Agricultural innovation and resilience in a long-lived early farming community: the 1500-year sequence at Neolithic-early Chalcolithic Çatalhöyük, central Anatolia

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Abstract

Intensive archaeobotanical investigations at Çatalhöyük have created a unique opportunity to explore change and continuity in plant use through the *c*. 1500-year Neolithic-early Chalcolithic sequence of an early established farming community. The combination of crops and herd animals in the earliest (aceramic) part of the sequence reflects a distinct and diverse central Anatolian 'package' at the end of the 8th millennium cal BC. Here we report evidence for near continual adjustment of cropping regimes through time at Çatalhöyük, featuring recruitment of minor crops or crop contaminants to become major staples. We use panarchy theory to frame understanding of Çatalhöyük's long-term sustainability, arguing that its resilience was a function of three key factors: its diverse initial crop spectrum, which acted as an archive for later innovations; its modular social structure, enabling small-scale experimentation and innovation in cropping at the household level; and its agglomerated social morphology, allowing successful developments to be scaled up across the wider community. This case study in long-term sustainability through flexible, changeable cropping strategies is significant not only for understanding so-called boom and bust cycles elsewhere but also for informing wider agroecological understanding of sustainable development in central Anatolia and beyond.

Introduction

Intensive archaeobotanical recovery and analysis since 1995 at Çatalhöyük have yielded an archive of over 10,000 samples. Rapid scanning of every sample in the field, combined with prioritization of those from *in situ* burning events (e.g., hearths, ovens, rakeouts, adjacent 'dirty' floors and burned buildings), has resulted in full analysis of over 600 samples to date (Fairbairn et al. 2005; Bogaard et al. 2013; Filipović 2014; Charles and Bogaard in prep; Stroud et al. in prep). Çatalhöyük's archaeobotanical assemblage is one of the largest ever recovered from a Neolithic site in western Asia, and offers unparalleled insight into plant-related activities across the settlement and through time. Spanning a *c.* 1500-year sequence of Neolithic-early Chalcolithic occupation (East mound, *c.* 7100-5950 BC; West mound ~6000-5500 BC – Bayliss et al. 2015; Marciniak et al. 2015; Orton et al. in prep), the archaeobotanical assemblage offers the opportunity to build, for the first time, a high-resolution picture of how early established farming was sustained locally over the long-term.

As with all sedentary, food-producing societies, Çatalhöyük was subject to a number of risk factors that could undermine its ability to sustain the settlement's population.

A particular risk factor was variability in precipitation in this semi-arid zone – the southern Konya plain is one of the driest regions of Turkey – affecting not only water availability to crops but also local hydrology across the runoff-dependent alluvial fan of the Çarşamba river, which flows past the site (Roberts and Rosen et al. 2009; Ayala et al. submitted). A further risk factor would have been the growing population of the site itself, which peaked in at least the low thousands in the mid-7th millennium BC (Cessford 2005).

Here we report evidence for near continual adjustment of cropping regimes through time, featuring recruitment of minor crops or crop contaminants to become major staples. We argue that certain shifts in cropping practice by Çatalhöyük farmers reflect the ecological challenges of farming in a mosaic of local environments, and in particular of coping with aridity, while others articulate with changes in material culture, and in other aspects of subsistence practice and cuisine. We also observe change as well as continuity in use of fruit and nut resources. The available data suggest that certain innovations in plant use and husbandry began in particular households or neighbourhoods and were subsequently adopted by the wider community: a gradual pattern of change noted also in aspects of material culture (e.g., mudbrick materials - Love 2013; pottery fabrics - Yalman et al. 2013; chipped stone raw materials and technology - Carter and Milić 2013). We use panarchy theory (Gunderson and Holling eds 2001; Holling 2001) to frame these patterns, arguing that experimentation and innovation at small social scales insulated the wider community from risks of failure, prior to scaling up of successful innovations in cropping strategy. Several innovations cluster in the mid-Neolithic sequence, and were widely adopted just after the community had attained its maximum size and showed signs of reorganisation (Hodder 2014c). It is plausible that such developments played a key role in maintaining resilient, flexible responses (*sensu* Holling 1973) to the challenges of farming, enabling remarkably long-term sustainability through change. Given recent interest in apparent 'boom and bust' cycles in the western European Neolithic (e.g., Downey et al. 2016), the Çatalhöyük sequence offers the opportunity to consider how a community managed the long-term challenges and risks of established farming.

The Anatolian background

Table 1 summarises the archaeobotanical data currently available for central and eastern Anatolia, from the late Pleistocene to the end of the eighth millennium cal BC, while Fig. 1 shows the locations of relevant sites. The emerging picture will be corrected and refined by ongoing work at Aşıklı (Özbaşaran 2012) and Boncuklu (Baird et al. 2012), and re-study of the Can Hasan III assemblage (Fairbairn and Hillman forthcoming), but some general trends are evident. First, as noted by Fairbairn et al. (2014), pre-agricultural nut use in cave/rockshelter sites is evidenced in south-west (Öküzini) and central Anatolia (Pinarbaşı). Second, more diversified plant use, sometimes including cultivation, emerges alongside hunting in open-air 'sedentarising' communities of south-east/eastern Anatolia (Hallan Çemi, Demirköy, Körtik Tepe, Göbekli Tepe) through the 10th millennium BC, and similar patterning is recorded during the 9th and 8th millennia at Boncuklu in the Konya plain of central Anatolia. Ongoing work at Aşıklı will clarify the equivalent period in Cappadocia. A third 'phase' can be recognised as constituting cultivation of a range of crops undergoing domestication, and continued gathering of fruits and nuts. This third phase is evident in south-eastern Anatolia by the middle of the 9th millennium BC, at sites such as Çayönü, Nevalı Çori and early Cafer Höyük, with equivalent data further south, such as in Syria.

