN, B.

2014b *The power of feasts: from prehistory to the present.* Cambridge: Cambridge University Press.

HILLMAN, G.C.

2000 The plant food economy of Abu Hureyra 1 and 2. *In: MOORE, A.M.T., HILLMAN, G.C. and LEGGE, A.J. (eds.) Village on the Euphrates: from foraging to farming at Abu Hureyra: 327-398.* Oxford: Oxford University Press.

HILLMAN, G.C., COLLEDGE, S.M. and HARRIS, D.R.

1989 Plant-food economy during the Epipalaeolithic period at Tell Abu Hureyra, Syria: dietary diversity, seasonality, and modes of exploitation. *In: WATSON, P.J., HARRIS, D.R. and HILLMAN, G.C. (eds.) Foraging and Farming: The Evolution of Plant Exploitation: 207-239.* London: Unwin Hyman.

HILLMAN, G., HEDGES, R., MOORE, A., COLLEDGE, S. and PETTITT, P.

2001 New evidence of Late glacial cereal cultivation at Abu Hureyra on the Euphrates. *The Holocene* 11,4: 383-393.

HODDER, I.

2012 *Entangled.* Oxford: Blackwell

HODDER, I.

2016 *Studies in Human-thing Entanglement.* <http://www.ian-hodder.com/>

- HOLE, F., FLANNERY, K.V. and NEELY, J.A.  
1969 *Prehistory and human ecology of the Deh Luran Plain: an early village sequence from Khuzistan, Iran* 1. University of Michigan Museum of Anthropology, Ann Arbor.
- HUNT, H.V., SHANG, X. and JONES, M.K.  
2017 Buckwheat: a crop from outside the major Chinese domestication centres? A review of the archaeobotanical, palynological and genetic evidence. *Vegetation History and Archaeobotany*: 1-14.
- LUCAS, L.  
2014 *Crops, culture, and contact in prehistoric Cyprus*. Oxford: Archaeopress.
- LUCAS, L. and FULLER, D. Q.  
2018 From intermediate economies to agriculture: trends in wild food use, domestication and cultivation among early villages in southwest Asia. Dataset [open access data tables]. <http://discovery.ucl.ac.uk/id/eprint/10052960>
- LYONS, D. and D'ANDREA, A.C.  
2003 Griddles, ovens, and agricultural origins: An ethnoarchaeological study of bread baking in highland Ethiopia. *American Anthropologist* 105,3: 515-530.
- MAEDA, O., LUCAS, L., SILVA, F., TANNO, K.I. and FULLER, D.Q.,  
2016 Narrowing the harvest: Increasing sickle investment and the rise of domesticated cereal agriculture in the Fertile Crescent. *Quaternary Science Reviews* 145: 226-237.
- MARSHALL, F. and HILDEBRAND, E.  
2002 Cattle before crops: the beginnings of food production in Africa. *Journal of World Prehistory* 16,2:99-143
- MARTINOLI, D.  
2004 Food plant use, temporal changes and site seasonally at Epipalaeolithic Öküzini and Karain B caves, southwest Anatolia, Turkey. *Paléorient* 30,2: 61-80.
- MEIER, J.S., GORING-MORRIS, A.N. and MUNRO, N.D.  
2017 Aurochs bone deposits at Kfar HaHoresh and the southern Levant across the agricultural transition. *Antiquity* 91,360: 1469-83.
- MILLER, N. F.  
2011 Reconciling nature and culture after “Naissance des divinités, Naissance de L’agriculture”. *Paleorient*37,1: 61-74
- MOORE, A.M. and HILLMAN, G.C.  
1992 The Pleistocene to Holocene transition and human economy in Southwest Asia: The impact of the Younger Dryas. *American Antiquity* 57,3: 482-494.
- MOORE, A. M. T., HILLMAN, G. C. and LEGGE, A. J  
2000 *Village on the Euphrates. From foraging to farming at Abu Hureyra*, Oxford: Oxford University Press.
- MUELLER, N.G.

2017a An extinct domesticated subspecies of erect knotweed in Eastern North America: *Polygonum erectum* subsp. *watsoniae* (Polygonaceae). *Novon* 25,2: 166-179.

MUELLER, N.G.

2017b Evolutionary “Bet-Hedgers” under cultivation: investigating the domestication of Erect Knotweed (*Polygonum erectum* L.) using growth experiments. *Human Ecology* 45: 189-203.

RAMSEY, M.N. and ROSEN, A.

2016 Wedded to wetlands: exploring Late Pleistocene plant-use in the Eastern Levant. *Quaternary International* 396: 5-19.

RIEHL, S., BENZ, M., CONARD, N.J., DARABI, H., DECKERS, K., NASHLI, H.F. and ZEIDI-KULEHPARCHEH, M.

2012 Plant use in three Pre-Pottery Neolithic sites of the northern and eastern Fertile Crescent: a preliminary report. *Vegetation History and Archaeobotany* 21,2: 95-106.

RIEHL, S., ZEIDI, M. and CONARD, N.J.

2013 Emergence of agriculture in the foothills of the Zagros Mountains of Iran. *Science*, 341,6141: 65-67.

RIEHL, S., ASOUTI, E., KARAKAYA, D., STARKOVICH, B.M., ZEIDI, M. and CONARD, N.J.

2015 Resilience at the transition to agriculture: The long-term landscape and resource development at the aceramic Neolithic tell site of Chogha Golan (Iran). *BioMed research international*: 1-22.

ROBERTS, N., WOODBRIDGE, J. BEVAN, A., PALMISANO, A., SHENNAN, S. and ASOUTI, E.

2018 Human responses and non-responses to climatic variations during the last Glacial-Interglacial transition in the eastern Mediterranean. *Quaternary Science Reviews* 184: 47-67

SAVARD, M., NESBITT, M. and JONES, M.K.

2006 The role of wild grasses in subsistence and sedentism: new evidence from the northern Fertile Crescent. *World Archaeology* 38,2: 179-196. SHENNAN, S.

2018 *The First Farmers of Europe: An Evolutionary Perspective*. Cambridge: Cambridge University Press.

SHERRATT, A.G.

2007 Diverse origins: regional contributions to the genesis of farming. In: COLLEDGE, S. and CONOLLY, J. (eds.) *The origins and spread of domestic plants in southwest Asia and Europe*: 1-20. Walnut Creek (CA): Left Coast Press.

SMITH, B. D.

2001 Low-level food production. *Journal of Archaeological Research* 9,1: 1-43.

SMITH, B. D.

2015 A comparison of niche construction theory and diet breadth models as explanatory frameworks for the initial domestication of plants and animals. *Journal of Archaeological Research* 23,3: 215-262.

- SNIR A, NADEL D, GROMAN-YAROSLAVSKI I, MELAMED Y, STERNBERG M, BAR-YOSEF O, WEISS E.  
2015 The origin of cultivation and proto-weeds, long before Neolithic farming. *PLoS ONE* 10: e0131422. (doi:10. 1371/journal.pone.0131422)
- STEVENS, C.J., MURPHY, C., ROBERTS, R., LUCAS, L., SILVA, F. and FULLER, D.Q.  
2016 Between China and South Asia: A Middle Asian corridor of crop dispersal and agricultural innovation in the Bronze Age. *The Holocene* 26,10: 1541-1555.
- STEVENS, C.J. and FULLER, D.Q.  
2017 The spread of agriculture in eastern Asia. *Language Dynamics and Change* 7,2: 152-186.
- TANNO, K.I. AND WILLCOX, G.  
2012 Distinguishing wild and domestic wheat and barley spikelets from early Holocene sites in the Near East. *Vegetation history and archaeobotany* 21,2: 107-115.
- TWISS, K. C.  
2008 Transformations in an early agricultural society: feasting in the southern Levantine Pre-Pottery Neolithic. *Journal of Anthropological Archaeology* 27,4: 418-442
- VAN ZEIST W. and BAKKER-HEERES J.A.H.  
1984 Archaeobotanical studies in the Levant 3: Late Palaeolithic Mureybit. *Palaeohistoria* 26: 171-199
- VAN ZEIST, W. and BAKKER-HEERES, J.A.H.  
1985 Archaeobotanical studies in the Levant. 4. Bronze Age sites on the north Syrian Euphrates. *Palaeohistoria* 27: 247-316.
- VAN ZEIST W., SMITH P., PALFENIER-VEGTER R.M., SUWIJN M, and CASPARIE W.A.  
1984 An archaeobotanical study of Ganj Dareh Tepe, Iran. *Palaeohistoria* 26: 201-224.
- VAN ZEIST, W., and DE ROLLER, G. J.  
2000 The plant remains. In: VERHOEVEN, M. and AKKERMANS, P.M.M.G. (eds.) *Tell Sabi Abyad II: The Pre-pottery Neolithic B Settlement*: 137-147. Istanbul: Nederlands Historisch-Archaeologisch Instituut.
- WEISSKOPF, A. and FULLER, D.Q.  
2014 Buckwheat: origins and development. In: SMITH, C. (ed.) *Encyclopedia of Global Archaeology*: 1025-1028. New York: Springer.
- WENGROW, D., CARTER, R., BRERETON, G., SHEPPERSON, M., HAMARASHI, S.J., SABER, S.A., BEVAN, A., FULLER, D., HIMMELMAN, H., SOSNOWSKA, H. and GONZALEZ CARRETERO, L.  
2016 Gurga chiya and Tepe marani: new excavations in the Shahrizor plain, Iraqi Kurdistan. *Iraq* 78: 253-284.
- WILLCOX, G.