The emerging domestic crop spectrum of the mid-9th millennium cal BC was combined with variable forms of animal husbandry: herding of sheep and goat in both central and south-east/eastern Anatolia, plus pig-keeping in the latter region (Peters et al. 2013; Stiner et al. 2014; Baird et al. forthcoming). Recent zooarchaeological results from late 9th-millennium cal BC Aşıklı show the beginnings of a trend towards sheep-oriented husbandry that continued in central Anatolia through the later Pre-Pottery Neolithic and Pottery Neolithic (Stiner et al. 2014), with ovicaprid dietary evidence at Boncuklu suggesting contemporary experiments with husbandry (Middleton 2014; Baird et al. forthcoming).

The complementarity of crops and livestock encompasses not only the nutritional benefits of combining carbohydrate- and protein-rich foods, but also complementary forms of storage (long shelf-life vs social storage - Bogaard et al. 2009) and ecological affordances (foddering, manuring etc - Bogaard 2005). Moreover, the emergence of distinctive domesticated crop varieties, and behavioural and morphological changes in animals, would reinforce bonds among farming households investing in the perpetuation and protection of viable populations of local crop and livestock strains. This is the context of the large, long-lived tell communities that developed at Aşıklı, and later Çatalhöyük.

In terms of early crops under cultivation and variously under domestication, regional differences are becoming apparent (Table 1). In south-east/eastern Turkey, several glume (or hulled) wheats undergoing domestication – einkorn, emmer and the so-called 'new type' (the latter termed 'machaoid type' in De Moulins (1997: 36-7, 53); see Jones et al. 2000) emerge by the later 9th millennium cal BC, but barley appears morphologically wild until the later 8th millennium cal BC, and naked barley is absent. Intensive use of pulses is evident, as at Çayönü (van Zeist and de Roller 2003b). In central Anatolia, by the late 8th millennium BC, at aceramic Çatalhöyük, the dominant cereals are the glume wheats (including the 'new type' – see below), naked barley and free-threshing (hexaploid) wheat, alongside a diverse range of pulses. Naked barley and free-threshing wheat are attested at Aşıklı by the 8th millennium cal BC (Table 1); ongoing work at Aşıklı and Boncuklu will be crucial to shed further light on the earlier history of crop spectra in central Anatolia.

It is apparent that different regional crop and livestock combinations had emerged by the end of the eighth millennium cal BC in Anatolia. The establishment of mixed Neolithic farming 'packages' was thus a multi-centric process in western Asia, much like cultivation, herding and the eventual domestication of crops and animals (e.g. Fuller et al. 2011; Colledge et al. eds 2013; Willcox 2013). These mixed farming regimes launched dramatically new ways of life in western Asia and beyond (e.g., Bogaard 2005; Peters et al. 2005; Harris ed. 2010).

Çatalhöyük and the archaeobotanical dataset

The double mound of Çatalhöyük (Fig. 2) consists of a ca. 13-ha East mound spanning the aceramic to ceramic Neolithic (late 8th millennium to late 7th millennium cal BC, Early Central Anatolian IIIA-B, Özbaşaran and Buitenhuis 2002), and a ca. 8-

ha West mound, across the channel of the Çarşamba river, dating to the Early Chalcolithic (early 7th millennium cal BC). The archaeobotanical record currently available from the East mound at Çatalhöyük is the product of twenty years' large-scale excavation and systematic sampling. Archaeobotanical sampling and recovery procedures are set out by Hastorf (2005), Fairbairn et al. (2005), Bogaard et al. (2013) and Filipović (2014). Multiple archaeobotanical datasets, each resulting from a distinct phase of analysis, are integrated here for the first time in order to develop a detailed understanding of continuity and change in cropping practice and plant use through the sequence. A dataset of 62 archaeobotanical samples from the early-middle Neolithic sequence in the South and North areas analysed by Fairbairn et al. (2005) is combined with 93 samples from the same sequence analysed by Filipović (2014), an additional acorn concentration reported by Hastorf (1996) and 318 samples from the middle-late Neolithic sequence by Bogaard et al. (2013)[1]. Additionally, 31 samples analysed during the 2015 season to fill gaps in the South Area sequence (Bogaard et al. 2015) are included here, along with 80 samples from Last and Gibson's 1998-2003 West mound excavations analysed by Charles and Bogaard (in prep) and 45 samples from Biehl and Rosenstock's excavations in Trench 5 on the West mound, analysed by Stroud et al. (in prep). The term 'samples' includes some units of analysis comprising multiple similar amalgamated samples from the same deposit, as well as occasional distinct samples from the same excavation unit (see Bogaard et al. 2013; Filipović 2014). The resulting dataset consists of 630 samples (i.e. independent units of analysis representing distinct behavioural/depositional events). The deposits sampled are mostly mixed detritus of daily processing and consumption activities preserved in rake-outs from ovens and hearths, smeared onto adjacent 'dirty floors' and subsequently discarded in outdoor middens, but also include plant concentrations ('stores') preserved in burned buildings (Fairbairn et al. 2005; Bogaard et al. 2013; Filipović 2014). Burned building assemblages dominate the data available from certain phases (Table 2), and these effects are noted below in the presentation of the data.

Identification procedures for the charred plant remains from Çatalhöyük are set out in Bogaard et al. (2013: 94, Figs 7.2-7.5). Identification of cereal material included differentiation of the glume bases and grains of the so-called 'new type' glume (hulled) wheat from emmer and einkorn (Jones et al. 2000; Kohler-Schneider 2001), and also differentiation of two- and six-row naked barley rachis (the segmented stem within the ear) using new criteria presented by Charles et al. (in prep). Fig. 3 illustrates the relevant anatomical components of glume (or hulled) and 'free-threshing' wheats separated by threshing/subsequent dehusking and preserved by charring: grains, spikelet forks/glume bases of hulled wheats and rachis of free-threshing cereals. Barleys (whether naked or hulled) behave under processing like free-threshing wheat and are thus represented as grains and rachis segments.

Plant remains were quantified wherever possible by counting a 'minimum number of individuals' (mni) using diagnostic anatomical regions of cereal grains (apical and

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[1] We excluded the following due to contextual and/or chonological uncertainty: three samples from the KOPAL area (Fairbairn et al. 2005), one from natural sediment in the South area (Filipović 2014) and one unphased unit from the North area (Bogaard et al. 2013).

embryo ends), pulse seeds (embryo ends) and 'chaff' components (glume bases, upper parts of rachis internodes, culm nodes etc. - Bogaard et al. 2013: 94). For large fruit stones and nuts/nutshell, fragment counts were converted to mni estimates (Bogaard et al. 2013: 94). Fairbairn et al. 2005 quantified grains, nuts etc using charred weight, and we have incorporated their conversions to mni estimates here. Since tuber material (parenchyma tissue) was not quantified for samples fully analysed ('Phase 3') by Fairbairn et al. (2005), it is not included here.

Table 2 gives a spatial and chronological summary of the archaeobotanical dataset discussed here, while Fig. 2 shows a plan of the site with all excavation areas mentioned. The stratigraphic sequence currently documented in the South Area of the East mound (South G through South T) is the central 'spine' used in this paper; its aceramic start date is modeled at around 7100 cal BC (Bayliss et al. 2015). The end of the East mound sequence, as documented in the TP area, is modeled at around 5950 cal BC (Marciniak et al. 2015), by which time the West mound was already occupied, continuing to the mid-6th millennium cal BC (Orton et al. in prep). The TP archaeobotanical data, covering Mellaart's latest levels, are still under study, and will be supplemented by ongoing analysis of the archaeobotany of the overlapping TPC sequence. Since the TP and TPC sequences are also not (yet) linked into the South sequence, here we discuss South G to South T, and the overlapping sequence of North F-I, leaving a 'gap' between South T and the West mound. However, it is probable that a burned storeroom (Space 493) of a late Neolithic structure (Building 122) recently excavated in the TPC area is equivalent to Mellaart III-IV (Marciniak et al. 2016). Another relatively late Neolithic burned structure is Building 63, excavated by the Istanbul team (Özbaşaran and Duru 2013), which corresponds to Mellaart IV-V. Though archaeobotanical data from these structures (Ergun et al. in Özbasaran and Duru 2013; Bogaard et al. 2015) are not formally included here given their uncertain chronology and, in the case of Space 493, because excavation and analysis are as yet incomplete, we will make strategic reference to crop stores in these two late Neolithic structures since they provide important corroborating evidence for the trends that emerge in the South and North sequences. Plant 'storage' concentrations in burned Buildings 79 and 80 in the South Area (South O), and Buildings 113 and 131, North Area (North F-G), are partially studied (Bogaard et al. 2015) and available data are included in the analysis. Table 2 indicates how burned building assemblages not or only partially included in the quantitative analysis fit chronologically and spatially alongside the central dataset analysed here. Provisional results from an analysis of plant remains recovered by Hans Helbaek during James Mellaart's excavations are also included in the discussion below. The Mellaart archive derived from the later Neolithic occupation phases at Çatalhöyük East (Table 2), and while it represents sampling only of 'storage' concentrations in burned buildings, it usefully complements the broader sample set collected in recent decades.

Results

Table 3 summarises the occurrence of crops and gathered plants by Level; the East mound is represented by the South and North areas. Here, and in Figs 4-6, 10-13 below, adjacent Levels represented by less than 5 samples each have been amalgamated (e.g. South H and South I), as have Levels yielding less than 10 botanical items (of given categories under consideration). The diversity of pulses and cereals at the bottom of the tell, in South G, is especially high and encompasses all of the crops that came to play a major role through the subsequent East mound sequence; only hulled barley arrived later, as sporadic grains through the mid-later Neolithic (Bogaard et al. 2013).