2005 The distribution, natural habitats and availability of wild cereals in relation to their domestication in the Near East: multiple events, multiple centres. *Vegetation History and Archaeobotany* 14,4: 534-541.

WILLCOX, G.

2012 Searching for the origins of arable weeds in the Near East. *Vegetation History and Archaeobotany* 21,2: 63-167.

WILLCOX, G., BUXO, R. and HERVEUX, L.

2009. Late Pleistocene and early Holocene climate and the beginnings of cultivation in northern Syria. *The Holocene* 19,1: 151-158.

WOLLSTONECROFT, M.M.

2009 Harvesting experiments on the clonal macrophyte sea club-rush (*Bolboschoenus maritimus* (L.) Palla): an approach to identifying variables that may have influenced hunter-gatherer resource selection in Late Pleistocene Southwest Asia.

In: FAIRBAIRN, A.S. and WEISS, E. (eds.) *From Foragers to Farmers: Papers in Honour of Gordon C. Hillman*: 127-139. Oxford: Oxbow Books.

WOLLSTONECROFT, M.M., ELLIS, P.R., HILLMAN, G.C. and FULLER, D.Q.

2008 Advances in plant food processing in the Near Eastern Epipalaeolithic and implications for improved edibility and nutrient bioaccessibility: an experimental assessment of *Bolboschoenus maritimus* (L.) Palla (sea club-rush). *Vegetation History and Archaeobotany* 17,1: 19-27.

WOLLSTONECROFT, M.M., HROUDOVÁ, Z., HILLMAN, G.C. and FULLER, D.Q.,

2011 *Bolboschoenus glaucus* (Lam.) SG Smith, a new species in the flora of the ancient Near East. *Vegetation history and archaeobotany* 20,5:459-470.

ZEDER, M.A.

2015 Core questions in domestication research. *Proceedings of the National Academy of Sciences* 112,11: 3191-3198.

ZOHARY, D., HOPF, M. and WEISS, E.

2012 *Domestication of Plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin*. Oxford: Oxford University.

**Table 1.** Archaeobotanical assemblages classed by frequency of crop remains (including wild ancestors) in each broad period. List includes: Site name (median data cal. BC) and % total crops.

## Figure Captions

**Figure 1.** Map of sites considered in this paper, divided into geographical groups. Sites numbered: 1. Ilipinar, 2. Hacilar, 3. Hoyucek, 4. Karain and Okuzini caves, 5. Erbaba, 6. Catalhoyuk, 7. Pinarbasi, 8. Can Hassan, 9. Asikli Hoyuk, 10. Ais Yiorkis, 11. Mylouthkia, 12. Shillourokambos and Klimonas, 13. Khirokitia and Kalavassos Tenta, 14. Cape Andreas Castros, 15. Ras Shamra, 16. Tell Kurdu, 17. Ain el-Kherkh, 18. Dederiyeh, 19. Tell Qaramel, 20. Fistikli Hoyuk; 21. Tell Abr, Dja'de, Kosak Shamali, Halula, Jerf el Ahmar, 22. Mureybet, 23. Abu Hureyra, 24. Sabi Abyad, 25. El Kowm, 26. Tell Bouqras, 27. Gobekli Tepe, 28. Nevali Cori, 29. Cafer Hoyuk, 30. Cayonu, 31. Girikihaciyan, 32. Salat Camli Yano, 33. Kortik Tepe and Demirkoy, 34. Hallan Cemi, 35. Hasankeyf Hoyuk, 36. Halaf, 37. Tell Aqab, 38. Feyda, 39. Kashkashol, 40. Umm Qseir, 41. Magzalia, Qermez Dere and Yarim Tepe, 42. Nemrik 9, 43. Umm Debaghiyah, 44. M'lefaat, 45. Hajji Firuz, 46. Jarmo, 47. Tell es-Sawwan, 48. Tepe Marani, 49. Choga Mami, 50. Chogha Golan, 51. Tell el'Oueili, 52. Sarab, 53. Sheikh-e Abad, 54. Ganj Dareh, 55. Chia Sabz, 56. Chaga Sefid, 57. Tepe Abdul Hosein, 58. Ali Kosh, 59. Chogha Bonut, 60. Tepe Sialk, 61. Sang-i-Chakhmaq, 62. Tall-e Mushki and Tall-e Jari, 63. Tepe Yahya, 64. Ramad, 65. Ghoraife, 66. Aswad, 67. Tell Teo, 68. Hayonim Cave, 69. Yiftahel, 70. Atlit-Yam, 71. Nahal Zehora, 72. Gilgal and Netiv Hagdud, 73. Jericho, 75. Nahal Hemar, 76. Wadi Fidan A, 77. Wadi Faynan 16, 78. Wadi Fidan C, 79. Beidha, 80. Basta, 81. El-Hemmeh, 82. Dhra and Zahrat adh-Dhra, 83. Wadi Jilat 7, 84. Azraq 31, 85. Sha'ar Hagolan, 86. Tell Qarassa, 87. Wadi Hammeh 27, 88. Iraq ed-Dubb, 89. Jebel Abu Thawwb, 90. Ain Ghazal, 91. Arjoune and Tell Nebi Mend.