Diachronic trends in cereal and pulse crops

Figs 4-5 reveal two distinct changes through time in the forms of barley cultivated. An initial shift is apparent in changing proportions of rachis types: two-row naked barley virtually replaced six-row naked by the mid-Neolithic on the East mound (Fig. 4). Detection of this shift has relied on recent taxonomic work to clarify the morphological distinction between two- and six-row barley rachis across both naked and hulled forms (Charles et al. in prep; cf. Bogaard et al. 2013). The shift from six- to two-row naked barley seems to have occurred around the same time in the South and North areas of the settlement, and resulted in a clear predominance of two-row naked barley by South N and North G. Burned buildings of North G (Building 52) and South O (Building 80) have yielded 'storage' concentrations of what appear to be mostly or entirely *two-row* naked barley grains (i.e. well preserved grains of the straight type, from the central spikelet, with few to no twisted/asymmetrical grains from lateral spikelets, as in the six-row form), as has later Neolithic Building 63 (IST area) and TPC's Building 122 (Space 493) (Table 2; see also Fig. 7). There are also large stores of naked barley grains from the Mellaart archive (Table 2) – the plant assemblage studied by Helbaek (1964) from Mellaart's 1960s excavations – in the late Neolithic levels (buildings E.IV.4, A.III.4, A.II.1) that lack asymmetrical grains indicative of six-row barley. It appears, therefore, that the increasing preference for two-row naked barley involved its cultivation and storage as a 'pure' crop by the mid-Neolithic sequence, with little to no admixture from the six-row form. Six-row naked barley increases in frequency on the West mound but two-row barleys (now hulled as well as naked) remain dominant (Figs 4-5). A plausible ecological motive for the shift from six- to two-row barley was selection for enhanced drought-tolerance, to be discussed further below.

A second shift in barley forms occurs towards the end of the South sequence, when increasing proportions of hulled barley occur alongside the dominant form, naked barley, a change most readily identified in grain morphology (Fig. 5). Hulled barley is currently first recorded in North F and South Q, and was a minor component through to South T; future work on the TP and TPC assemblages will determine whether or not hulled barley became dominant over naked barley prior to the West mound occupation, but it is clear that TPC's burned storeroom Space 493 (Table 2) contained *naked* barley stores. Two-row hulled barley is the dominant variety on the West mound (Figs 4-5, cf. Bogaard et al. 2013).

Fig. 5 also shows other changes in cereal usage over time on the basis of cereal grain. Here we amalgamate different forms of glume wheat into a single category since criteria for differentiating 'new type' grain from emmer and einkorn (Kohler-Schneider 2001; Bogaard et al. 2013: Fig. 7.3) were not readily available in earlier phases of work (we consider different forms of glume wheat on the basis of chaff below). There is a general trend towards decreasing glume wheat grain through time in favour of free-threshing wheat and barley. Wheats generally outnumber barley throughout the sequence. The occurrence of burned buildings with *in situ* crop concentrations creates discrepancies among South O and North F-G, but both areas of the settlement follow a general trend away from predominance of glume wheats and towards a more even balance with free-threshing wheats and barley. This shift is reversed on the West mound. The implications of the East mound trend for differentiation of growing conditions for wheat versus barley, and also for the labour-intensity and 'sociality' of crop processing activities, are considered further below.

Fig. 6 summarises changing cereal proportions through time on the basis of chaff. The dominance of glume wheat glume bases more or less throughout the sequence reflects frequent dehusking of grain stored in spikelet form (grains enclosed by glumes – see Fig. 3), in contrast to barley and free-threshing wheat, which appear to have been threshed and winnowed off-site following the harvest and stored as clean grain, with only late processing stages (such as fine sieving) routinely taking place on-site (Fairbairn et al. 2005; Bogaard et al. 2013). Fig. 6 reveals a clear mid-sequence shift in the relative importance of emmer versus 'new type' glume wheat: in the South sequence, emmer is the dominant form until South N-O, but minor in comparison to the 'new type' in South P through T. In the North sequence, the 'new type' is the dominant glume wheat form in North F-G: distinctly *earlier* than in the South sequence. By South P and North H, the 'new type' is similarly dominant over emmer in both areas. Emmer occurs at slightly higher levels in the West mound but the 'new type' remains dominant. Einkorn, a third glume wheat type, occurs in minor proportions throughout the sequence, though einkorn grain features in a probable store in Mellaart's building A.II.1 and made up most of the fill of storage bin 7 in house E.VI.17 (storage bin 7) (Table 2).

Further insight into this shift is provided by variation in the occurrence of one or the other crop as 'storage' deposits in burned buildings of the mid-Neolithic sequence (South O, North F-G) (Fig. 7). In the North area, pure 'storage' concentrations of 'new type' spikelets occur in burned Building 77 (North G) (Bogaard et al. 2013) and in an earlier neighbouring burned building, assigned to North F, Building 131 (Bogaard et al. 2015) (Table 2, Figs 7a, 8). In the South area, Mellaart's excavations yielded two known concentrations of 'new type' glume wheat, originally identified as emmer by Helbaek and currently under analysis by Fairbairn. One of these is from a building (E.VI.1) described by Mellaart (1962: Fig 7) that could be from VIA (South O) or VIB (South N); the second 'new type' glume wheat concentration is labelled A.VI.3, probably corresponding to what Mellaart later called E.VI.63 (Mellaart 1964: Figs 1-2). By contrast, burned Building 79 in the South Area (Table 2, Fig. 7b), excavated in 2009 (Eddisford 2009), has yielded 'pure' deposits of emmer, also stored as spikelets (Fig. 9), alongside free-threshing wheat grain, and no 'new type' (Fig. 7b). While B.131 and B.79 are still under study, two inferences appear justified from the available evidence. First, 'new type' and emmer were stored and likely also grown *separately*, as distinct crops. Secondly, burned buildings of the mid-Neolithic sequence have yielded concentrations of one *or* the other glume wheat, reflecting possible contrasts in social geography that require further study. Rather than an increasing proportion of 'new type' over emmer in a mixed/maslin crop (cf. Jones and Halstead 1995), therefore, 'new type' was grown and stored separately to emmer, and the shift in preference represents a conscious innovation, perhaps initially in the North area of the settlement. The only glume wheat concentration excavated so far from a later Neolithic building, the burned storeroom (Space 493) of TPC's Building 122 (Table 2), has yielded a large, pure concentration of 'new type' spikelets (Fuller et al. 2014), currently under study.

Fig. 10 summarises proportions of pulses through time, and reveals another mid-Neolithic shift, from lentil to pea, approximately parallel to the shift from emmer to 'new type'. Burned buildings of the mid-Neolithic in both the South (O) and North (F-G) areas provide multiple instances of 'storage' concentrations of (predominantly) lentil *or* pea (Fig. 7), which, like those of emmer and the 'new type', clearly reflect contrasting crop choices and potential social geographical patterning. Following these burned building horizons, the shift from lentil to pea is clear by South (P) and North (H-I) but is reversed on the West mound, presenting another contrast with trends observed on the East mound. It is notable that the earliest burned building in the North area – Building 131 – yielded a pea concentration, suggesting an early focus on this crop, while Building 1 (North G) yielded a large lentil deposit, indicating continued interest in this pulse by some households in the same neighbourhood (Fig. 7a).

Other diachronic changes in the pulse spectrum include the sporadic occurrence of grass pea and chickpea after South G (Table 3; Bogaard et al. 2013: Table 7.3), and a tendency towards lower proportions of bitter vetch through time (Fig. 10). Pulse concentrations in Mellaart's archive (Table 2) include several of pea (E.VI.25, E.V.8, E.IV, A.II.1), one of bitter vetch (E.VI.14/17) and a unique deposit of grass pea (A.VI.1). The dominance of lentil and/or pea in most phases and reduction in bitter vetch through time may reflect a general preference for pulses lacking concentrations of toxins in the testa (outer seed coat) that must be removed by soaking, leaching etc. to avoid detrimental effects on human health (cf. Valamoti 2009). This preference could be analogous to the observed decrease in usage of the glume wheats – more labour intensive to process than free-threshing wheat and naked barley – through time (above, Fig. 5).

Crops and gathered plants

Fig. 11 summarizes ubiquities of cereal, pulse, small-seeded mustard (mostly *Descurainia sophia*, an oil-seed plant, possibly cultivated - Fairbairn et al. 2007; Bogaard et al. 2013) and fruit/nut taxa through time. Lower ubiquities of *all* categories in the mid- and later Neolithic levels are at least partly an artefact of the deposit types represented: the proliferation of fire spots in the mid- to later sequence (especially South P) dominated by non-food (dung-derived) plants, and the occurrence of burned buildings (South O and North F-G) with *separate* stores of cereals, pulses and collected plants (Bogaard et al. 2013). By contrast, the samples analysed from both the earlier Neolithic sequence and the West mound are dominated by middens and other 'mixed' deposits in which all categories tend to be ubiquitous (Fairbairn et al. 2005; Filipović 2014; Charles and Bogaard in prep; Stroud et al. in prep). Fig. 12a-b summarizes percentages of cereal grain, cereal chaff, pulse, mustard and fruit/nut material through time; Fig. 12c-d show percentages excluding wild mustard, whose small seeds are very numerous in certain 'storage' deposits and hence swamp some phases in Fig. 12a-b. The dominance of cereals in most levels reflects the abundance of preserved chaff; high proportions of cereal grain in South O and North F, and of pulses (and mustard) in North G, reflect the prevalence of storage deposits from burned buildings in these levels (Fairbairn et al. 2005; Bogaard et al. 2013; Filipović 2014). There is a slight tendency for pulse proportions to decrease through time in the earlier Neolithic levels, and for fruit/nut proportions to increase through the South sequence, but the clearest observation is that cereals remain dominant, accompanied by minor proportions of pulse and fruit/nut, throughout.