**Figure 2.** Timelines of the Near East charting aspects of the evolution of domesticated crops and crop production. On this graph domestication status grades are defined as *Incipient Pre-Domestication Cultivation* [IPDC], *Entrenched Pre-Domestication Cultivation* [EPDC] and *Domestication Cultivation* [DC] and these are correlated with conventional regional chronology, i.e. *Epipalaeolithic* [Epi], *Pre-Pottery Neolithic A* [PPNA], *Early/Middle Pre-Pottery Neolithic B* [EMPNNB], *Late Pre-Pottery Neolithic B* [LPPNB], and *Pottery Neolithic* [PN]. All data points represent the average of the site/phase assemblages plotted against median calibrated age. A. Crop package diversity in terms of the number of crops in the assemblage, with representative polynomial trend line of the northern region. B. grain size increase in 5 crops expressed as percentage change from the average of smallest sized assemblage (original data from Fuller *et al.* 2014; percentage comparison as per Fuller and Stevens 2017). C. The increase in non-shattering wheat and barley rachis remains (original data from Allaby *et al.* 2017).

**Figure 3.** A comparison of the presence of economy grades defined on the percentage of crops in assemblages of different regions and periods. Economy grades are defined as foraging dominant (<20% crops), intermediate economies (20-80% crops), and agricultural (80% crops). Phases relate to those defined in Figure 2. Sites included in each region are mapped in Figure 1, including Anatolia [An], Cyprus, Eastern [E], Northern [N], Levant - northern [LN], Levant - southern [LS]. Sites are classed in economy grades in Table 1.

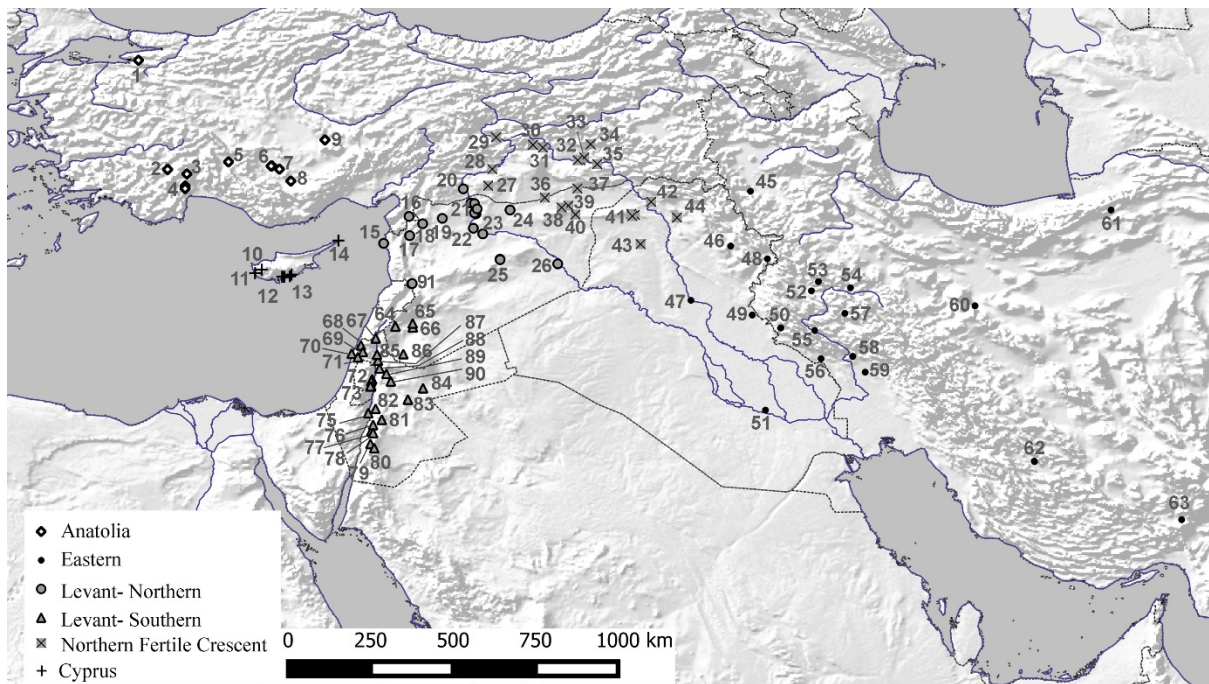
**Figure 4.** General composition of foraging dominant and intermediate economies in archaeobotanical assemblages from the northern and southern Levant (LN, LS) and the Northern Fertile Crescent (N). A. Relative proportions of crops, fruit/nut, nutlets and wild grasses out of all plant remains in sites graded as foraging dominant economies. B. Relative proportions of crops, fruit/nut and nutlets out of all plant remains in sites graded as intermediate economies.