Diachronic trends among fruit/nut taxa

Finally, we consider trends in the occurrence of fruits and nuts from perennial trees and shrubs. Though these resources are often referred to as 'wild', they were likely subject to management and protection, like the annual crops dealt with above. As noted earlier, sedge tubers were not fully quantified in all of the available datasets, and so are not included here. The tubers (and nutlets) of sedges, especially *Bolboschoenus glaucus*, are ubiquitous throughout the sequence. The nutlets are at least partly derived from the burning of animal dung as fuel (Bogaard et al. 2013), while the tubers may have been collected as food, as a few examples have been found embedded in cereal-based, bread-like food remains (Gonzalez Carretero et al. 2017), probably consumed fresh given their absence in 'storage' deposits (Fairbairn et al. 2005; Bogaard et al. 2013).

Fig. 13 summarises proportions of fruit/nut taxa through time, revealing continuity in use of hackberry (preserved in the absence of charring due to its silica-rich shell) and pistachio. Poorly preserved nut shell/fruit stone identified as 'almond/plum' is attested more or less throughout the sequence, sometimes alongside better preserved remains mostly identifiable as almond (relatively few plum stones have been observed, and are included here with 'almond/plum').

There is a notable decrease in acorn from South P onwards that coincides with a replacement of oak by juniper as the dominant fuel wood species (Asouti 2013). Though the fragile shell of acorn is never very abundant, a burned building of North G (Building 1) contained a cluster of *c*. 40 whole acorns in a side room (Hastorf 1996), whereas a nearby burned structure (Building 52) yielded a cache of whole almonds in one of its clay bins (Fig. 7) (Bogaard et al. 2013), accounting for unusually high proportions in that phase (Fig. 13). It is possible that these differences in nut storage reflect social geographical patterning, parallel to the different crop distributions in these and other burned structures (Fig. 7a). The Mellaart archive (Table 2) has yielded several acorn concentrations from burned buildings (A.VI.1, A.VI.4, E.VI.1), all belonging to Mellaart's Level VI (South N-O).

The 'other' fruit/nut category is dominated by fig seeds (Fig. 14), which occur sporadically throughout the sequence, from South G onwards (Bogaard et al. 2013: Table 7.3), and are relatively abundant in South T (Building 44) (Regan and Taylor 2014). The restricted occurrence of fig seeds generally at Çatalhöyük contrasts notably with Neolithic sites in Greece such as 6th millennium Halai (East Lokris), where the charred flesh and seeds of fig are ubiquitous, pointing to drying/storage and frequent consumption (Fig. 14c) (Diffey and Bogaard in prep). Fig wood identifiable as *Ficus carica* is also attested at Çatalhöyük but at very low levels (Asouti 2013: Tables 8.2-3). Trees of the Mediterranean *Ficus carica* complex can be observed in riverine settings today throughout semi-arid southwest Asia, including south-central Turkey (Davis et al. 1965).

Discussion

Recent stable carbon isotope analysis of crop remains from the East mound of Çatalhöyük (Wallace et al. 2015) has shown that barley was grown under drier conditions than wheats, likely due to greater drought tolerance (cf. Riehl 2009).

Modern two-row barley has higher water use efficiency than six-row barley, meaning that it is better yielding in droughted environments, while six-row barley is better yielding in well watered conditions (Voltas 1999; Jiang et al. 2006; Aniya et al. 2007). The inherent reproductive superiority of six-row barley means that shifts towards two-row barley, as documented at Çatalhöyük, require strong selection for two-row barley, either through cultural practices or ecological conditions (Palmer et al 2009). It is plausible that Çatalhöyük cultivators valued the greater drought tolerance of two-row barley over the six-row form, and that they increasingly selected two-row naked barley for strategic planting in the drier parts of the arable landscape through time. The local landscape offered a very variable set of niches for crops, ranging from dry marl hummocks to better watered areas on the margins of seasonal flooding (Charles et al. 2014; Ayala et al. submitted). Moreover, while regional pollen records suggest that precipitation was generally higher during the Neolithic than today (Charles et al. 2014), variability in rainfall in this semi-arid zone would have threatened crop yields from one year to the next. Stable carbon isotope analysis of crops from multiple Neolithic-Bronze Age sites in western Asia and the eastern Mediterranean by Wallace et al. (2015) has shown that crop growing conditions at Neolithic Çatalhöyük were if anything relatively water-limited. There is evidence of increasing dryness around 8.2 kya in central Turkey from recent lake geochemistry (Dean et al. 2015; Roberts et al. 2016), and in the local landscape from specific hydrogen isotope analysis of lipid residues in cooking pots (Pitter et al. 2013). Selection of a more drought-tolerant form of barley was likely a key Neolithic adaptation to such conditions, and may have played a particular role in resilience through phases of greater aridity such as the 8.2 kya event (Flohr et al. 2016). Ongoing stable isotope analysis of hulled barley from TP and the West mound (Stroud and Bogaard in prep) will reveal whether or not this crop, like naked barley, was preferentially grown under drier conditions than wheats.

Wheats generally remained dominant throughout the East mound sequence (Fig. 5), and were planted in better watered parts of the landscape (Wallace et al. 2015). The general trend from glume (hulled) to free-threshing wheat through time (Fig. 5) may reflect a better yield response to relatively well watered soils in the latter, or at least an interest in diversifying this better watered niche. It could also reflect an increasing interest in growing crops that were processed off-site, immediately following the harvest and stored in cleaned form, as opposed to piecemeal processing (i.e. dehusking of glume wheat spikelets) at the household level throughout the year. Increasing interest in ease of processing may also explain the decrease in bitter vetch in favour of less toxic pulses through time (Fig. 10). This increasing preference for less labour intensive crop processing through the East mound sequence coincides with a diversification of other activities demanding space within the house (Hodder 2014c). On the West mound, however, this trend is reversed, with preference for hulled over naked barley and glume wheats over free-threshing wheat (Fig. 6).

The shift from emmer to ‘new type’ glume (hulled) wheat presents a clear instance of a crop innovation that was initially taken up by some households and not others. Currently the earliest evidence for a ‘pure’ cache of new type glume wheat spikelets occurs in Building 131 of the North Area; storage deposits in the later neighbouring structure, Building 77 (North G), appears to have perpetuated this tradition of cultivating the ‘new type’ glume wheat rather than emmer (Figs 7-8). By contrast, emmer deposits in burned Building 79 (South O), for example, suggest that some households continued to favour this crop. In resilience theory terms (Holling 2001), the important point is not so much which house(s) or part(s) of the settlement were the chief innovators, but rather that such innovations were rooted in *some* households and not *others*. The implication is that certain households were 'incubators' of new potential staples, meaning that the risks of such innovation were confined to small-scale social groups (cf. Holling 2001: 397). In the case of the 'new type', this form of glume wheat was eventually adopted as the preferred glume wheat species across the community, presumably because it proved to be a hardy crop that coped well with the local landscape and suited the evolving culinary tradition.

Multiple innovations in resource use at Çatalhöyük cluster in the mid-Neolithic sequence, and were widely adopted just after the community had attained its maximum size – variously estimated in the low thousands at least (Cessford 2005; cf. Bogaard in press) – in the mid 7th millennium BC around South M-O/North G (Table 2), and showed signs of reorganisation (Hodder 2014c). Shifts in subsistence practice, established by South P, include that from emmer to 'new type' glume wheat, the change from lentils to peas, the choice of juniper over oak as wood fuel (Asouti 2013), increased sheep consumption, smaller scale herding at the subcommunity level and cattle herding (Russell et al. 2013). These changes parallel a staggered series of changes in material culture that reflect reorganization of household activities, including a shift from clay ball 'boilers' to cooking pots, the development of external activity areas ('yards') including ovens and increased use of stamp seals (Atalay and Hastorf 2006; Bogaard et al. 2014).

One way to understand these clustered adjustments is the perspective of panarchy theory (Gunderson and Holling 2001; Holling 2001), which predicts that innovations will escalate under conditions of ecological uncertainty, and also that complex social obligations may limit flexibility and lead to a 'rigidity trap' that can only be overcome through significant reorganisation. At Çatalhöyük climatic variability was coupled with the internal pressure of the community's increasing fertility and population size in the middle Neolithic sequence (cf. Hillson et al. 2013). It is plausible that many of the innovations in cropping practice emerged as 'experiments' on the part of particular households or neighbourhoods, which acted as testing grounds for new patterns of behaviour that might or might not prove successful enough to be adopted across the community as a whole. A similar pattern of behaviour has been observed in changing mudbrick sources through time, with particular houses anticipating the subsequent, wider shift to new materials (Love 2013). Though some panarchies are hierarchical, many are not (Gunderson and Holling 2001), and Çatalhöyük's 'aggressively egalitarian' community (Hodder 2014a) facilitated permeability and transfer of successful innovations among individuals, households and neighbourhoods.

The long-term sustainability of Çatalhöyük thus appears to have depended on several factors that enabled flexible strategies over time. First, the founders of the community brought with them a wide range of cereal and pulse crops, as well as a tradition of diversified plant management and collection. While certain cereals and pulses were initially favoured, other taxa persisted as minor crops or contaminants, lingering to be recruited later as staples by individuals and households interested in developing new crops and tastes. Second, while land tenure was likely organized at the supra-household level, perhaps in radial 'wedges' allocated to particular neighbourhoods (cf. Charles et al. 2014; Hodder 2014b; Bogaard in press) acknowledging territorial inheritance from founder settlements (Fairbairn 2005), individual households appear to have made contrasting choices of which crops to sow, with particular variation amongst glume wheats and pulses around the mid-Neolithic sequence. That such decision-making took place at a small social scale – the individual household or house group perhaps – was ecologically crucial, because the risks of growing pure stands of minor crops were thus contained. While it could be argued that (deliberately) burned houses reflect a more complex choreography, the fact that different crop species occur in different houses plausibly reflects similarly scaled agency (e.g. the 'new type' glume wheat deposited in Building 77 (Fig. 7a) was not necessarily chosen/grown by its inhabitants, but clearly *was* chosen by another affiliated household(s)). A third factor was permeability across co-residential groups, enabling pure seed corn of unusual crops, collected by certain innovating households, to be dispersed more widely.