	up to 8500 cal BC	8500-7000 cal BC	7000-5000 BC
<b>Crops &lt;20%</b>	<b>Levant South</b> Jilat 6 (11330) 0% Wadi el-Hammeh 27 (11875) 15.56% Gesher (9950) 2.44% Dederiyeh cave (11065) 1.74% Dhra' (9500) 11.37% Iraq ed-Dubb (PPNA) (9200) 12.22% el-Hemmeh (PPNA)(8855) 9.29% <b>Levant North</b> Mureybet (II) (9675) 1.28% Mureybet (I) (9950) 2.06% Abu Hureyra (1) (10650) 5.04% <b>North</b> Hasankeyf Höyük (9440) 0.38% Demirköy (9360) 0.77% Hallan Çemi Tepesi (9485) 6.62% Körtik Tepe (9500) 1.18% Göbekli Tepe (8900) 7.52% <b>Central Anatolia</b> Pınarbaşı (8800) 0.53%	<b>Levant South</b> Azraq 31 (7335) 5.64% Beidha (PPNB) (7925) 7.45% Nahal Hemar (7525) 5.47% Jilat 7-I (7775) 4.47% Jilat 7-II (7775) 10.79% Dhuweila (PPNB) (7265) 9.52% <b>Levant North</b> Ain el-Kerkh (EPPNB) (8430) 4.05% Ain el-Kerkh (LPPNB) (7550) 6.65% Abu Hureyra 2A (7400) 5.16% Abu Hureyra 2B (7400) 7.41% <b>Central Anatolia</b> Can Hasan III (7150) 2.97% Aşıklı Höyük (7670) 4.07% <b>East</b> Chogha Golan (8200) 16.34% <b>Cyprus</b> Tenta (5-1) (7175) 17.02%	<b>Levant South</b> Dhuweila (PN) (6100) 0% Jilat 13 (6815) 0.44% Sha'ar Hagolan (6230) 7.81% el-Hemmeh (6915) 14.58% <b>Levant North</b> El Kowm 1a (6220) 3.47% El Kowm 1b (6220) 6.81% El Kowm 2 (6725) 18.04% Bouqras (6900) 13.22% Abu Hureyra (2C) (6200) 12.72% <b>Central Anatolia</b> Hacilar II (5920) 8.90% <b>East</b> Choga Mami (5795) 16.72%
<b>Crops 20-80%</b>	<b>Levant South</b> Qarassa (8590) 35.57% Netiv Hagdud (9075) 30.43% Aswad (I) (8590) 72.20% El-Wad (12000) 45.19% <b>Levant North</b> Qaramel (10000) 38.30% Jerf el-Ahmar (9075) 51.41% Tell 'Abr 3 (9350) 79.28% Mureybet (III) (9075) 73.13% Mureybet (IV)(9010) 15.00% Dja'de (8550) 41.22% Ras Shamra (VC) (7100) 76.50% <b>North</b> Qermez Dere (9450) 21.67% Çayönü (Round Bldg.) (9500) 72.22% M'lefaat I (9150) 64.90% M'lefaat II (9150) 39.36% Çayönü (Grill) (8550) 57.24% <b>Cyprus</b> Mylouthkia (IA) (8500) 47.32%	<b>Levant South</b> Ghoraifé (I) (7550) 53.69% Ghoraifé (II) (7150) 54.12% Basta (7300) 30.05% Aswad (II) (8300) 75.43% <b>Levant North</b> Halula (MPPNB) (7550) 38.49% Halula (LPPNB) (7320) 48.36% <b>North</b> Cafer Höyük (III-IV) (7350) 45.04% Cafer Höyük (V-VIII) (7800) 68.32% Cafer Höyük (IX-XIII) (8100) 55.61% <b>East</b> Jarmo (PPN) (7300) 78.09% East Chia Sabz (8075) 27.63% Chogha Bonut (7900) 64.46% Ganj Dareh (8040) 38.75% Ganj Dareh-E (8040) 21.25% <b>Cyprus</b> Mylouthkia (IB) (7150) 33.78% 'Ais Yiorkis (7550) 30.77%	<b>Levant South</b> Nebi Mend (6830) 40.60% Ramad I (6975) 38.68% <b>Levant North</b> Halula (PN) (6550) 51.58% Tell Kurdu (5550) 20.84% Aqab (5550) 47.87% Halula (Halaf) (5925) 33.33% Sabi Abyad (6300) 29.23% <b>North</b> Maghzaliyah (6650) 37.33% <b>Central Anatolia</b> Hacilar I (6290) 35.48% Çatalhöyük CtHIX-X (6660) 37.04% Çatalhöyük CtHVI-VIII (6660) 59.92% Çatalhöyük CtHXI-XII (6660) 34.78% <b>Cyprus</b> Cape Andreas-Kastros (6450) 48.76% Khirokitia (6475) 59.00% <b>East</b> Tepe Marani (5420) 46.84%
<b>Crops &gt; 80%</b>		<b>Levant South</b> Wadi Fidan A (7275) 90.13% Jericho (PPNB) (7850) 100% <b>Levant North</b> Çayönü (Cell) (7765) 98.61% Çayönü (Cobble) (8150) 93.08% <b>North</b> Nevalı Çori (8275) 85.76%	<b>Levant South</b> Ramad II (6975) 83.14% Wadi Fidan C (6350) 97.75% Nahal Zehora II (5450) 81.82% Nahal Zehora II (6050) 99.12% Jericho (PNA/PPNB) 5700 99.66% Yiftahel (6275) 100% <b>Levant North</b> Arjouna (5520) 79.16% Ras Shamra (VB) (6340) 91.43% Domuztepe (5590) 88.02% Bouqras Storage (6900) 69.68% Sabi Abyad (5960) 87.76% Ras Shamra (VA) (6540) 92.28% Umm Qseir (5750) 90.84% <b>North</b> Çayönü (PN) (6400) 97.78% Salat Cami Yanı (6345) 85.28% Yarim Tepe I (6400) 100% Çayönü (LR) (6980) 95.73% <b>Central Anatolia</b> Erbaba (6450) 90.54%

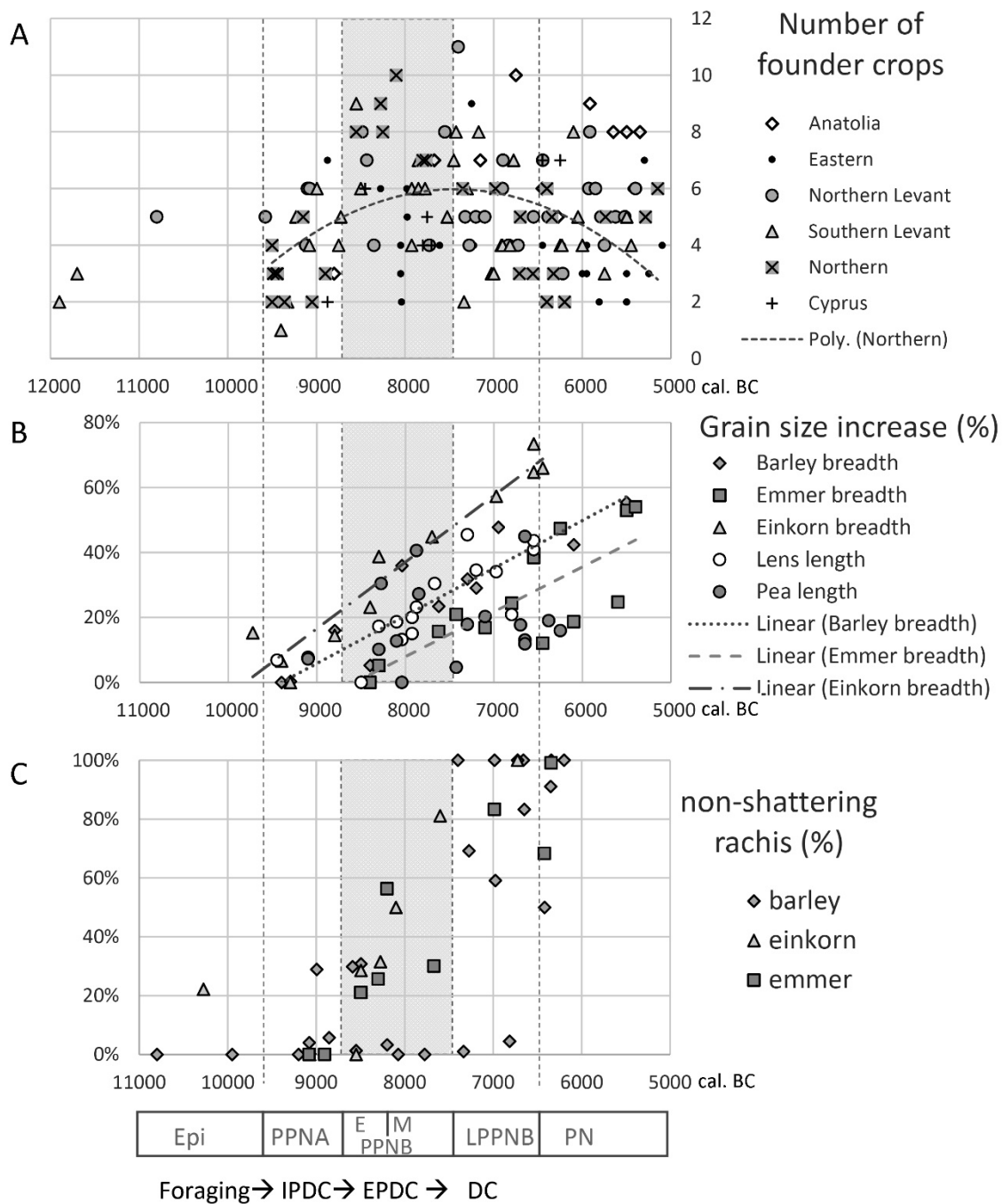
Grey highlighted: changed percentage

Yellow highlighted: changed percentage and moved category

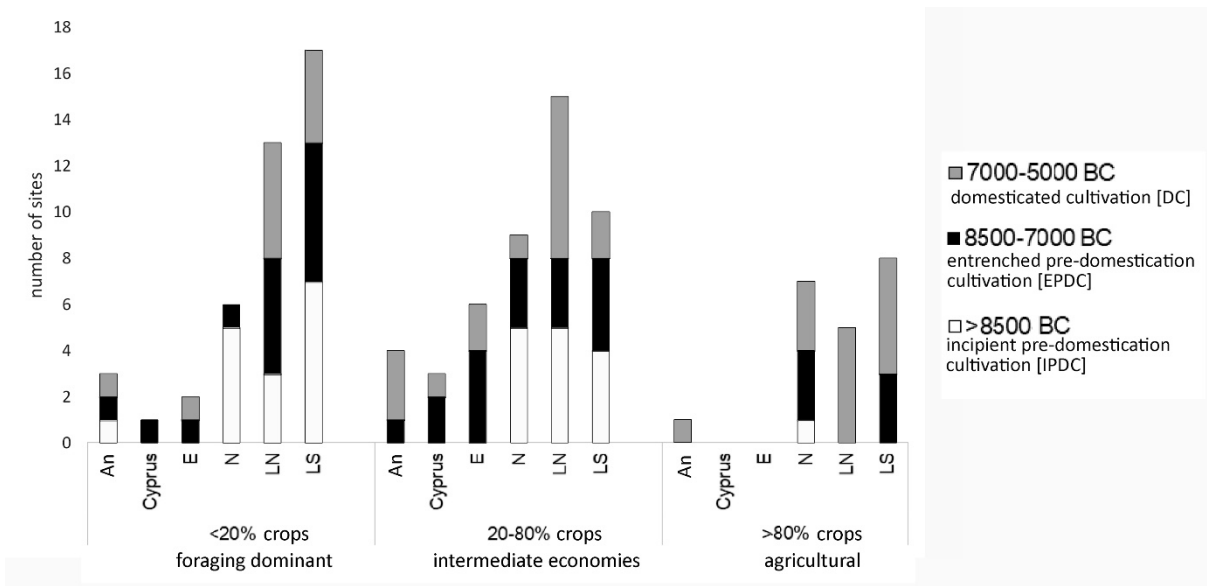
**Figures** for Fuller *et al*, From intermediate economies to agriculture: trends in wild food use, domestication and cultivation among early villages in southwest Asia