While resilience theory usefully frames consideration of Çatalhöyük's persistence as a community, it does not of course account for the whole story of crop change. The developments in cropping described here concern not only growing conditions and field ecology but also cooking and culinary tradition. Closely related crops with similar generic uses can have subtly different cooking properties; variable preferences for einkorn or emmer in present-day Kastamonu, for example, are reportedly based on preferences for different grain qualities in bulgur production (Ertuğ 2004). It is thus plausible that changing cropping strategies at Çatalhöyük – including variation amongst contemporary households (Fig. 7) – fostered different tastes and identities. Study of charred amorphous fragments of foodstuffs indicates the preparation of batters and breads throughout the East mound sequence but with increasing preparations of cereal-based porridges in the latest (TP/TPC) levels (Gonzalez Carretero et al. 2017). Diachronic trends also imply changing priorities in the organization of daily tasks, with less time devoted to frequent, labour-intensive processing activities such as soaking the toxins from bitter vetch seeds, or dehusking of glume wheats.

Conclusions

The long-term archaeobotanical record of Neolithic-early Chalcolithic Çatalhöyük affords unusual insights into processes of early agricultural innovation among households and over time. Rather than maintaining a fixed set of crops requiring stable ecological and social conditions, the diverse agroecology of Çatalhöyük enabled generations of cultivators to maintain flexible cropping strategies as part of a changing landscape. Panarchy theory provides a useful way of understanding the inseparability of social and environmental conditions in shaping long-term resilience and sustainability. Çatalhöyük's persistence was just as dependent on its social morphology as on the genetic/ecological potential of the crops with which it was founded.

Such case studies offer a useful perspective on so-called 'boom-bust' cycles in the western European Neolithic (e.g. Downey et al. 2016). While apparent demographic 'bust' events have naturally received the most attention, unpicking the complex causality of such cycles relies on detailed documentation of strategies that were *successful* over the long-term, as at Çatalhöyük. Moreover, very long-term prehistoric farming sequences can and should inform wider agroecological understanding of sustainable development, in present-day Anatolia and beyond, as dependent upon a diverse repertoire of crops, an active 'archive' of cropping potential in the form of minor crops and weedy contaminants and a nested set of permeable social scales. These potentials are currently threatened *inter alia* by the dominance of 'elite' commercial crop varieties demanding uniform, high-input conditions; centralised, top-down agricultural management; and restrictions on the movement and exchange of seed corn from traditional landraces.

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Table captions

Table 1. Summary of archaeobotanical data currently available from central and eastern Anatolia, from the late Pleistocene to the end of the 8th millennium cal BC; dashed lines = pre-agricultural nut use phase; dot-dash lines = open-air 'sedentarising' communities practicing more diversified plant use (sometimes including cultivation); solid lines = cultivation and gathering combined with various forms of animal husbandry

Table 2. Summary of the archaeobotanical assemblage from Çatalhöyük by Level and excavation area (see Fig. 2 for site plan), incorporating available relative chronological correlations between the South and North areas based on lithics and ceramics (Hodder 2014a), to be refined by an ongoing programme of radiocarbon dating and Bayesian modeling (Bayliss et al. 2014)

Table 3. Summary of the occurrence of crops and gathered plants by excavation area and Level

Figure captions

Figure 1. Map showing the location of Çatalhöyük and other Anatolian sites mentioned in the text

Figure 2. Plan of Çatalhöyük showing the East and West mounds and major excavation areas mentioned in the text

Figure 3. Schematic representation of the structure and processing stages of glume (or hulled) and free-threshing wheat; barleys (whether naked or hulled) behave under processing like free-threshing wheat and are thus represented as grains and rachis segments

Figure 4. Bar charts summarising proportions of barley rachis segments identified as two-row naked, six-row naked and (cf.) two-row hulled through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 5. Bar charts summarising proportions of cereal grain types through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 6. Bar charts summarising proportions of cereal chaff remains through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 7. Plan of a. North and b. South areas of the site, showing the composition of 'storage' concentrations of charred plant material preserved in burned buildings based on seed/chaff item counts. To provide a simplified overview of the major types of deposit in each structure, a single pie-chart is shown where there are multiple similar adjacent concentrations, and minor components have been left out. Counts of the tiny seeds of wild mustard (e.g. *Descurainia sophia*) and rock rose (*Helianthemum*) have been divided by 1000 to improve the visibility of other components for this overview. Material from various buildings is still under study

Figure 8. ‘New type’ glume wheat: a. spikelet fork; b. grain (drawings by Katy Killackey); c. intact spikelets in Building 77 (photograph by Müge Ergun); d. spikelet concentration in Building 131 under excavation in 2015 (photograph by Jason Quinlan)

Figure 9. Intact pairs of emmer grains in stored spikelets, unit 18596 s.1, burned Building 79 (South O) (photograph by Jason Quinlan)

Figure 10. Bar charts summarising proportions of pulse taxa through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 11. Bar charts summarising ubiquities of cereal material, pulses, small-seeded mustard and fruit/nut taxa through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 12. Bar charts summarizing proportions of cereal grain, cereal chaff, pulses, small-seeded mustard and fruit/nut taxa through time from the a. South area of the East mound, and West mound, and b. North area of the East mound; c. and d. show proportions excluding mustard

Figure 13. Bar charts summarising proportions of fruit/nut taxa through time from the a. South area of the East mound, and West mound, and b. North area of the East mound

Figure 14. Scanning electron microscope photographs of fig seeds from a., b. Çatalhöyük and c. Neolithic Halai, Greece (Diffey and Bogaard in prep)