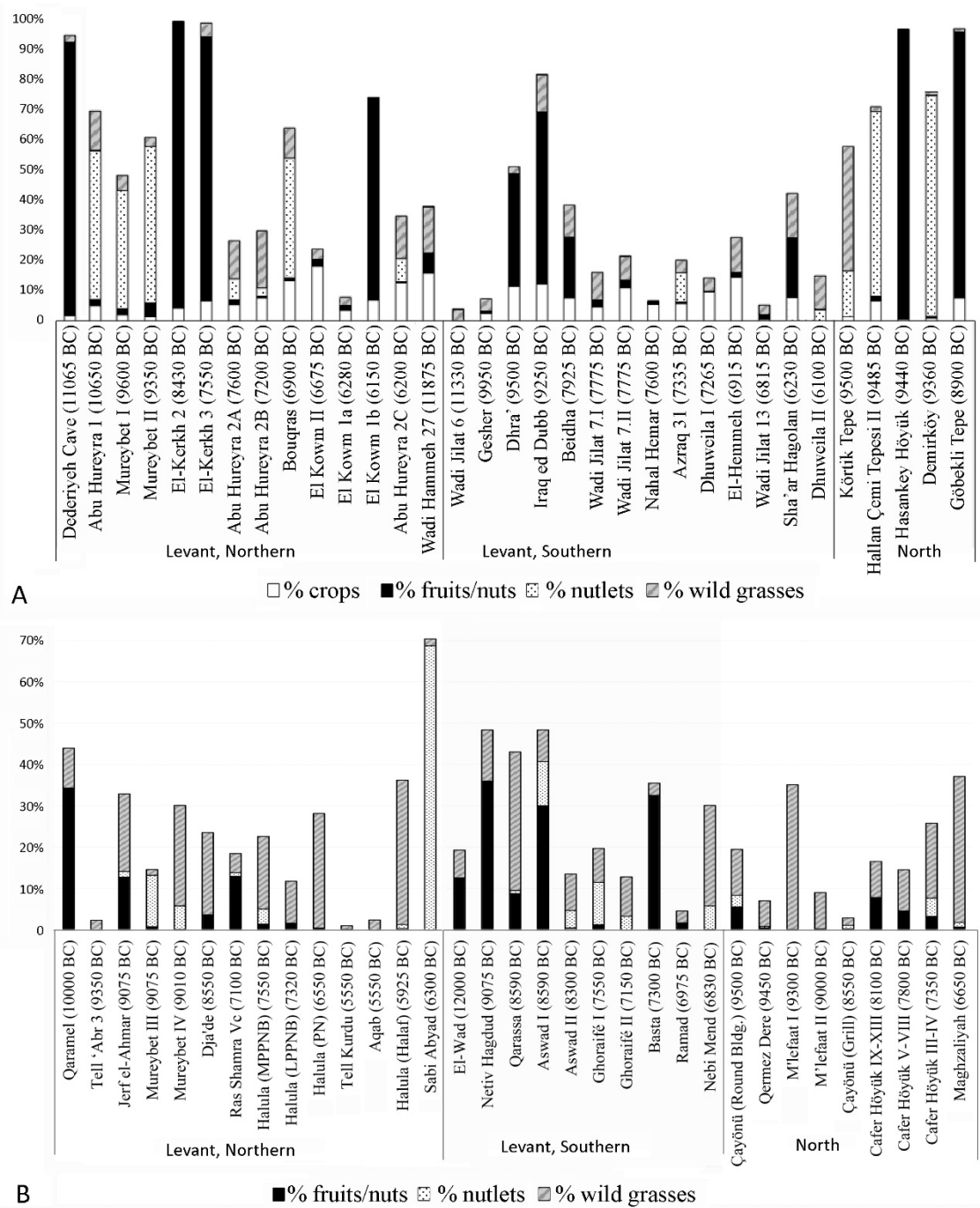
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